Revolution: In communication; in education

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Abstract
Radical change is being demanded of engineering education today—the result of the electronic-information revolution. Other information revolutions have occurred in the past; and each has led to radical changes in education. We look at some of these, giving particular attention to the little-recognized fast press revolution of the early 19th century. Perhaps these examples will help us to better see, and cope with, present change.

Problem statement
We engineering teachers face a difficult problem. Today we struggle to be effective from within an information revolution that has disrupted everything we have known about teaching. That is true, not only in engineering, but in all education. The world has undergone previous information revolutions and each has been followed by euphoria and chaos. The Gutenberg printing revolution is best known of these, but far not the only one.

I would like to focus on another sudden improvement in the availability of information that occurred between Gutenberg and the coming of the Internet—a revolution that few people are aware of. A closer look at this should help us in coping with the present upheaval.

But first, let us set the stage by looking at two earlier information revolutions. I suppose the earliest one was the invention of speech. But that was, if I may say so without sounding facile, very poorly documented. We begin instead with the rise of alphabetic writing.

Alphabetic writing
The first writing was all pictographic, ideographic, or logographic—i.e., writing systems that consisted of pictures, ideograms that called up ideas, or symbols for entire words.
Then a revolutionary new idea arose just over 3000 years ago. People in several cultures realized that they could transcribe speech by inventing symbols for each of a language’s component sounds. They invented alphabets. Systems like Cuneiform and Linear B appeared (Figure 1). Egyptian writers streamlined their hieroglyphs into symbols for sounds. These systems all came into use just before the first millennium BCE [Robinson (1995), Miller (1991), Ogg (1961), Drucker (1995)].

Written narratives had been created apart from speech up until then. The new alphabets made it possible to transcribe thoughts; and that led to a huge change in the very texture of knowledge. Psychologist Julian Jaynes went a step further and offered a most convincing argument in 1976. He showed how alphabetic writing changed the texture of thought itself (Jaynes, 1976).

Consequently, the content and the methods of teaching had to change radically. Teaching had been done solely by the spoken word; now it would be wed to reading. As alphabetic writing matured, students of all kinds turned to so-called authoritative writings. The works of Aristotle, Pliny, Galen, Heroditus, the Hebrew Scriptures, and the Roman physician Galen emerged as the final word on their subjects.

While this was going on, Plato told of Socrates’ lingering objection to writing (Fowler, 1925). Socrates had told Plato that:

\[\text{Writing \ldots has a strange quality and is very like painting; for the creatures of painting stand like living beings, but if one asks them a question, they preserve a solemn silence. And so it is with written words; you might think they spoke as if they had intelligence, but if you question them, wishing to know about their sayings, they always say only one and the same thing. And every word, when once it is written, is bandied about, alike among those who understand and those who have no interest in it, \ldots} \]

Never mind that Plato turned around and committed Socrates’s objections to writing. Socrates nevertheless left us with a wrenching glimpse into how his concepts of teaching and learning were being overturned in Hellenic Greece.

**Gutenberg revolution**

The so-called Gutenberg printing revolution is the best known information revolution (Lienhard, 2006 a) (Figure 2). Yet when Gutenberg printed his great Bible in 1454 he saw himself, not as a revolutionary but as a clever forger. Elaborate hand-written and decorated Bibles cost a small fortune. He meant to forge handwriting and to make a great deal of money.

Printing remained little more than an improved system for producing the old authoritarian writings during the next thirty or so years. It made money for printers, but the nature of books changed little. Then fifteenth-century hackers and nerds got into the game. They said, in effect,
“Wait a minute, we can translate these books and print them in local languages. We can add illustrations so everyone can understand how things work.”

When that happened, books began losing their old authority. Commoners interpreted them and added their own ideas. Diverse voices undermined the authority of the written word. That led to religious reformation and to the democratization of reading.

It also led to wonderful new knowledge. Whole new sciences began arising. The first of those was botany: Illustrated books of plants and flowers appeared (Figure 3); and agreement on plant families and species became possible. Surgeons began publishing accurate anatomical drawings. They shared what they knew of the human body’s workings, and the new science of anatomy arose.

