The Biophysicist

Eight Suggestions for Future Leaders of Science and Technology

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Encouraging our high school and college students to gain experience and specialize in science, technology, engineering, and math (STEM) fields has never been more important. These fields are central to our countries' health, wealth, and security. They also provide numerous opportunities for employment and stability for our young people. In contrast to doctors and lawyers, whose functions are familiar, being a scientist, mathematician, or engineer may be elusive to youngsters not exposed to these specialties at home.

Counselors and parents encourage students to acquire technical knowledge in these fields through course and research experiences; thus we often see today hard-working young students with perfect high school and college grade point averages, two or three college majors, advanced placement certifications, and a bundle of research accomplishments and prizes. Some students today are better prepared because technology has awarded them new sets of tools to explore and incorporate in education and training. It has also offered them numerous ideas and incentives for creation and innovation. The technical experiences they are acquiring are prerequisites for STEM career paths. However, there are softer and more general professional aspects and skills that are as important for becoming successful leaders in these fields. Here are my suggestions.

Learn math, the more advanced the better

The general public often associates math with arithmetic. It is perceived that math is helpful for computing compound interest or tips at restaurants, managing medication dosages, or adjusting recipe quantities. But higher-level math is abstract and creative. It will teach you how to think, how to express thought via equations, and how to define concrete outcomes from prescribed scenarios. Higher-level math—from logic and graph theory to optimization and dynamical systems—is relevant to our nation's security networks, phone systems, and financial instruments. Learning math will teach you how to think in new organized ways about anything you read or experience, and having these innate skills will ultimately help you innovate.

Become proficient in programming

Some coding is a prerequisite to, and essential component of, any STEM-based job. Whether you have to decipher someone else's code

or write your own, programming teaches you how to translate problems into solutions. A program expresses succinctly a logical path toward a solution. It incorporates specific input variables, output variables, and a method (algorithm) in a rigorous fashion to solve a well-defined problem. You truly understand a solution process toward a problem when you code it—because you discover odd ways in which the method fails that you might not have incorporated into your thought path before. ''Debugging'' codes to remove errors also inspires you to think like a detective, gathering data and testing hypotheses. Thus, just as strong analytic and logic skills are acquired through high-level math, learning how to write computer code emboldens you further to think logically, create innovative solutions, and be confident that you are able to solve a problem.

Embrace opportunities for project-based learning

Advanced training in math and programming teaches you how to think logically and broadly, devise solutions, and analyze solution pathways. You should further develop practical problem-solving skills through critical thinking. Such thinking is best practiced through projects that require you to incorporate various creativity skills. Many real-life problems contain more complex objectives than calculating the square root of a number. Such challenges may require translation of the objectives into math, science, engineering, or other terms. Remember those story problems in placement tests? Seek such challenges and volunteer to solve research problems in your school, home, or community. Go ahead and draft a plot line for a mystery play, tackle an engineering problem at home, explore how statistics are used for data analysis in sports or politics, or volunteer to estimate environmental waste. As a child, I loved to engineer simple solutions to fix an uneven table, devise a storage contraption for my socks, or solve a variety of puzzles. Besides learning to be creative, such project-oriented problem solving may require consultation of resources to learn about advanced concepts you may not be familiar with in a variety of fields, along with trial and error to test and iterate your inventions. You will undoubtedly grow, learn through the thought process, and open your mind in new ways, discovering more about fields that interest you.

