

Reflections After 50-Plus Years in the Classroom

While the theme of this special issue is “Innovation Starts With Education,” it is also true that “education thrives on innovation.” And as technology continues to advance, new opportunities continue to present themselves for innovation in the classroom. Some remarks during the education panel at the 2019 International Conference on Acoustics, Speech, and Signal Processing started with the playful but nevertheless attention-getting comment that “we’ve been teaching for more than 50 years and are just realizing that, for all that time, we’ve been doing it wrong.” That is perhaps somewhat like saying during the late 20th century that, with hindsight, when traveling from Boston to California in 1900, it would have been better to fly than to travel by rail.

The good old days and the good old ways

From ancient times (measured in decades or millennia) to the present, the passing of knowledge from “the master” to “the student” has relied on various technologies and methods. Drawing pictures in the sand and on cave walls and verbal exposition were eventually enriched by writing, the printing press, video, audio recordings, and other means by which knowledge could be stored, archived, and shared. And throughout time, the

process has been dynamically augmented with experiments and real-world demonstrations to help bring concepts to life.

In more recent times, and especially before the massive disruption created by COVID-19, classroom presentation has taken a form in which the initial content exposure happens with “the master” presiding in front of a gathering of students, and, in particular, it has dealt with mathematically rigorous topics, developing in great detail—including all the epsilons and deltas and conditions for interchanging the order of integration and summation—the theorems, proofs, and examples related to the material being taught. Traditionally, in this setting, students dutifully try to copy everything, and they frequently get lost early in the presentation, confused about concepts and details, without questioning whether the math is indeed correct.

In subjects with large enrollments, lectures are generally augmented by smaller recitation sections and through even more intimate tutorial sessions and office hours with the professor. (As an interesting side comment, when one of us changed the terminology from *office hours* to *open hours* and moved the location from his office to a conference room, attendance tripled. As students pointed out, going to a professor’s office can sometimes feel intimidating.) This is followed by assigned reading in

textbooks and/or detailed lecture notes and homework exercises. Classroom development is typically performed with chalk on a blackboard, a marker on a white board, slides, or some combination of these. Ideally, the smaller recitation sections are highly interactive between the instructor and the students. However, in practice, too often recitation and tutorial sessions are given by relatively inexperienced graduate students who overprepare and are reluctant or unable to nimbly direct the interaction based on the needs of the students.

The use of overhead projectors and then computer-generated slides offered many opportunities to easily incorporate rich graphics and visuals (including “eye candy”) into teaching. And it also provided the opportunity to focus on the highlights of mathematical derivations without “dragging” students through every small step unless there was specifically an important point to be made in doing so. Accompanying a presentation with a hand-out would often nicely augment a transparency or slide show and free students from having to laboriously copy everything. Unfortunately, however, instructors would often bundle the entire content of a course into static slides and then, during each semester, pull out the package without updates and without enriching it with some blackboard/whiteboard interaction. In other words, the technology had the potential to be overused, often for the convenience of the instructor. In a rapidly changing environment

such as ours, we need to consider when new ideas in teaching, motivating, and inspiring students are just substitutes for old ones and when they are another enriching dimension to be included in the tool bag.

In 1992, there was a “Reflections” column article in *IEEE Signal Processing Magazine (SPM)*, “A Personal View of Education” [1], and another, in 2006, “One Plus One Could Equal Three (And Other Favorite Cliches)” [2], that contained some reflections on research. In preparing this article, those pieces seem as relevant today as they were then. But times have also changed in many significant ways. The profiles, expectations, and prior educational experiences of the student population are clearly different than they were two and three decades ago. And there have been significant advances in the richness of technology for sharing content, knowledge, and teachers’ insights and experiences with students.

Massive open online courses and the flipped classroom

A significant step forward in incorporating technology in education was driven, in part, by the introduction of massive open online courses (MOOCs). The development of MOOCs inspired the organization of presentations into smaller modules that had video, rich graphics, concept demonstrations, and, perhaps most significantly, the automatic grading of simple exercises interspersed with the other segments. There are now many excellent MOOCs available for the signal processing community, as described, for example, in the article “MOOC Adventures in Signal Processing,” published in *SPM*, in 2016 [3]. Of course, by necessity, the structure of MOOCs constrains the opportunity for rich interaction between students and teachers.

