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2. How to Grow Strong, Healthy Engineers

Graduating engineering students have a rough time of it lately. Used to be, most grads were employable and could be hired for many jobs. Ten years ago and earlier, there were a lot of jobs. Now, there aren't so many and employers demand relevant course work for the myriad of esoteric pursuits in electrical engineering. Of those grads that do get hired, the majority fail in their first professional placement.

We should wonder, is this an unhealthy industry for young engineers? Well, I guess so. Although I am productive and comfortable now, I was not successful in my first three jobs, encompassing nine years of professional waste. Although I designed several analog ICs that worked in this period, none made it to market.

Let me define what I call professional success:

The successful engineer delivers to his or her employer at least 2½ times the yearly salary in directly attributable sales or efficiency. It may take years to assess this.

For many positions, it's easy to take this measure. For others, such as in quality assurance, one assays the damage done to the company for not executing one's duties. This is more nebulous and requires a wider business acumen to make the measure. At this point, let me pose what I think is the central function of the engineer:

Engineers create, support, and sell machines.

That's our purpose. A microprocessor is a machine; so is a hammer or a glove. I'll call anything which extends human ability a machine.

It doesn't stop with the designer: the manufacturing workers and engineers really make the machines, long-term. There's lots of engineering support, and all for making the machines and encouraging our beloved customers to buy them. Some people don't understand or savor this definition, but it's been the role of engineers since the beginning of the industrial revolution. I personally like it. I like the structure of business, the creation of products, the manufacture of them, and the publicizing of them. Our products are like our children, maybe more like our pets. They have lives, some healthy and some sickly. Four of my ICs have healthy, popular lives; ten are doing just OK; and six are just not popular in the market. Others have died.

A young engineering student won't ever hear of this in school. Our colleges' faculties are uneasy with the engineers' charter. The students don't know that they will be held to standards of productivity. They are taught that engineering is like science, sort of. But science need not provide economic virtue; engineering pursuits must.

So what is the state of engineering for the new grad? Mixed. Hopefully, the grad will initially be given procedural tasks that will be successful and lead to more independent projects. At worst, as in my experience, the young engineer will be assigned to projects better left to seasoned engineers. These projects generally veer off on some strange trajectory, and those involved suffer. Oddly enough, the young engineer receives the same raises per year for each possibility. After all, the young engineer is nothing but "potential" in the company's view.

What, then, is the initial value of a young engineer? The ability to support ongoing duties in a company? Not usually; sustaining engineering requires specific training not available in college, and possibly not transferable between similar companies. Design ability due to new topics available in academia? Probably not, for two reasons. First, colleges typically follow rather than lead progress in industry. Second, new grads can't seem to design their way out of a paper bag, in terms of bringing a design through a company to successful customer acceptance. Not just my opinion, it's history.

This is what's wrong with grads, with respect to the electronics industry:

They are not ready to make money for their new employer.

They don't know they're not scientists; that engineers make and sell things. They don't appreciate the economic foundation we all operate with.

They don't know just how under-prepared they are. They are sophomores—from the ancient Greek, suggesting "those who think they know." They try to change that which they don't really understand. They have *hubris*, the unearned egotistical satisfaction of the young and the matriculated.

They see that many of their superiors are jerks, idiots, incompetents, or lazy. Well, sure. Not in all companies, but too often true enough. Our grads often proclaim this truth loudly and invite unnecessary trouble.

They willingly accept tasks they are ill-suited for. They don't know they'll be slaughtered for their failures. Marketing positions come to mind.

Not all grads actually like engineering. They might have taken the career for monetary reward alone. These folks may never be good at the trade.

So, should we never hire young engineers? Should we declare them useless and damn them to eternal disgrace? Should we never party with them? Well, probably not. I can see that at Elantec, a relatively young and growing company, we need them now and will especially need them when we old farts get more lethargic. It's simple economics; as companies grow they need more people to get more work done. Anyway, young people really do add vitality to our aging industry.

It behooves us all, then, to create a professional growth path where the company can get the most out of its investment, and the new grad can also get the most lifelong result from his or her college investment. I have a practical plan. I didn't invent it; the Renaissance tradespeople did. It's called "apprenticeship."