The nature of knowledge itself changed again. Old misconceptions and myths came under attack. For a while, the new books on Zoology tried to include unicorns and mermaids. But unicorn and mermaid images came from imagination, not real life. They had no consistency and did not ring true. They had to go.

All this meant that education had to become something radically different from what it had been. Authority became fluid and the changing landscape of modern science as we know it
Figure 3: An ox tongue plant from Johann Petri's 1486 Herbarium. Woodblock illustration colored by hand.
arose. Teachers had to shift their attention away from frozen authoritative works, and toward methods of acquiring new knowledge.

**An intermediate interpretation**

It should be clear where we are headed here: History is repeating itself again after a generation of electronic information has made knowledge far easier to access. The texture of knowledge itself changes as we grapple, not just with new means for teaching, but with radical new ideas about just what we should be teaching.

It took a full century after Gutenberg for medical schools to figure out how to teach anatomy—well after accurate pictures were available. Physicians continued trying to teach the works of Galen—all text, no pictures. They were not about to let go of Galen's old descriptive words.

It took a new breed to understand that printed picture books were far more informative. Meanwhile, old teachers said, “How are we going to teach Galen when our students see these new pictures that contradict what Galen taught us?” They reacted as we older engineering faculty did when we asked, “How are we to teach slide rule use, now that our students have pocket calculators?”

We ask ourselves today, how to teach the algorithms of arithmetic when we have calculators, or grammar and spelling when our word processors fix our prose as we go. How do we engineers teach differential equations when students can solve any differential equation with a few keystrokes?

But are those the right questions? Maybe the teaching of algorithms of spelling, or of solving differential equations, should be replaced with something wholly new. Perhaps, instead of asking about differential equations, we should ask, “What do students, armed with new tools, need to know about the mathematics that describes our physical world?”

I said at the outset that we would look at another information revolution, much more recent than the Gutenberg revolution, and almost unknown to most people. By understanding what this new technology did to teaching and learning 200 years ago, we can gain some insight into our situation today.

**The roller press revolution**

Consider how books were made in the early 19th century. Presses were still similar to those of Gutenberg's time. They had been improved, of course, but their operation was much the same as Gutenberg's. Printers set a bed of type that held one or more pages of text. They spread ink on the type and laid a sheet of paper (or animal skin) on top of it. Next they slid the bed in under the press; then heaved on a lever that pressed the paper against the type. The ink had to dry before they could do the backside. Finally, they folded that sheet to get 2, 4, 8, 16 or even 32 pages in sequence. Later, a bookbinder would sew those foldings (called “signatures”) together and bind them.

A pair of printers might thus make one or two books ready to be bound each day. It was slow, but still a huge improvement over handwritten manuscripts. Now a commoner could have a book for a few weeks' wages. Printing improved between 1454 and 1810, but the principle of one sheet for one loading of the press remained. Buying a book became easier, but it remained an investment much like buying computer today.
Today, a wage earner can have a cheap book for a several minutes’ pay. That huge improvement was the result of a revolutionary new technology—one as significant as Gutenberg’s press—maybe even as significant as the coming of the Internet. It was the roller press.

Some of us have had the visceral thrill of seeing a large so-called “web-fed” newspaper press in action. Paper leaves huge rolls that weigh over a ton, to fly through a vast machine that prints, cuts, and folds it, all faster than the eye can follow.

Compare that with those old hand presses, still in use all through the eighteenth-century Industrial Revolution. Some major improvements took place during the Industrial Revolution. French printers added metal parts and clever mechanisms to presses.

Around 1800, the Earl of Stanhope built an all-metal press with compound levers to drive a conventional screw mechanism. It imposed very high pressure at the end of the printing stroke. Printers who once had to impress each half of the paper separately could now print the whole sheet in one much easier stroke. The American Clymer press appeared with a pure lever system (Figure 4). It finally eliminated Gutenberg’s old screw-drive completely.