MOOCs and associated creative technologies have made an extraordinary contribution to education. They have enabled rich content presented by highly talented teachers to be accessible to anyone with Internet access anywhere in the world. And even in residential teaching environments,

MOOCs have offered an opportunity for teachers who have less experience with a course’s content to deepen their understanding and to incorporate elements such as the selective utilization of demonstrations, video segments, and auto-graded exercises. The development of MOOCs has also intensified the discussion of “flipped classrooms,” where, before in-person sessions, students watch videos of the course content and perform simple exercises to, at a minimum, get a sense of the concepts and notation. Learners then carry out at-home or in-class applications of the methods under consideration, perhaps even employing their personal signals, e.g., their voice, electrocardiograms, and so forth (see, for example, [4]). Of course, there are many variations, from relatively strong expectations and requirements for the preclassroom components to more relaxed but encouraged assumptions.

In some ways the flipped classroom is in the spirit of the more traditional (but often ignored) suggestion to students that they spend some time with the course textbook or other reading material before coming to class. However, typical textbook material is prepared to be highly complete and detailed. Consequently, requiring textbook reading prior to any classroom exposure to context and motivation can be difficult and cumbersome and is often more meaningful after the basics have been absorbed. In any case, with whatever advance preparation students can be encouraged to do, the classroom experience becomes more than just a lecture theater: it is also a forum for inspiring, motivating, and interacting.

Well-chosen and prepared videos and autograded exercises can be enormously beneficial in acclimating students to notation and basics before a lecture or classroom interaction. The potential effectiveness of aggressive or partial classroom flipping is highly dependent on the nature of the material, the resources available to students, and the creativity and style of instructors in utilizing and building on advance preparation by the students. And again, the

flipped or somewhat flipped classroom can be overdone and purposely or inadvertently take the path of being more for the convenience of the instructor than for the enhanced learning of the students.

“Necessity is the mother of invention”

As this article was being written, we were clearly experiencing another potential major step forward in incorporating technology into our teaching, precipitated by the worldwide COVID-19 crisis. During this period, schools at all levels abruptly closed their physical spaces, with the requirement to move to online platforms. This naturally meant that many of the “old” ways of delivering content—e.g., by long, detailed blackboard derivations—were, by necessity, rapidly replaced by more creative ways of presentation and engaging students. And as we all watched in real time in our respective environments, very clearly there was a lot of innovation and creative experimentation undertaken, which we all believe has impacted and will continue to influence our residential teaching methods during both the short and the long term, when life settles to whatever the new normal will be.

So, as abrupt and painful as the pandemic shutdown has been, and as extensive as the debris field will be, there are some silver linings, among them, new opportunities for presenting content and interacting with students. We’ve all heard the old English proverb, sometimes attributed to Plato, that “necessity is the mother of invention.” With online classroom experimentation rapidly happening throughout the world, there are clearly new avenues to pursue and likely many hazards and unintended consequences. This, of course, is always the case when introducing new technology into the classroom.

Another important element in the education process is the role of mentoring, which is clearly different than that of delivering content. In this magazine, the 1992 article about education [1] emphasized the importance of live mentoring and coaching. What we are seeing at our universities during the adjustment to the

pandemic are many innovative ways of having rich interaction with and among our students, evidenced, for example, by the use of “breakout rooms” (as they’re referred to on the Zoom platform) and other methods of holding online open hours, maintaining accountability during exams, and so on. All these innovations have enormous potential for enhancing both residential and distance learning. Again, it’s important to focus on utilizing these new resources to enhance the experience of the students rather than to benefit or provide convenience to teachers.

Textbooks

It’s also important to comment on the role of textbooks. Historically, these have played an important part as a companion to the other elements of a classroom experience and as future reference material. Textbooks are often written to be highly detailed and self-contained on their own. Therefore, the content can be hard to digest during a first exposure to the material. As phrased by Andrew Wu, a Massachusetts Institute of Technology undergraduate who commented on a draft of this article:

A problem that I personally have with textbooks is that using them can often be cumbersome. More typically, I consult a source because I have a question on some specific aspect of the material. If what I’m searching for exactly corresponds to a section in a textbook, then the textbook works well; however, if it’s just a few paragraphs within a textbook, it can be tedious and cumbersome to find the exact information that I’m looking for. Modern education, to me, with its vast arrays of different technologies and methods of information delivery, offers students much more of an opportunity to learn in a more personalized way.

