Math phobia explained; STEM done right
By Lawrence Bottorff

Is it too far off to say the malaise generally referred to as *math phobia* affects the vast majority of us? So how did this come to be? There are many reasons. First, we might as well admit math is not a natural thing, it's not a normal, natural *flow* kind of thing we do. Math is a great abstraction of reality, to which many have a natural resistance and aversion. Socially, math is highly stigmatized. The message in school is loud and clear: If you're not doing great in math, that means you're *stupid*. Nothing produces a brain pecking order like math. Let's admit math has been poorly taught, poorly presented in our schools—where motivation was typically negative: fear of failure, fear of bad grades, fear of being seen as stupid. What can we do to correct this situation? First, I'll describe some of the characteristics of math phobia as I see it.

Problem 1: *We are not meant to sit and stare at paper covered in symbols and numbers.*

This comes from being *Homo sapiens*, a species that, for all those years prior to the modern world, was outdoors—hunting, gathering, farming, shepherding. That means our attention-concentration regime is still probably not that well oriented to sitting indoors for long periods in deep concentration. Sure, we can handle indoors. Sure, we can handle long periods of TV-watching or book reading. But math is not a *narrative.* Humans are narrative-oriented. Fictional books and movies have a narrative. For millennia the only sitting and concentrating we did was when we made something with our hands, or listened to the storyteller. Math is not like this. No, says our not-quite-caught-up-to-the-modern-world brain, not going there.

Problem 2: *We HATE being lost.*

When we take a wrong turn, when we get lost, the brain goes into a high state of alert. Most of us don't outright panic at getting off the wrong freeway exit, but, yes, we do switch into "get me outta here!" mode. Trouble is, math is all about being lost—often for very long, uncomfortable periods of time.

I once asked a math professor about this. He laughed and said, "Oh yes, I've spent most of my career fighting back that panicky feeling of being lost." But at some point, he tells, he got used to it, learned to deal with it. He kept his cool—until, slowly, surely, he got himself *un*-lost, until he closed the loop and grabbed that brass ring of finding a deeper understanding of a very complex subject. The Nobel-prize-winning physicist Richard Feynman once said the same thing about ". . .

that terrible, uncomfortable feeling called confusion. It's a very difficult and unhappy business. . ." (See https://youtu.be/lytxafTXg6ch)

Let's throw in the accumulated stress of all those times in the past when we didn't understand even half of what was going on, but had a big test bright-and-early the next morning. Psychologists say that when we're really stressed, anxious, fearful, our higher brain functions tend to bow out and the fight-or-flight chemicals begin to surge.

So there you sit at your desk stuck on a math problem. "I'm lost!" Every fiber of our being is in revolt . . . which, again, my math prof friend could totally relate to. "My career is on the line. I *must* get this!" And yet through years of practice, the math pro knows how to cope, how to reduce the stress, how to flush the bad stress chemicals and keep sitting and concentrating until the breakthrough happens. It's a hard-won skill.

Problem 3: *Math is hard physical work—which often feels like it will never end.*

Back in basic training, the drill sergeants had us doing push-ups throughout the day. Sometimes they'd tell us how many they wanted. Sometimes they wouldn't. "Keep going until *I* get tired." That was the worst! Not only did you have the spiking physical agony, but also the mental torture of *not knowing when the physical agony would end.*

Make no mistake about it, math is hard physical labor. What? Physical labor? Yes indeed, from a neurological standpoint, you are doing heavy lifting when you tackle math. It makes your brain hurt. And again, we don't like pain—especially when we don't know how long it will go on—*especially* when we don't know *why* we're subjecting ourselves to such neural-physical torture.

Problem 4: *Like Pavlov's dog, you've been conditioned to hate math.*

Remember "class participation?" If you think about it, class participation is no different from Pavlovian conditioning. So the teacher calls on you to give the answer to the problem on the board. That gives you two, three seconds to summon vast networks of neocortex neurons designed primarily for hunting, gathering, farming, shepherding to *quick-quick!* come up with that answer. You don't. . . . Now, repeat this sad scenario for all those years of math class. Laugh it off if you want, but trying to get your brain to work real hard and real fast, *then* being (slightly?) humiliated in front of your peers is, at least in my opinion, how many math-haters are created. You are coupling hard exertion with humiliation, over and over again, year after year.