Figure 4: Clymers “Columbian” press as shown in the 1832 Edinburgh Encyclopaedia
But all that was a much like the arrival of IBM Selectric typewriters in the 1960s, or pocket calculators in the 1970s. Those were just the last hi-tech days in the age of typewriters and calculating machines. Printers in the early 1800s likewise lived in the last hi-tech days of the hand press.

The best hi-tech eighteenth-century printing presses were still intolerably slow compared with our huge industrial presses today. They were as primitive as electric typewriters and pocket calculators of the 1970s soon proved to be. Hand presses clearly had to give way to a steady flow of paper through rollers.

Finally, Friedrich Koenig began work on a steam-powered machine with an inked roller in 1810 (Figure 5). Koenig contrived to print sheets of paper as they flowed by, and he solved the difficult problem of printing on both sides of paper. It took only a decade for complex cylinder machines to overtake hand presses. Cheap books flowed forth, and the printed word reached the public in ways that would transform the world and transform knowledge.

What happened next should have been predictable. People clung to the old ways as best they could. As an example, consider a disturbing old book printed in 1824. The title was A Short View of the First Principles of the Differential Calculus (Figure 6). The author was one Rev. Arthur Browne at Cambridge University (Browne, 1824).

Browne began with a long preface, setting out his objectives. He was teaching calculus to young men who would go on to become clergymen, lawyers, and statesmen. He said it was important for students to develop a sense of logic and order, but why calculus? He concluded that its only value was as an exercise in logic, undistracted by any problem solving.

Brown wrote 200 pages of propositions and demonstrations. He offered no hierarchy of ideas and said nothing at all about the uses of calculus. He also mentioned that some people were anxious to see Cambridge become “eminent in scientific pursuits.” That was nonsense, he said.

Figure 5: A Koenig double roller press manufactured by Applegath and Cowper in London before 1827. (Image from the 1854 Cyclopaedia of Useful Arts.)
The only purpose of universities was “that they may continually yield a supply of men, well qualified to fill the various offices, both in Church and State.”

We read Browne’s cynicism against the backdrop of Cambridge University’s emergence as the center of a mathematical revolution in England. Astronomer John Herschel finished his mathematics studies at Cambridge and stayed on to translate French work in math. France was then well ahead of Great Britain in mathematics, and Browne took special pains to sneer at the French. Herschel’s friend Charles Babbage, who first conceived programmable computation, also
finished math at Cambridge. Both were driving England toward a deeper understanding of mathematics and of its use.

Browne offers a grim lesson in how we can miss the vitality around us by trying to freeze the world into what we think it should be. So much life swirled about him in 1824. Cambridge, the calculus, and learning itself were all energized by a world in motion—by a world changing.

Browne believed that college was about serving a static nation with the same students who had served that nation last year. It is no surprise that we cannot find Browne in today’s biographical encyclopedias. Calculus itself is the mathematical science of change and Browne was typical of those unfortunate people who tried to avoid change by condemning it.

The physical book that contains Browne’s thinking was another matter. It was printed on one of the new roller presses that were disrupting everything. Browne and his book form a contradiction that reminds us of Internet Bloggers who curse the influence of the Internet.

Another textbook writer emerged during Browne’s tenure at Cambridge. She was Jane Haldimand Marcet, born the daughter of a wealthy London merchant in 1769. She married a professor of medicine when she was thirty. Soon after, she began writing instructive books for young people. The title of her first book was *Conversations on Chemistry, intended more especially for the female sex* (Marcet, 1813).

Marcet’s style is arresting. She writes a running conversation between a Mrs. B and two young ladies, Caroline and Emily. Listen as they talk about heat radiation. Mrs. B says, “Before I conclude the subject … I must observe … that different surfaces [radiate heat] in different degrees.”

Emily asks, “These surfaces [are all] the same temperature?” Mrs. B answers, “Undoubtedly. I will show you [an] ingenious apparatus.” She produces a cubical tin. One side is sanded, one rusted, one covered with soot, one polished. She fills the tin with hot water. Then she uses a focusing mirror to reflect the heat from each side onto a thermometer and gets four different readings. It is a splendid way to explain the radiative properties of different surfaces. This is exactly the sort of thing we try to teach in our senior heat transfer courses.

