EDITORIAL

Is Today's Engineering Education Properly Training Young Engineers?

***Timothy Marinone**, ATA Engineering, San Diego, California*

More than 10 years ago, Strether Smith wrote a very spirited editorial here[1] where he questioned whether engineering schools were providing a curriculum of what he called "dirty-hands engineering" (DHE for short).

The original hypothesis – that engineering schools as a whole were not providing this education – was both confirmed and denied through comments from "codgers" (old engineering professionals), "youngsters" (younger engineering professionals), and "educators" (engineering professors).

While multiple excellent editorials were written in response by the educators and codgers (see back issues of *Sound & Vibration* to read the responses), there were no editorials written by the youngsters – just a couple of email excerpts that Smith chose to include in a follow-up editorial.

As a result, I'd like to take this opportunity to speak as a recent graduate of a DHE curriculum (University of Massachusetts Lowell, MS 2012) and as a current practical engineer (test engineer at ATA Engineering, Inc.) to discuss my experiences.

As well as drawing from my own experiences, I did a little digging to find out just how dissimilar the engineering curricula were between the "good old days" and today. I was able to find a mechanical engineering curriculum from UCLA in 1950 and compared it to both my alma mater and MIT's curricula from 2015. If the course was offered, I listed the year students took the course (Fr, So, Jr, or Sr, with semester 1 or 2), as shown in Table 1. Note that this investigation was by no means conclusive or exhaustive, and I would welcome any additional research on this topic.

Although it is a challenge, some trends can be pulled from this table. First, engineers still have one of the most demanding four-year degrees – typically, 4.5 credit years are taken in a four-year span. Second, the "building-block" classes (calculus, physics, chemistry, etc.) are still considered fundamental to engineering, with the first two years of classes being relatively consistent among schools. Last, many engineering classes, then and now, have labs associated with them – indicating that students are at least being exposed to DHE.

So my initial inquiry didn't appear to show a loss in DHE teaching. How else could I look at this hypothesis?

Perhaps a look at the Accreditation Board for Engineering and Technology (ABET) requirements would indicate whether or not DHE is a priority. So I looked at the *National Society of Professional Engineers' Engineering Book of Knowledge* (EBOK),[5] where they identify 30 broad engineering capabilities that they consider important to being a professional engineer. The group self-polled and identified on a scale from 1 to 4 (1 being primary, 4 being little or none at all) where they felt each capability was primarily developed (baccalaureate education, graduate education, continuing professional development, or experience).

As seen in Table 2, engineers have a perception that they tend to develop many of their capabilities through experience, not through education or professional development. Aside from the topics that lend themselves best to an academic setting (math, science, economics), most found that their college curriculum education was not where they developed these skills.

Of course, this raises the question of whether engineers are developing these capabilities through experience because schools are doing a poor job of providing opportunities to develop them, or if this development is a natural result of working as an engineer. Or, to rephrase the question: are schools providing a good foundation upon which to build a career?

What about engineering school rankings – can we glean any information from them? I decided to look at the *US News & World Report* rankings and see if they considered being a DHE school significant. Here's the scale they use to determine rankings:

Table 1. Comparing mechanical engineering curricula or three major universities[2,3,4]

	UCLA, 1950	UML, 2015)	MIT, 2015
Military Science	Fr (1-2), So (1-2)	X	X
Physical Education	Fr (1-2), So (1-2)	X	X
Chemistry 1 (Class+Lab)	Fr (1)	Fr (1)	Fr (1)
Chemistry 2 (Class+Lab)	Fr (2)	X	X
Calculus 1	Fr (1)	Fr (1)	Fr (1)
Calculus 2	Fr (2)	Fr (2)	Fr (1)
Physics 1 (Class+Lab)	Fr (2)	Fr (2)	Fr (1)
Physics 2 (Class+Lab)	So (1)	Jr (1)	Fr (2)
Physics 3 (Class+Lab)	So (2)	So (1)	Fr (2)
Calculus 3	So (1)	So (1)	So (1)
Differential Equations	So (2)	So (2)	So (1)
Engineering Mathematics	Jr (1)	Jr (1)	So (1)
Social Humanities	So (1-2)	Fr (1-2), So (2), Sr (2)	Fr (1)-Sr (2)
Electives	Jr (1-2), Sr (1-2)	Sr (1-2)	Jr (2), Sr (1-2)
Surveying (Class+Fieldwork)	Fr (1-2)	X	X
Material Properties	Fr (2)	So (1)	So (1)
Engineering 101	Fr (1)	Fr (1)	X
Engineering Drawing (Class+Lab)	So (1)	So (1)	X
Processing of Engineering Materials (Class+Lab)	So (1)	Sr (1)	X
Strength of Materials (Class+Lab)	So (1-2)	So (2)	So (1)
Circuit Analysis (Class+Lab)	Jr (1)	So (2)	X
Electrical Machines (Class+Lab)	Jr (2)	X	X
Engineering Dynamics	Jr (1)	So (2)	So (2)
Fluid Mechanics	Jr (2)	Jr (1)	Jr (1)
Heat Transfer and Thermodynamics	Jr (1-2)	So (2), Jr (2)	Jr (1)
Advanced Strength of Materials (Class+Lab)	Jr (1)	Jr (2)	Jr (2)
Engineering Ethics / Technical Writing	Sr (2)	Jr (1)	Jr (20)
Engineering Design (Class+Lab)	Sr (1)	Jr (1-2)	So (2), Sr (2)
Mechanical Engineering Lab	Sr (1-2)	Jr (2), Sr (1)	Jr (1)
College Writing 1	X	Fr (1)	X
College Writing 2	X	Fr (2)	X
Statics	So (1)	So (1)	So (1)
Economics	Jr (1)	Jr (2)	X
Thermofluid Systems	X	Sr (2)	Jr (2)
Senior Design Project	X	Sr (2)	?
Machine Shop	So (2)	So (2)	So (2)
Dynamic Systems	X	Sr (1)	Jr (1)
Micro/Nano Engineering Laboratory	X	X	Jr (2)
Product Engineering	X	Sr (1)	Sr (1)
Biology 1 (Class)	X	X	So (2)