Contrast this with your local weightlifting gym. There is no Schwarzenegger type lording over the place, demanding that you, the new guy, bench-press the "daily" amount, while a muscle-bound minority looks on, grinning slyly, ready to show off how they can do it. Of course not. So why do we do math class that way? In every gym I've ever been to, I've seen teams of two, three people doing their weightlifting sets together, all vociferously encouraging each other. And, of course, each person does *exactly* as much as they can handle, not some set, prescribed amount.

Why can't we do math that way? Math is, as I see it, the equivalent of weightlifting in the science world. Everybody at the weight room knows why they're there: They want to get bigger, faster, stronger—either for some other activity or sport—or just because it's cool. Math strengthens you in your field. And just by itself it's plenty cool, too.

Problem 5: *The locked-doors nightmare.*

Imagine a nightmare where you are trapped in a long hallway and every door you try is locked. You push, jiggle, fool with the locks, but nothing will open. At each failed attempt your panic intensifies. This is how getting stuck on a math assignment can feel.

Example: Ian Stewart's neat little book *Professor Stewart's Cabinet of Mathematical Curiosities* has a treatment of the *Golden Ratio.* He states . . . *[there is] a line AB being cut at a point P, so that the ratios AP : AB and PB : AP are the same.* . . . But when I read it I mistakenly thought *P* could be placed anywhere on *AB*—which I finally realized it could not be. Rather, *P* had to be at one particular point on *AB* for both ratios to be the same, namely, the *golden ratio* (roughly 1.61803398875). Now, if Professor Stewart had said . . . *a line AB being cut at <u>one particular</u> point P* . . . I would have probably understood immediately. Instead, I found myself out in the nightmare hallway pounding on a door that refused to open. Definitely my fault. Luckily, I found other treatments of the issue and spotted my error. The door opened.

Contrast this with the plumber fixing your sink. If he hits a snag, he steps back and thinks about it. He may call a friend with more experience. He may try something he found on the Internet. The point is, everyday kinds of problems—from carpet stains to crossword puzzles—don't seem to evoke the panic that getting stuck on math does. Why is that?

Here's the typical high school math experience: The teacher assigns a new chapter in the book. Let's say it's about logarithms. It begins with an outline of the theory behind logarithms. Then

come the examples and perhaps a "real-world" application or two. Now it's time to tackle the homework problems assigned for Monday. So you get past the first few "easy" ones—but problem five just sits there unsolvable, and you get that sinking feeling that you really didn't fully grasp all the nuances of the theory—not to mention how those puny examples and applications didn't even scratch the surface. You're in the nightmare hallway, a uniquely mathematical place. But understanding logarithms is important. . . .

The locked-doors nightmare could have been included with Problem 2 above, but I thought it merited its own treatment, mainly because math problems shouldn't be different from any other everyday problem or puzzle—right?—but somehow they are. And like Problem 2, we simply have to slowly build confidence and coping mechanisms to deal with it. . . .

Problem 6: *I can't remember all this stuff . . . and I have a test tomorrow!*

Don't worry, you really weren't designed to "remember all that stuff." When a mountain climber climbs a mountain, she might stand at the peak for a while and enjoy the view and feel really triumphant—but then she climbs down the mountain and she stands once again at the base, full of memories of how tough the climb up was and how great it felt to be at the top. So you can't be at the top of something permanently. Applied to math, no, you can't (and shouldn't try to) remember everything from every math lesson or textbook.

One huge panic producer in math is that awful feeling of not remembering something. But then maybe you should stop and ask this question: Did I once know it? If the answer is yes, then it's not that important to have remembered *everything* about it. Perhaps it's good enough to know that once we knew it and, if we need to, we can learn it again. Same with the mountain climber. She's got the experience under her belt, so if she wants to, she can climb it again. But again, she cannot stay on top of *all* the mountains she has climbed. So yes, *it's okay to forget stuff*. Math is a constant cycle of learning and forgetting. But the more math we learn, the more strength and confidence we build. Forgetting some of the details is not a crisis.