Famous inventors provide interesting examples of how they advanced talents in their youth. Businessman Warren Buffett developed his interest in investments as a teen when his installation of a pinball machine in a local barbershop earned him profit. In his childhood, chess master Magnus Carlsen grew his problem-solving abilities through building complex Lego structures. Two-time Nobel Prize winner Marie Curie developed her reading, writing, and math skills early and used her talents to help support her family as a governess after her mother died, so she could attend university. Nobel Prize–winning chemist Gertrude Elion expressed her insatiable thirst for learning in her youth by exploring history, writing, and dramatic acting by participating in respective clubs and winning awards for her products and performances. Napster software developer Sean Fanning was inspired by his music file-sharing college peers to create a new, compressed file type called MP3. Chemist Rosalind Franklin focused her college studies on using coal and charcoal effectively during World War II and applied that work to her pioneering studies of analyzing carbons by using x-ray diffraction; that work laid foundations for the elucidation of the DNA double helix. Technology magnate Bill Gates created computer games at age 13 and later, together with high school friends, established methods to detect and exploit computer operating-system bugs to obtain free computer time on a new minicomputer. As a postdoctoral fellow, Nobelist neurobiologist Rita Levi-Montalcini studied the growth of chicken-embryo nerve fibers in her bedroom during World War II when she was barred from university by Mussolini's anti-Jewish laws. Engineer Elon Musk designed and sold the space battle video game *Blastar* at age 12. Home-schooled chess player Judit Polgár was educated through intensive chess training, going on to win US top prizes at age 9. Statistician and Detroit Tigers fan Nate Silver extended his

math skills as a child to analyze and predict baseball players' performances. Social media mogul Mark Zuckerberg applied his programming skills as a young teenager to connect all the family's home computers to assist in his father's dental practice.

Master good writing

Good writing may be undervalued today, given the dominance of emails, instant messaging, and interactive computer communication, all of which have evolved into separate worlds, with associated conventions. However, good writing remains the most fundamental way to transmit information from generation to generation. Because many scientists read a large amount of technical and nontechnical books and articles, you may think that readers are naturally good writers. Unfortunately, that it is not necessarily the case. Writing requires all the tools that we learn from reading (vocabulary, form, and structure), but it also demands mastering your subject matter, organizing your material well, understanding what your reader wants, using proper grammar, and having a talent for keeping your reader engaged. These elements, along with sheer hard work and practice, are required to communicate scientific ideas with a well-written text.

Being a good writer will also open professional opportunities in communicating science. There is a strong need for good writers who can both understand and communicate science and health topics to the general public. Thus, keep writing, editing, and scrutinizing your writing and that of others. Become a better writer, and you will become a better professional in any field.

Gain experience in science communication and public speaking

Writing will help you become a better scholar, but oral communication is a different skill set. Learning how to explain your work to other people, whether members of your team or the general public, is an essential aspect of scientific research. Expressing clear thought "on the fly" without the ability to edit and refine is also an important capacity in all aspects of our lives. Develop your oral communication skills by working in teams and volunteering for public speaking opportunities, both with scientists and nonscientists. Giving a talk to scientists will emphasize scientific details, while a presentation to the general public will focus on communicating the broader impact of the issues that are of societal interest. Translating complex equations or scientific concepts into simple and clear language is a difficult but important competency to develop.

Plan your presentation carefully. Whether you are speaking orally, writing on the board, or presenting slides, scrutinize your presentation's content, organization, and clarity, and practice your script, delivery, and material. If relevant, make sure you have covered both the broad aspects of your topic and an in-depth treatment of your contribution or emphasis. Ensure that your audience leaves with a clear take-home message.

I often advise my students to write out the entire text of what they intend to say in a presentation. This gives you an opportunity of thinking carefully about what you want to say and why. It may seem rehearsed to you when you memorize all the important points to communicate and how to do so, but to the audience it will appear polished. With ample practice, you will deliver technical material more effortlessly and with confidence. Finding your own style, in slide or talk format and content, is also important for establishing your "brand." My college professor once gave me the best advice before a public talk to my peers, "Know your stuff, know whom you are stuffing, and know when you have stuffed them enough."

Take advantage of professional development opportunities

Early on in my career, I discovered that my funding agency paid for professional development opportunities. Excitedly, I registered and took many professional development courses and workshops, such as how to negotiate, present public talks, deal with difficult people, delegate

tasks, write well, read efficiently, resolve conflict, build a team, ensure high ethical and scientific standards, develop new skills, develop self-awareness, propagate equity, and more. These learning experiences were both informative and entertaining. Having such insights will help you deal better with many real-life situations. They may make difficult situations easier to handle.

Related career information sessions are also important for broadening your perspectives on how you might use STEM skills in a variety of jobs. There are numerous professional opportunities in scientific communication, advocacy, and public relations that are just as important, perhaps more so, than practicing science in academia, industry, or the private sector.

