

Surprise

How many scientific discoveries can you think of that were made by mistake or serendipity? Without checking Google, I can think of penicillin, Teflon, nickel titanium, X rays, and the big bang echo. Most of us wouldn't include serendipity as a key step in our next project, but we would be delighted if such an event were to occur.

Compared to scientists, engineers seem to have fewer of these exciting and romantic tales of unexpected breakthroughs. When Black built his feedback amplifiers, he quickly discovered that stability was an important issue, leading to elegant analysis by Nyquist. Likewise, I suppose that Kalman didn't expect to find a Riccati equation at the end of his filter derivation. But neither of these "discoveries" has the instant serendipity that makes headlines and legends.

What *is* unexpected in engineering is the way in which engineering innovations are used. It's easy to think of examples. The magnetron was developed for radar but now cooks food in most kitchens. The iPod was developed for music and is now used for PODcasting lectures (presumably reducing live classroom attendance). Although both uses were unexpected, unanticipated applications are not new. The windmill governor was adapted to the steam engine governor, while amplifier feedback advanced from triodes to semiconductors without missing a beat.

But not all outcomes meet the developer's expectations, especially when engineers invent with high ideals, believing that the fruits of their labor will contribute to peace



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A snow sculpture at the Harbin snow festival.



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The Harbin ice festival.



At the entrance to the Forbidden City.



Inside the Forbidden City.

and well-being. Philo T. Farnsworth, the inventor of television, felt that way about the medium he invented. His innovation was a coated glass tube, scanned in electronic boustrophedon, which he envisioned at age 14 while plowing a potato field in Iowa. But later in life he expressed disappointment at how television steals time from reading and conversation. Today, television is practically a metaphor for deca-

dence (for a graphic depiction, see the movie *Avalon*).

Farnsworth, who died in 1971, could not have foreseen how his CRT would develop as an essential component of computer technology. Likewise, we continue to be surprised by the innovative and unexpected benefits of the Web. We can take satisfaction in its many remarkable uses, except possibly the widespread games, gambling, and pornography.

Engineers develop technology and hand it off to others who use it in unexpected ways. Some of these uses please us, and others do not. But we hope that what we create will benefit peace and well-being in the long run, serendipitously or not.

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Hidden Leverage

When a process engineer attempts to construct a set of algorithms that will be the basis for automating some portion of the production process, he or she first interviews those individuals who currently perform the tasks that will be automated. The process engineer must learn the detail of their actions in order to translate their practice into the terms of a mathematical model. The algorithms in such a model explicate, rationalize, and institutionalize know-how. In the course of these interviews, the process engineer is likely to run up against the limits of implicit knowledge. A worker may perform competently yet be unable to communicate the structure of his or her actions. As one engineer discovered: There are operators who can run the paper machine with tremendous efficiency, but they cannot describe to you how they do it. They have built-in actions and senses that they are not aware of. One operation required pulling two levers simultaneously, and they were not conscious of the fact that they were pulling two levers. They said they were pulling one. The operators run the mill, but they don't understand how. There are operators who know exactly what to do, but they cannot tell you how they do it.

—S. Zuboff, *In the Age of the Smart Machine: The Future of Work and Power*, Basic Books, 1988, p. 60.