Of course, some of that student’s concerns are mitigated by e-textbooks that support word search functions. But just as with poor search engines, it can often be difficult to find the right combination of terms to search for. Word search in an

e-text is certainly a significant improvement over a poorly composed index in a hard-copy book, but it is often cumbersome and unhelpful.

While textbooks are usually not the best resource for initial exposure to material, they have always played an essential role since they can provide a more detailed exposition than is typically necessary and appropriate in the classroom. Furthermore, textbooks give students ready access to details as pupils engage material through homework exercises and related activities. Perhaps more importantly, well-written textbooks often become lifelong, trusted companions and reliable reference sources. For a host of reasons, writing and publishing textbooks—and particularly in printed, rather than electronic, form—has become less attractive to educators. Among the factors causing this are the increasingly rapid advance of the concepts, perspectives, and techniques in our field and many

others and what seems like the broken “business model” of many publishers. Textbooks are typically perceived by many students as incredibly expensive to purchase, and most often they are rented or purchased used and then resold. Increasingly, there are pirated, unauthorized versions of popular texts for sale or simply posted for free on the Internet. Consequently, any financial incentives for publishers to commission, and for authors to write, textbooks are diminished.

Furthermore, there is an increased desirability, expectation, and requirement to incorporate hypertext links and lots of supplemental material to augment a textbook, which intensifies the overall effort on the part of authors and publishers. It currently seems unclear, at least to us, what good alternatives there are for providing students with well-written textual material while providing authors with incentives to produce it (beyond the immense satisfaction of explaining topics to a broad audience) and,

indeed, for motivating publishers and publishing platforms to make content widely available at a reasonable cost. All of this again requires innovation directed toward education.

The modern student

As commented earlier, the important evolutionary changes impacting our roles as educators include the backgrounds, experiences, and expectations of students. In our own student days and throughout a major part of our personal careers, a literature search typically began with a trip to the library. Now, for all of us, including students, a literature search often starts with accessing an appropriate search engine. And in the midst of working on a problem, all of us as researchers, teachers, and students

frequently find ourselves initially turning to our favorite search engine or some other online resource to direct us to the solution of, or resources related to, a problem.

The vast array of online

Today’s students have also grown up in an era of multitasking, for which they have developed a habit and sometimes an addiction.

resources makes many aspects of learning and research more efficient and in many respects provides more “instant gratification.” The opportunity for students to ask questions and get answers more rapidly than in decades past naturally generates a certain impatience. On the other hand, much of the information available online has not been reviewed and vetted and consequently, to some extent, it’s “searcher beware.”

As another aspect, students who have grown up in the era of TiVo, online and on-demand content streaming, and handheld devices have more reluctance than we did to be required to be at a specific place at a specific time. Today’s students have also grown up in an era of multitasking, for which they have developed a habit and sometimes an addiction. Always having a laptop, smartphone, and smart watch nearby is wonderful for keeping up with friends, family, news, and social media, but there seems little doubt that those devices represent a strong temptation that can quickly lead students to become distracted

and then lost in the classroom. This can and should be taken into account as we incorporate the rapidly expanding array of technologies for interacting with our students and delivering content.

The evolving field of signal processing

Next, we'd like to reflect on how our field has changed during the past five decades and suggest how this impacts what we choose to teach going forward. Signal processing has always been characterized by a strong symbiotic relationship between mathematics, motivating applications, and platform implementations. During the 20th century, much of the innovation was motivated by applications such as radar, sonar, avionics, communications, entertainment, and the venture into space. Platform developments were largely centered around electromagnetics, electricity, and electronics. Advances in signal processing system design and analysis relied heavily on the mathematics related to continuous functions and differential equations. And practitioners' education included, at a minimum, a firm grounding in both the fundamental mathematics and the physics related to the implementation platforms.