Thus, I advise you to actively seek various professional development opportunities in your school, community or through a professional society, and learn about job possibilities available in STEM fields broadly. Such information will help you decide on a career path to best match your talents and personality, as well as navigate successfully throughout your work life.

Develop yourself as a mentor

Most of us who are not trained educators learn to be mentors by trial and error. For any professional, inspiring others is important for building a team, working with a variety of people, and becoming a leader in one's field. Mentoring is also important for learning how to work with a diverse set of trainees and teaching them both specific, as well as general, life and professional skills. Consider volunteering for a mentoring opportunity or participating in leadership activities at home or school (groups or clubs). As mentor, try to incorporate motivation, constructive criticism, encouragement, concrete guidance, and gentle prodding into new directions. Lead by example, be sensitive to weaknesses others may have, and try to help them build on strengths rather than dwelling on weaknesses. You will undoubtedly make mistakes throughout this process, especially in stressful situations, but with hard work and compassion, you will grow in your mentorship role.

Based on my own experience, the most difficult part of mentoring is knowing when to speak up and when to hold back when your expectations are not met. Finding the right balance between criticism and encouragement is difficult and must be tailored to the individual. Often, it is challenging to manage a diverse group of people who think and express themselves differently. Some may be louder than others, and some may shy away from teamwork, while others thrive in competitive environments. Learning how to manage your mentees requires awareness of different personality types and backgrounds and the ability to promote a sense of equivalence in your team.

Developing yourself as a teacher and leader will compel you to understand and integrate different characters and talents toward a common goal. As there is no magic formula, you will do your best and learn from your mistakes. Start practicing on your younger sibling or cousin today!

Follow your heart

Professional life will likely offer you many choices along the way. You will be tempted to select among these choices based on trends and estimations of what is best for your career. My advice is not to become influenced too much by trends. Always be yourself and not the mold of someone else's vision for you. Choose heart over head 90% of the time. Reserve exceptions for short-term sacrifices that can easily be incorporated into your life. For example, you have been offered two excellent graduate school fellowships on the East and West coasts. You like the former's school and feel more comfortable in that environment, but your friends and family urge you to consider the latter, where the sun shines brighter and the start-up companies await you. My advice is to go with your natural inclination, as you will likely be happier and more productive in the long run. On the other hand, if you are offered a short-term (e.g., semester) fellowship abroad with short notice, and you hesitate to leave your current project and friends, this might be a good situation to make the opposite type of choice. Consider a bold move, perhaps inconvenient in the short term, but

possibly enriching in the long run. You will undoubtedly grow and learn through the experience. Thus, seize good short-term opportunities with a sense of adventure, but follow your heart in long-term decisions—whether a job, place to live, or spouse—and you will be happier in the long run.

Although these skills and opportunities may be easy to articulate, dedication and practice are required to master them. You will fail and you will succeed along the way, but through persistence and perseverance, you will learn from and correct your mistakes and eventually rise and excel. From my experiences of mentoring high school and college students over 3 decades and seeing them attain excellent academic, industrial, and government positions, I believe that you will be thankful for the prodding to work hard and embrace many scientific and professional development opportunities. These experiences will not only expand your knowledge base but also teach you how to process and create new knowledge. You will appreciate the push to become a better writer, skilled programmer, broad thinker, clear communicator, compelling public speaker, and effective mentor. The many drafts of scientific papers that you have sweated over or the detailed explanatory comments forced upon you in code documentation will lead you to think more deeply about what you are writing or coding and why. Public speaking skills and good communication of scientific ideas to a broad audience will pay off handsomely at your job, whether in university classrooms or private hedge funds. Related collaborative and interpersonal skills that are part of science project teams will also help you succeed in both professional and personal relationships. Being a great, reclusive mathematician may once have been sufficient. Today, we need to be great at so many more things to succeed, but resources have never been better.

Enjoy these experiences and your journey in the exciting 21st century as you compute and analyze, code, tackle problems, write, speak, mentor, and make big life decisions—I await your discoveries in the coming decades.

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