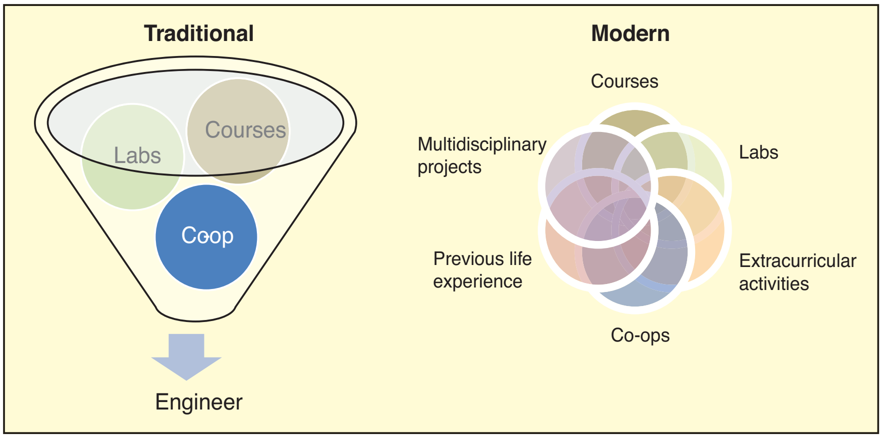

Figure 1. Traditional vs. modern approach to gaining engineering experience

- 25% amount of research activity (how much money the university faculty bring in and how many papers they publish)
- 25% student-to-faculty ratio
- 25% peer assessment (from other engineering school deans)
- 15% recruiter assessment (from various companies)
- 10% student selectivity (percentage of students who apply are accepted)

As seen in their methodology, the DHE aspect of each school is at best reflected in the 40% due to peer and recruiter reviews (and that's only if both recruiters and engineering deans value this aspect of engineering). So no obvious correlation can be drawn between schools considered good DHE schools and high magazine rankings.

At this point, Smith's hypothesis has neither been confirmed nor rejected: school curricula do not appear to have significantly changed, and we can't tell whether schools are failing in giving engineers DHE experience. Therefore, let's take a look at his questions (repeated verbatim) and see if we can gather more insight.

- Have they ever done any welding?
- Have they ever operated a lathe or milling machine?
- Have they ever installed a strain gage?
- Have they welded a thermocouple (and done an error analysis on the result)?
- Can they free-hand sketch a connecting rod? (That means: can they sketch and do they know what a connecting rod is?)
- I assume that, under your auspices, they have installed an accelerometer and it was proven to provide proper results.

Right?

He then sums it up by asking, "If they haven't gotten their hands dirty with the real stuff, how will they know what to ask for and know whether it is any good when it is done."

There are two different types of skills that Smith identified, which, borrowing from sports terminology, are called technical and tactical skills:

Technical skills are easy to understand; they are specific actions and are usually developed by repetition and by seeing it performed by others (questions 1–6 above).

Tactical skills, on the other hand, relate to the why or how of an action: identifying which technical skill to apply to best meet the objective. And throughout the engineering profession, engineers have been able to successfully distinguish themselves from technicians by the use of these tactical skills.

So his six technical questions could be reframed as tactical questions:

- Do you understand how welding affects structural properties, and can you identify when welding is an appropriate technique to use to join parts?
- Are you able to determine whether your engineering design can be made using CNC, a milling machine, or a lathe; are you able to redesign and make it simpler or easier to machine?
- Can you look at test results and assess whether the results are realistic?
- Do you understand that every sensor and data acquisition system has built-in assumptions and limitations associated with the hardware/software that affect measured data?
- Can you simplify a complex design enough to be able to perform a back-of-the-envelope calculation?
- Can you set up a simple example to prove to yourself that you have the right modeling/testing approach?