Toward the end of the 20th century, the digital computer moved from its role of offline analog system data analysis and simulation to a true platform for real-time and deployable signal processing systems. This opened the door to designing and implementing signal processing systems that were freed in some sense from the constraints of the physics imposed by the electronics. And, in addition to utilizing the mathematics of continuous functions, the field increasingly harnessed discrete mathematics, numerical methods, and difference equations. This transition correspondingly expanded the essential foundational mathematics, which required including and incorporating a strong understanding of linear algebra and optimization methods, statistical inference, and other approaches that are exploited in closely related fields, such as machine learning and artificial intelligence. In terms of implementing

signal processing systems, computer programming skills became more central, as did a proficiency with, or at least some understanding of, integrated circuit design.

Signal processing curricula

Signals and the need for processing them arise in a very broad set of fields and disciplines, including every branch of engineering, many aspects of health science, all the physical sciences, financial data analysis, and so on. Students taking advanced undergraduate and graduate signal processing classes often have learned the prerequisites from diverse perspectives and perhaps even picked up the knowledge informally, i.e., "learning it on the street." During the first few weeks of a course, this often presents the challenge of synchronizing everyone to similar notation and perspectives. While the concepts and foundational mathematics are essentially universal across these disciplines, students will obviously relate most strongly to application contexts with which they have some familiarity.

In thinking about appropriate curricula related to signal processing, it is also important to draw a distinction between students who will be heading toward the development of signal processing tools as a technology and those who are learning signal processing primarily to apply the field's tools and methods to advance specific applications. In both cases, there is a mathematical foundation so that tools don't get misused and so that results aren't misinterpreted. (No! The MATLAB function fft does not generate the Fourier transform of the input signal!) Intelligent use of high-level platforms, such as MATLAB, Mathematica, and LabView, does not require an in-depth and highly sophisticated fluency with the underlying mathematics.

But interpreting results correctly does demand a basic mathematical understanding of the underlying principles as typically taught in an advanced undergraduate signals and systems course that incorporates both continuous-time and discrete-time material as well as the basic mathematics of contin-

uous functions, linear algebra, and statistical inference. For students preparing for advanced development and research to significantly advance the technology of signal processing, an appropriate curriculum would likely also include more advanced mathematical topics, such as optimization methods, advanced statistical inference, and perhaps some functional analysis and nonlinear mathematics. For example, it is quite likely that the future of our field will involve the creative and methodical design of nonlinear systems and algorithms and the processing of signals that are best characterized on more general manifolds than Cartesian ones.

In our view, it is essential that students and practitioners advancing the technology of signal processing have real-world signals to process. Less crucial, in our opinion, is a strong commitment to advance any specific application. But it does seem indispensable that, in the process of developing creative new signal processing tools, the concepts and algorithms be tested on real as well as simulated signals. Signal models are important for developing and refining signal processing algorithms, but models are typically only approximations of real signals. It is important for students to understand the difference between signals and signal models. Anyone involved in signal processing, whether for research toward advancing the technology or for developing a specific application, needs to have real signals to process.

Some final thoughts

Our field has had a rich history, and clearly it has incredible potential going forward. There is always an opportunity for discovering or rediscovering mathematical principles that have not yet been fully exploited in the context of signal processing. And physics will continue to provide us with new ways of implementing signal processing systems. While digital platforms have played an increasingly important part in signal processing system implementation, the role of analog platforms also continues to grow, as does a mix of both. And quite likely, as the technology advances,

it will become increasingly difficult to define precisely which parts of a system are considered analog and which are digital.

An additional dimension is the inevitable advancement, overlapping, and merging of multiple disciplines, offering new, rich contexts and applications on which sophisticated signal processing can have an impact. These increasing dimensions and the rapid pace of progress place further demands for the constant updating, upgrading, and modification of the material taught in classrooms. Static presentations are quickly outdated and at an accelerating pace. Industrial and societal needs are continuously evolving, pressing the need for further innovation. The confluence or divergence of different disciplines puts further pressures on the modes and content of teaching for evolving educational needs.

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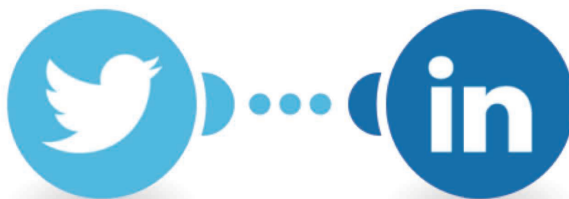
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