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Shining a Light on the Impacts of Our Innovations

In 2014, the Nobel Prize in Physics was awarded to a trio of physicists who struggled for years to bring the blue light-emitting diode (LED) into the world. On a highly anticipated autumn day, the Nobel Committee rightly recognized Isamu Akasaki, Hiroshi Amano, and Shuji Nakamura for their invention, which, according to the committee, "enabled bright and energy-saving white light sources." Not only had these researchers convinced a hardworking class of materials known as semiconductors to create light, but in developing the blue LED, which had the ability to generate white light when combined with red and green LEDs, they had, in effect, found the Holy Grail of materials science. Cost effective and energy efficient, blue LEDs were a model technology for a greener age. Yet the extraordinary achievement of this new form of light cast a shadow that society is still reckoning with—particularly its adverse effects on human health.

The creation and the adoption of the blue LED illuminates the persistent disconnect between day-to-day science and society. Scientists are commonly portrayed as spending long days in the laboratory bringing their ideas to life—and out into the world. However, what gets neglected in their toil is the broader consideration of how their brainchild will live in the world.

Personally speaking, I have come to understand this all too well, having witnessed and experienced the thrill of discovery. For nearly two decades, I worked as a materials scientist, first at Bell Labs and later as an associate professor at Yale. For me, there is no greater joy than hearing the whispers of nature and then translating that understanding into something useful. With this hard-won knowledge, we, as scientists, can build technologies that are better, stronger, and faster. But after years of doing research and later nurturing future researchers in my laboratory, I have come to understand that an important question gets overlooked. In our exuberance for making and creating, we fail to address the societal ramifications of what we create.

As scientists, we concern ourselves with working on our research, securing funding for it, and recruiting students to carry it out. Even textbooks, including the dozens of materials science books I own, relegate the environmental and societal impacts of innovations to their final chapters, sending a strong message to future scientists about these considerations' perceived priority. Consigning the impact of our innovations to a postscript has given rise to many current dilemmas now facing society, such as climate disruption and bias in algorithms. Not acknowledging how profoundly science affects society is naive at best and dangerous at worst. It is in this spirit that the story of the blue LED sheds light on how the euphoria of great breakthroughs can render us uncritical of them and as a result can catalyze a new set of problems and unintended consequences.

The development of the blue LEDs was carried out by numerous well-funded scientific institutions and laboratories, which were furiously competing to solve a huge global energy problem. Incandescent bulbs often wasted most of their energy as heat. These bulbs were hot enough to bake cakes in the popular toy ovens that had been on children's Christmas lists since the 1960s. Fluorescent lights were designed to address this inefficiency by exciting a gas to create a luminous plasma without creating heat. But these newer lights also housed mercury. Before the arrival of the blue LED, the choices for artificial light were either inefficient or environmentally unsound.

When the Nobel Prize-winning scientists embarked on creating the blue LED, there were glimmers of hope to encourage them. Red LEDs had been invented in the late 1960s and were quickly adopted by the 1970s, embedded in culturally iconic products including digital watches, calculators, and VCR clocks. The omnipresence of red LEDs in culture became a beacon of what was scientifically—and socially—possible. But unlike with red LEDs, the path to blue LEDs was far more challenging. Akasaki, Amano, and Nakamura faced numerous difficulties in convincing layers of semiconductor materials to make light, with each researcher tackling different parts of the problem. (Akasaki and Amano worked together and Nakamura worked independently).

To create a semiconductor diode with one side containing negative carriers (the n-type side) and the other side with positive carriers (the p-type side), Akasaki and Amano first had to persuade the semiconductor gallium nitride to form a p-type region. Later, Nakamura coaxed high-quality thin films of gallium nitride to grow and then had to negotiate the crystallographic mismatch between gallium nitride and its supporting substrate of sapphire, which gave rise to an astronomical number of defects called threading dislocations, which often limited the performance of the device. Lastly, Nakamura had to corral all the light the device produced into a small region by using a series of thin layers to create heterostructures and quantum wells. In many ways, the task of bringing better light into the world was largely done in the dark.

This research path was also a lonely one. When Nakamura spoke at conferences in the early stages of his work on gallium nitride, there were many empty seats. Neighboring sessions featuring other, seemingly more promising materials for blue LEDs, such as zinc selenide, had standing-room-only crowds. Furthermore, Nakamura worked at a small chemical company far from the academic and industrial hubs of Tokyo and Kyoto. For all these reasons, the invention of the blue LED was a marvelous achievement on many levels—and it took less than 20 years to enter in the marketplace at a price that consumers could tolerate, appearing in homes and streetlights worldwide.