The "crafts" were developed in the 1400s, mostly in Italy. The work was the production of household art. This might be devotional paintings, could be wondrous inlaid marble tables, might be gorgeous hand-woven tapestries to insulate the walls. In most cases, the artistic was combined with the practical. Let me amplify: the art was profitable. There was no cynicism about it; beauty and commerce were both considered good.

We have similar attitudes today, but perhaps we've lost some of the artistic content. Too bad: our industrial management has very little imagination, and seldom recognizes the value of beauty in the marketplace. At Elantec, we've made our reputation on being the analog boutique of high-speed circuits. We couldn't compete on pure price as a younger company, but our willingness to make elegant circuits gave us a lot of customer loyalty. We let the big companies offer cheap but ugly circuits; we try to give customers their ideal integrated solutions. We truly like our customers and want to please them. We are finally competitive in pricing, but we still offer a lot of value in the cheaper circuits.

Do college grads figure into this market approach? Not at all. You can't expect the grad to immediately understand the marketplace, the management of reliable manufacturing, or even effective design right out of college. Just ain't taught. The Renaissance concept of the "shop" will work, however. The shop was a training place, a place where ability was measured rather than assumed, where each employee was assigned tasks aimed for success. Professional growth was managed.

An example: the Renaissance portrait shop. The frame was constructed by the lowliest of apprentices. This frame was carved wood, and the apprentice spent much of his or her time practicing carving on junk wood in anticipation of real product. The frame apprentice also was taught how to suspend the canvas properly. Much of the area of the canvas was painted by other apprentices or journeyman painters. They were allowed to paint only cherubs or buildings or clouds. The young painters were encouraged to form such small specialties, for they support deeper abilities later. So many fine old paintings were done by gangs; it's surprising. Raphael, Tintoretto, and even Michelangelo had such shops. The masters, of course, directed the design and support effort, but made the dominant images we attribute to them alone. Most of the master painters had been apprentices in someone else's shops. We get our phrase "state of the art" from these people.

Today's engineers do practice an art form. Our management would probably prefer that we not recognize the art content, for it derails traditional business management based on power. We engineers have to ensure that artistic and practical training be given to our novices.

So, how does one train the engineering grad? I can only speak for my own field, analog IC design. I'll give some suggestions that will have equivalents in other areas of engineering. The reader can create a program for his or her own work.

1. The grad will initially be given applications engineering duty. Applications is the company's technical link with the buying public. This group answers phone calls of technical inquiries and helps customers with specific problems with the circuits in the lab, when published or designer information is unavailable. Phone duty is only half of applications; they develop applications circuits utilizing products and get the write-ups published, typically through trade magazines such as *EDN*. They produce application notes, which serve as practical and educational reading for customers. A well-developed department will also create data sheets, lifting the burden from the designers but also enforcing a level of quality and similarity in the company's literature. My first two years in the industry were in this job. In one instance, I forced a redesign of a circuit I was preparing the data sheet for because it simply did not function adequately for the end application. Of course, designers always think their circuits are good enough. A truly seasoned applications engineer can be involved in new product selection.

The point of this assignment is to teach future designers what to design, what customers need (as opposed to what they want), how to interact with the factory, and general market information. I wouldn't let new grads speak to customers immediately; first they would make data sheets for new products and be required to play with circuits in the lab to become familiar with the product line. Making application notes would be required, guided by senior applications engineers. I believe that developing good engineering writing skills is important for the designer.

After a couple of months, the engineer would start phone duty. I think the first few calls should be handled with a senior apps engineer listening, to coach the young engineer after the calls. It's important that the engineer be optimally professional and helpful to the customer so as to represent the company best. Most of us have called other companies for help with some product problem, only to reach some useless clone.

This stint in applications would last full-time for six months, then be continued another six months half-time, say mornings for us West Coast folks.

2. Device modeling would be the next part-time assignment. In analog IC circuit design, it's very important to use accurate and extensive model parameters for the circuit simulators. Not having good models has caused extensive redesign exercises in our early days, and most designers in the industry never have adequate models. As circuits get faster and faster, this becomes even more critical. Larger companies have modeling groups, or require the process development engineers to create models. I have found these groups' data inaccurate in the previous companies where I've worked. We recently checked for accuracy between some device samples and the models created by a modeling group at a well-known simulator vendor, and the data was pure garbage. We modeled the devices correctly ourselves.

