Rajeev Bansal

Light-Bulb Moments

Scientists, intent on categorizing everything around them, sometimes divide themselves into the lumpers and the splitters. The lumpers, many of whom flock to the unifying field of theoretical physics, search for hidden laws uniting the most seemingly diverse phenomena: Blur your vision a little and lightning bolts and static cling are really the same thing. The splitters, often drawn to the biological sciences, are more taken with diversity, reveling in the 34,000 variations on the theme spider, or the 550 species of coniferous trees.

—*George Johnson in* The New York Times, *1999 [1]*

In what way is a person like a 100-W light bulb? Before you rack your brain for the punch line, let me hasten to add that my question is not a joke but a serious scientific matter. I first came across it more than 40 years ago while doing a literature review during my graduate work on the absorption of radiofrequency (RF) radiation by the human body. Some of the earliest work on establishing safety standards in this area was done by H.P. Schwan in the 1950s and 1960s. He explained the rationale for his 10 mW/cm^2 (100 W/m^2) safe-exposure limit (IEEE Standard C95.1—1966) in a 1971 article [2]: "We assume one side of the human body completely illuminated, i.e., an exposed area of about 1 m^2. Thus the total thermal load is about 100 W." This figure of 100 W was, by Schwan's reckoning [3], equal to "the amount of heat body dissipates under normal conditions." How did he estimate that? If a person consumes 2,000 kilocalories per day, it will represent roughly 8.4 x 10^6 J of energy over a period of 86,400 s. That is a rate of around 100 J/s; hence the figure of 100 W used by Schwan. He reasoned that an extra thermal load (from the RF radiation) of the same magnitude should not pose a thermal challenge for the human body, which can dissipate much more heat during vigorous exercise.

Recently I came across the same (approximate) 100-W figure for the base metabolic rate for human beings in a very different context in a book [4] by the physicist Geoffrey West. In 1993, West was in charge of the high-energy physics program at the Los Alamos National Laboratory and was involved with the design and development of the Superconducting Super Collider. When later that year, the U.S. Congress abruptly pulled the funding from the project, West decided to team up with two biologists from the University of New Mexico to focus on the life sciences, bringing a physicist's search for a unifying theoretical framework to biological problems. The successful collaboration resulted in papers in *Science* and *Nature* in the late 1990s and, more recently, in a book [4] on biological scaling laws.

As West notes [4], "metabolic rate is the fundamental rate of biology, setting the pace of life for almost everything an organism does…The basal metabolic rate of the average human being is only about 90 watts, corresponding to a typical incandescent light bulb and equivalent to the approximately 2,000 food [kilo]calories you eat every day." How does this metabolic rate change with the size of an organism? The Swiss physiologist Max Kleiber had already observed in 1932 that "the metabolic rate scales as a power law whose exponent is very close to the number ¾" [4]. For example, an animal twice the size of another one requires only 75% more food and energy each day, rather than 100% more. This scaling law was found to be valid across all taxonomic groups and all sizes from mice to elephants. West and his colleagues developed a quantitative framework to explain this scaling law "rooted in the universal mathematical, dynamical, and organizational properties of the multiple networks that distribute energy, materials, and information to local microscopic sites that permeate organisms" [4]. Amazingly, according to West, the same scaling law applies even to the growth of cities and companies!

As sophisticated computer simulations and laboratory data have become available, the IEEE RF safe exposure standard C95.1 has also continued to evolve since the days of Schwan's heuristic analysis based on the base metabolic rate. More research, especially in the millimeter-wave frequency bands now

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Digital Object Identifier 10.1109/MAP.2021.3115773
Date of current version: 6 December 2021

support with the activities of phases 2 and 3. When the feedback was collected, several girls noted that they enjoyed the phase 1 lab tour, others indicated it was their first time working with conductive threads, and some noted that they built their very first circuit on that day.

- *Grow the program*: Building on such promising foundations, we are set to further grow the program and address a bottleneck raised by the girls and their parents: the lack of continuity in STEM outreach programs. Together with CoolTechGirls, we envision a year-long TechnoFashion program that includes a set of eight workshops with homework assigned in between, culminating in a design challenge. The role of YPs is now significantly expanded such that they can design any of the aforementioned activities, deliver them, mentor other YPs and student volunteers in the process, provide hands-on support to girls throughout the year, and brainstorm with them. Indeed, several YPs participated in the first pilot of our year-long TechnoFashion version, including Ph.D. students, lecturers, professors of practice, tenure-track faculty, and industry experts. We are currently building on the feedback received to improve the program and expand numerically and geographically.

CONCLUSIONS

STEM outreach enabled by YP volunteers is known to offer numerous benefits, not just to student participants, but also to YPs themselves. From designing and delivering activities, to mentoring other volunteers and student participants, YPs can build invaluable personal, social, and communication skills. A TechnoFashion paradigm was provided, which relied strongly on the efforts of YPs for its success, from concept to implementation and growth. Involvement in STEM outreach may not fulfill any formal degree requirements, but it certainly does augment training for YPs, which can prove valuable in their current and future careers.

ACKNOWLEDGMENTS

I would like to thank my Ph.D. students Katrina Tisdale, Jack Blauert, and Vigyanshu Mishra for participating in TechnoFashion in diverse roles over the years. I would also like to thank the founder of CoolTechGirls, Purba Majumder, and all of the CoolTechGirls volunteers for believing in the idea and working with us. And finally, I would like to thank Zahra Atiq and Julia Armstrong for joining the team to empower the year-long TechnoFashion program.

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TURNSTILE

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being used for 5G, is still needed. The U.S. Court of Appeals for the District of Columbia Circuit noted in a recent ruling that while "it takes no position in the scientific debate over the health and environmental effects of RF radiation," [5] the Federal Communications Commission needs "to explain why its current guidelines [dating to 1996] adequately protect against the harmful consequences of exposure to radiofrequency (RF) radiation unrelated to cancer" [5].

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