Unfortunately, we have math education that equates remembering math factoids with math mastery. This is a type of rote learning. Rote learning reduces learning to stimulus-response, i.e., when you see this sort of problem on the test, do this to get the answer. It reduces people to circus animals. Bad.

Problem 7: *Bad teaching. Poor learning materials. Uninspired presentation. Zero context. No amazement, excitement, fun, et cetera, et cetera.*

Let's face another sad fact about math: Some math teachers can't, don't teach math very well. They routinely crush all the amazement out of the most amazing math topics. And some math teachers are truly terrors. If you saw the movie *Beautiful Mind* you saw John Forbes Nash being a jerk to his students. For a refreshing change, check out another MIT math teacher, namely, Gilbert Strang, (https://youtu.be/ZK3O402wf1c). A real sweetheart, he's like Mister Rogers asking you "Won't you be my math neighbor?" If all math instructors were like Gilbert, we'd be saved.

Not just bad teaching. What about those bad, vague, poorly-worded textbooks, the ones that seem to be playing keep-away by not giving you enough to really understand the material? So often I've picked up a high school math textbook—and only been able to understand what it was saying because I already understood the material! Very few students coming at it new would have a chance! Sad but too often true. Sure, at some point your "math stride" needs to lengthen. But until you're on your feet, you need to take baby steps—and you should not be stigmatized for how long and confident your stride is—ever. Only you know how much you can lift and when you're ready to lift more, when you're ready to lengthen your stride.

Let's do a comparison: Think about health care education. How can the world of medicine and biology routinely turn 40-year-old single moms, people who didn't get above a C in their high school STEM courses, into registered nurses or even nurse practitioners, or even doctors and researchers? I'm guessing they know how to present, how to teach their material. Math, on the other hand, often seems to be a private club reserved for the Sheldon Coopers of the world. And, of course, the main criterion of being a math genius is the ability to somehow understand perfectly what hasn't been written or taught very well, all of this happening in a far-too-often socially toxic environment. A rare talent, indeed. While you stumble around with vague, misleading, flat-out wrong material, the math genius gets it first pass. Alas, we can't train the populace that way.

Problem 8: *Math is stuck in a much too abstract pigeonhole.*

"Why am I doing this?" is the typical question the math-adverse kid asks. So much of math is simply too abstract, too from-outer-space to really gain traction in a young mind. Galileo said mathematics is the language of science, but what sort of science education really teams up with

math? Yes, your typical math textbook has the ubiquitous "word problems" that seem to be describing a real-world setting. But it's hardly enough to truly engage a balking young mind.

All professions use tools. For example, your typical auto mechanic has a large set of tools and equipment. Likewise, a statistical researcher has large set of mathematical tools and methods. When the master auto mechanic asks his apprentice what approach, what tools to use on a particular engine problem, it's really no different than when, for example, a researcher needs to turn raw research data into mathematical functions and graphics. What tool should she use? *Regression analysis* or *polynomical interpolation* would be the right tool for that job. So why not teach the theory *and* application of math together—especially while studying other STEM subjects? And especially, why not immediately link a math concept to how it is accomplished in the computer world? The science-technology world is all about turning book math into working computer programs and circuit boards. This, however, is not the case now. Math topics like Algebra, Geometry, Pre-Calculus, and Calculus sit pretty much alone and unto themselves in far-removed-from-reality textbooks. Kids are hit hard with a level of abstraction and symbolism they're not ready or prepared for. As a result, students have no real-world reference point in such a white-out blizzard of abstractions.