But shortly after the blue LED delivered on its promise of providing cheap, efficient white light, it caused scientists in another field entirely to lose sleep—literally. Neurologists and biologists have long studied the way light affects human health. During the daytime, the metabolism, temperature, and the amount of growth hormone in the body increases. But at night, the body enters a repair and rest mode, and all those values decrease. The body's switch to daytime mode appears to be triggered when special cells in the retina, called intrinsically photoreceptive retinal ganglion cells, detect blue light. Sunlight is rich in blue light, but so is the blue LED. And by the early part of the twenty-first century, these cost-effective, energy-efficient, and now ubiquitous forms of light began to take part in altering our human physiology and even our ability to sleep.

But blue-rich lights didn't just affect our individual lives. They also profoundly changed the way society experiences the streets we share. Researchers have found that the ability to see blue light diminishes as we get older. The lenses in the eyes of a 65-year-old allow in about half the blue light that the lenses of a 25-year-old let in—and the rest of that light is rendered as glare. For older people, driving at night became significantly more hazardous when a great number of blue lights were installed in streetlamps. And as cities continue to use such bulbs, they are handicapping their senior drivers, making the roads less safe for everyone. Installing lights that use the part of the light spectrum that can reach the retina of all citizens could mitigate this.

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The saga of blue LEDs illuminates a greater cultural deficiency in the research community as well: scientists in a particular field are often unaware of the big questions that animate other scientific disciplines. Around the same time the blue LED was being developed, research papers on the topic of the connection between light and the body were being published in widely read journals such as *Science* and *Nature*. The culture of research, however, does not incentivize looking beyond one's own discipline. This state of affairs is partly because the structure and culture of academia does not encourage an understanding between fields.

There's a reason we so frequently cite the chemist and novelist C. P. Snow's "two cultures" to describe the gap between the humanities and the sciences, but he also warned that academic fields themselves are far too specialized. We, as scientists, prioritize our own discipline and neglect our understanding of others. But by doing so, we also relinquish our deeper participation in the broader pursuit of knowledge, and impair our ability to critique how our innovations intersect with these other fields. The development of the blue LED illuminates not only the division between science and society, but also how even scientists can be blind to research within the sciences.

Academic silos barricade us from thinking broadly and holistically. In materials science, students are often taught that the key criteria for materials selection are limited to cost, availability, and the ease of manufacturing. The ethical dimension of a materials innovation is generally set aside as an elective class in accredited engineering schools. But thinking about the impacts of one's work should be neither optional nor an afterthought. By allowing this to be the case, we, as educators, put blinders on the next generation of scientists.

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The impact of one's work should be an analysis taken almost as early as the birth of the idea itself. Currently, textbooks exclude or bracket off considerations of our humanness in an effort to expeditiously dispense information. This omission tells students that our humanity has a lesser value, and, as such, robs them of an opportunity to develop empathy. To better foster this kind of thinking, we need to integrate ethics and considerations of social impacts into all science and engineering classes, so that these considerations can be folded into the thinking of future scientists.

This lapse in the priority and timing of the instruction of ethics is only part of the issue, however. The other part is the emotionless way science is presented. For example, in materials science classes what is called the "glass transition temperature" of rubber is often portrayed as a dull concept. Rubber's ability to become rigid (or "glassy") when cooled to lower temperatures might be an esoteric point and even a bit mundane. But I will never feel that way about it.

Long ago, on January 28, 1986, I was an eager high school student with dreams of becoming a scientist. On that day, I experienced the crushing loss when the Challenger space shuttle tragedy occurred. I felt failed by science. Years later, in college, I learned the science behind this failure: rubber loses its elasticity when the temperature drops, making a rubber O-ring on a booster rocket an unreliable seal on an unusually cold Florida morning. This scientific concept was not merely an equation; it was part of a larger decisionmaking system with human lives at stake. The tragedy I witnessed could have been prevented if officials had heeded the warnings of engineers worried about the performance of the O-rings.

For this reason, when we teach science, we need to make students understand how every decision can touch lives. We must share a lesson that not only reaches their brains with the mechanical properties of rubber, but also their heart, with emotions of grief and loss. Pondering the impact of one's work should not be a distant and detached cerebral exercise. If it remains so, these future innovators will continue to follow a destructive mantra of seeking forgiveness and not permission.

And here is where the triumph of the blue LED turns into a cautionary tale about the social impacts of invention. Although the study of science is often taught as a series of immutable "facts," science is not done in a vacuum, and technologies are not deployed in one either. Although we may desire to distill out our humanness when we perform science, we must consider that very humanness when our scientific work goes out into the world.

One way we can achieve this is to tell better science stories. I have learned from my own experience as a science writer that stories about inventions are not only carriers of scientific concepts, but also of the values and emotions we want to pass along to the next generation. When students hear terms such as "light-emitting diodes" or "glass transition temperature," they should not only know them but also *feel* them. This will allow them to make better decisions and be more considerate of the stakes involved. This kind of thinking may not get a scientist a Nobel Prize, but perhaps it should.

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