This being a general design need, I would have the young engineer create model parameters from process samples, guided by a senior engineer with a knack for the subject. This would also be an opportunity to steep the engineer in the simulation procedures of the department, since the models are verified and adjusted by using them in the circuit simulator to play back the initial measurements. It's a pretty tedious task, involving lots of careful measurements and extrapolations, and would probably take three months, part-time, to re-characterize a process. Modeling does give the engineer truly fundamental knowledge about device limitations in circuits and geometries appropriate to different circuit applications, some really arcane and useful laboratory techniques, and the appreciation for accuracy and detail needed in design.

Because of the tedium of modeling, few companies have accurate ongoing process data.

3. A couple of layouts would then be appropriate. Most of our designers at Elantec have done the mask design for some of their circuits, but this is rare in the industry. The usual approach is to give inadequate design packages to professional mask designers and waste much of their time badgering them through the layout. The designer often does an inadequate check of the finished layout, occasionally insisting on changes in areas that should have been edited earlier. When the project runs late, the engineer can blame the mask designer. You see it all the time.

I would have the young engineer take the job of mask designer for one easy layout in the second three months of half-time. He would lay out another designer's circuit and observe all the inefficiencies heaped upon him, hopefully with an eye to preventing them in the future. Actually, we designers have found it very enlightening to draw our own circuits here; you get a feel for what kind of circuitry packs well on a die and what is good packing, and you confront issues of component matching and current/power densities. The designer also gains the ability to predict the die size of circuits before layout. The ultimate gain is in improving engineers' ability to manage a project involving other people.

4. The first real design can be started at the beginning of the second year. This should be a design with success guaranteed, such as splicing the existing circuit A with the existing circuit B; no creativity desired but economy required. This is a trend in modern analog IC design: elaborating functions around proven working circuitry. The engineer will be overseen by a senior engineer, possibly the designer of the existing circuitry to be retrofitted. The senior engineer should be given management power over the young engineer, and should be held responsible for the project results. We should not invest project leadership too early in young engineers; it's not fair to them. The engineer will also lay the circuit out, characterize it, and make the data sheet. Each step should be overseen by an appropriate senior engineer. This phase is a full-time effort for about five months for design, is in abeyance while waiting for silicon, and full-time again for about two months during characterization.

5. The first solo design can now begin. The engineer now has been led through each of the steps in a design, except for product development. Here the designer (we'll call the young engineer a designer only when the first product is delivered to production) takes the project details from the marketing department and reforms them to a more producible definition of silicon. At the end of the initial product planning, the designer can report to the company what the expected specifications, functionality, and die size are. There are always difficulties and trade-offs that modify marketing's initial request. This should be overseen by the design manager. The project will presumably continue through the now-familiar sequence. The designer should be allowed to utilize a mask designer at this point, but should probably characterize the silicon and write the data sheet one last time.

This regimen takes a little over two years, but is valuable to the company right from the start. In the long run, the company gains a seasoned designer in about three years, not the usual seven years minimum. It's also an opportunity to see where a prospective designer will have difficulties without incurring devastating emotional and project damage. The grad can decide for himself or herself if the design path is really correct, and the apprenticeship gives opportunities to jump into other career paths.

I like the concepts of apprentice, journeyman, and master levels of the art. If you hang around in the industry long enough, you'll get the title "senior" or "staff." It's title inflation. I have met very few masters at our craft; most of us fall into the journeyman category. I put no union connotation on the terms; I just like the emphasis on craftsmanship.

There are a few engineers who graduate ready to make a company some money, but very few. Most grads are fresh engineering meat, and need to be developed into real engineers. It's time for companies to train their people and eliminate the undeserved failures. I worked for five years at a well-known IC company that was fond of bragging that it rolled 20% of its income into research and development. The fact is, it was so poorly organized that the majority of development projects failed. The projects were poorly managed, and the company was fond of "throwing a designer and a project against the wall and seeing which ones stick." Most of the designers thrown were recent graduates.

We should guide grads through this kind of apprenticeship to preserve their enthusiasm and energy, ensuring a better profession for us all.

When I read the first Williams compendium (the precursor to this book), I was shocked by the travelogs and editorials and downright personal writings. Myself, I specialize in purely technical writing. But after Jim gave me the opportunity to offer something for the second book, the first book seemed more right and I couldn't resist this chance for blatant editorialization. I'm mad, see, mad about the waste of young engineers. Waste is bad.