What to do

The simple answer is to address and correct all the problems I've mentioned above. Or at least become more aware of them. The need for STEM in our daily lives might not be any easier to explain than it was in yesteryears, but our modern daily involvement in STEM-based technology is only getting deeper and deeper. I compare this to music. Back in my grandmother's day, nearly everyone learned a musical instrument, she the piano. And before radios and crank phonographs, if you heard music, that's because somebody was playing it. But today fewer and fewer young people are learning music. Do you hear music? Ninety-nine percent of the time it's a recording. Of course many people dedicated to music become very skilled musicians; but the gap between the musically literate and illiterate is growing. Not good. Likewise with STEM. If we live in a world of growing complexity *but* our ability to handle, think through this complexity is falling off, how can that end well?

For example, how many people really understand the difference between arithmetic and exponential growth? What about logarithmic growth? What if in a meeting at work someone told you one process was linear and another logarithmic, would you know which was the less resource-

intense process? Many reading this would not. But these are very important things to know about, that is, all the things going on in our modern lives.

Do we all have to be like *Star Trek* Vulcans? I'm sure Spock, Tuvok, and T'Pol were good at math. Vulcan education was never really specifically discussed on *Star Trek*, but we just assume the Vulcans were STEM champs. I like those existentialist Vulcans. They realized at some point in their past that a big change was necessary, and so they boot-strapped themselves into their logic-based lifestyle. Math scores, science literacy in general, is in a nose-dive in this country. Not good. We must change in order to keep living long and prospering.

I'll throw out one possible way to fight math illiteracy: Teach it weight-lifting style, that is, in small, intense groups. Take a page from the top universities, such as MIT where STEM courses have very high teacher-to-student ratios. Take a page from the St. John's College (Annapolis/Santa Fe) *tutorial* style. We've got a pretty good core curriculum in the form of our high school STEM offerings: Algebra I, II, Geometry, Pre-Calculus, Calculus, Biology, Chemistry, and Physics. So teach them better. And back up the teaching with aides or "personal trainers" when total mastery is not happening. *Above all, throw out the schedule; stop trying to cram a set amount in a set timeframe; and above all,* ***stop and wait for a kid to catch up!*** Because if a child doesn't get something, her chance of getting the next thing will be even lower. Math is the most cumulative subject in school. Didn't get Elizabethan poetry? That doesn't mean you won't sail through Romantic Era poetry. Didn't get Romantic Era poetry, either? That doesn't mean you won't love Modern poetry. Math, however, doesn't work that way. You absolutely have to master each level to go on to the next.

Striving for total mastery. Right. Today we have this warped situation where hardly one-tenth of the public high school students truly *masters* the material. So what does a C-minus in Algebra-I really mean? It means you didn't get past problem four in the logarithm chapter. *It means you're not really ready for Algebra-II.* How can the other nine-tenths of students get STEM—when they're not really getting it at all, when, year-in, year-out, their *math deficit* is growing?

Wouldn't it be nice if we could clone thousands of Bill Nyes and Neil deGrasse Tysons and all of the NASA astronauts to go out and evangelize STEM even more than they already do? But then why not make tens, *hundreds* of thousands of math aides/coaches/personal trainers? Hey, we have hundreds of thousands of fitness trainers, diet gurus, financial advisers. Why not STEM coaches, too? Too expensive, many would say. But can we afford to keep wasting billions each year on our clearly failing math secondary education?

If the teacher-to-student ratios cannot be improved, and we can't find enough math personal trainers, then there is very little hope. Likewise, if we can't do something about the steep abstraction learning curve, the white-out blizzard conditions of theory and application never reaching symbiosis then, again, we're just spinning our wheels. I say students should be presented a seamless body of learning where the math is woven into every other aspect of the hard and soft sciences. Again, the weight room analogy: The actual math courses would be the weight-training sessions, while the other STEM courses would be the playing fields.

In closing, I'll say we can beat math phobia and get our STEM act together. The consequences of not doing so, however, is sort of like walking around drunk and blindfolded in a mine field. No, STEM doesn't have to become the meaning of life, but we do need a good grasp of STEM to be effective citizens in this modern world. The first step would be to reassess nation-wide what's not working and what needs to happen to improve. We need to admit we're failing at math. Then we need to commit to a solution, hopefully taking into account the things I've mentioned above. So yes, I hope to be a part of the solution.