Obviously this doesn't free the engineer from developing technical skills; after all, tactical skills are only useful if they can be implemented. However, better an engineer who knows how to think critically than an engineer who can weld, lathe, and mill accurately but doesn't ask if there's a better way. And even better is a team with both of these engineers using their complementary abilities to conceptualize a solution and bring it to fruition. Perhaps we can see the humor of overemphasizing technical skills by considering a chemist designing better motor oil who doesn't know how to change the oil in their car; would we consider them any less of a chemist?

So now that those questions have been reframed as technical questions, I'd like to share my story to show how I became a DHE and help illustrate how engineering education is a piece of the puzzle rather than the entire picture.

If I were to broadly stereotype the engineering students in my class, I would have put them in two groups. The first group (mine) was made up of the traditional stu-

Table 2. NSPE's 30 capability areas with primary development method indicated.

	Undergrad Education	Graduate Education	Continuing Prof. Develpment.	Experience
Mathematics	1	2		3
Natural science	1	2		
Humanities / social sciences	2			1
Manufacturing / construction		3	2	1
Design	2	3	4	1
Engineering economics	1	3		2
Engineering science	1	2		3
Engineeringg tools	2	4	3	1
Experience	1	3		2
Problem recognition / solving	2	3		1
QA / QC		3	2	1
Risk, reliability, uncertainty	4	3	2	1
Safety			2	1
Social impact			2	1
Systems engineering	2			1
Operations and maintenance			2	1
Sustainability, environmental impact	3		2	1
Technical breadth	7	4	3	1
Technical depth	3	2	4	1
Business aspects	3		2	1
Communication	3	4	2	1
Ethical responsibility	3		2	1
Global knowledge			2	1
Leadership			2	1
Legal aspects			2	1
Lifelong learning			1	1
Professional attitudes			2	1
Project management		3	2	1
Public policy			2	1
Teamwork	2	3		1

dents who came right from high school. We tended to have a strong aptitude in math or science and to respond well to textbook problems. The second group tended to be a bit older, a couple years removed from high school or community college and with a bit more work experience. Several were auto mechanics who wanted to go beyond fixing cars and learn to design them; others came from a military background using VA benefits.

Now, perhaps if UML had not been a DHE school, the two groups would have had little interaction. (After all, the 20-year-old "kid" is in a much different set of circumstances than the mid-30s "adult," sometimes with one child and another on the way). However, with several of the classes requiring DHE projects, we quickly learned that the most successful project teams included students from both walks of life.

For example, the final project for our mechanical laboratory course consisted of designing, fabricating, and testing a system that could measure the lift and drag coefficients of a basic airfoil, and we spent just as much time designing the detailed LabVIEW GUI as we did machining the different parts of the assembly, learning how to properly integrate the sensors into our data acquisition system, or writing weekly reports summarizing our progress. The combination of theoretical and hands-on skills from the group ensured success.

And at ATA Engineering, as test engineers we appreciate the balance. We use wondrous mathematical algorithms to process data, but we also improvise test fixtures on site. We use highly detailed models to study complex spacecraft systems but then help provide confidence in those models through rigorous testing.

So what's the conclusion from this young engineer? I would say Smith's assertion is both right and wrong. DHE experience does provide a useful connection between education in the classroom and practical implementation of knowledge, and not all classes and schools provide this experience. At the same time, young engineers have many resources readily available and can easily gain this experience if they so choose. Or to put it another way, the traditional engineering path to gaining experience was to study hard in class, do the experiments in labs, and work hard during the co-op sessions (see Figure 1).

While this path is valid, today's engineer can pull from other sources as well: extracurricular activities (designing a website and learning the basics of coding), previous life experience (summer camp working with robots), or multidisciplinary projects (creating a human-powered submersible device for a competition). And of course, the wonders of YouTube can provide video tutorials on almost any subject and allow pause and rewinding until the material is understood (assuming that you can also use engineering discretion in watching these videos).

I've also been told by various engineers involved in the hiring process at different companies that there has been a shift toward the DHE principles that Smith espoused since the editorial was first published in 2004. They commented that senior design projects and participation in "design, build, test" clubs and projects are now becoming more commonplace when they review résumés of graduating students.

So perhaps there was a mini-crisis in the early 2000s, but there may have been a correction in the curriculum due to these concerns from senior engineers. I want to leave you with a quote from Sir Egbert of Liege in the 11th century and remind you that this is far from the first time we have bemoaned the state of the next generation.

"*Scholarly effort is in decline everywhere as never before. Indeed, cleverness is shunned at home and abroad. What does reading offer to pupils except tears?*"

References

1. www.sandv.com/downloads/0407smit.pdf
2. www.registrar.ucla.edu/archive/catalog/5051catalog.pdf
3. https://www.uml.edu/Catalog/Undergradate/Engineering/Departments/Mechanical/DPmechanical.aspx
4. http://meche.mit.edu/academic/undergradate/course2/samplesched/
5. http://www.nspe.org/resources/blogs/pelicensing-blog/practitioners-share-viewsengineering-body-knowledge
6. http://www/usnews.com/education/bestgraduate-schools/articles/engineering-schoolsmethodology

The author can be reached at: tim.marinone@ata-e.com.