Mrs. B. boldly takes on any subject. As they talk about Watt’s new steam engine, its valving and power takeoff mechanism, the impetus for learning comes from pupils who pepper Mrs. B. with questions. They will not take “yes” for an answer.

Marcet went on to write books on political economy, geology, botany, and much more. Her book on political economy was very popular. It sold over 160,000 copies in America alone. An intellectual velvet curtain separated women and men in the early nineteenth century. While Jane Marcet lived behind that curtain, her books marched into the middle of the nineteenth century and they transformed it. And Marcet’s material did not just appeal to young women. The year she wrote her book on chemistry, a 15-year-old boy who worked in a London bookbindery saw it.

The boy was Michael Faraday. He read Marcet’s chemistry book in his off hours, and it transformed him. Faraday went on to create our modern concepts of electricity; and a great irony appears on page 105 of the much-later 1833 edition of the book (Jone, 1833). The editor has added a version of the experiment in which Faraday anticipated the electric motor. Already Marcet’s book unconsciously displays its own profound effect upon learning.

Marcet’s first books were made on hand presses and sold to the wealthy. Dirt-poor Michael Faraday got to read one of them; but he did not have the money to own one. Marcet’s teaching
mentality was a century ahead of Cambridge professor Browne. Once the new presses found her books, they were rocketed into a very different world.

That was particularly true in the young United States. Ours was a thinly-populated, resource-rich country with few schools and universities. If a young American wanted to be educated, he or she could far more easily own one of these fast press books than go to college. A vast portion of learning in nineteenth-century America came through cheap books than through schooling.

Consider one copy of another Marcet book that offers a window into that process. This was a late edition of her *Conversations on Natural Philosophy*. This particular book was first published in London in 1819. Natural philosophy then included almost all science. It swept in astronomy, geography, biology, zoology, and more. This time, Mrs. B, Emily and Caroline talked about materials and motion, Newton’s laws, hydraulics, heat, light, optics, and electricity.

Fifteen years after Marcet first published it for hand press production, this 1834 American edition was run out on a fast roller press (*Marcet, 1834*) (Figure 7). I found one copy in wretched condition—used, stained, and worn out. An ink-blotty signature announced:

Figure 7: Left: The title page of Marcet’s *Natural Philosophy* text published in Boston with a man’s name substituted for hers as the author. Right: the signature of owner Joseph L. Whittenburg.
“Joseph L. Whittenburg’s book May 13, 1838”. Whittenburg was 17 at the time and he used a poorly-cut quill pen that spread out as he tried to write with it.

Whittenburg shows up in census records as a farmer. He was born in Missouri, lived for some time in Alabama, and appears to have died in Texas around 1903. Wherever he was when he got this book, he was still living in a remote and harsh land. He signed the book several times subsequently—in 1846, 1848 and 1850. We will never know if he was noting when he went back to refresh his understanding, or just reasserting his ownership.

Whittenburg’s book is completely factory-made on a roller press. No book-bindery finishing; and, as cheap books like his poured forth, there were no longer enough cotton rags to supply paper makers. Wood pulp paper would not be invented for decades, so early nineteenth-century paper makers mixed other plant fibers in with cotton. Then they added chemicals to digest those fibers. This book’s pages are discolored in various ways, as different batches of paper were used to make it.

This was a new world in which one no longer had to be upper-middle-class to afford a book. Reading was being democratized as never before. America’s spread-out agrarian population, with schools few and far between, was determined to be learned even if it could not be educated. These shabby factory-made books shaped the inhabitants of a new country into a people of enormous energy and confidence.

What then does this say about teaching? Well, teaching was often absent. Learning was not led by teachers; it was driven by curiosity. In that, it was much like our situation with the Internet today. Those who gained their learning from this spate of cheap books in the United States alone included Abraham Lincoln, Thomas Edison, the Wright Brothers, and countless others.

The emergent United States, sparsely-populated and egalitarian, was a perfect spawning ground for learning, nurtured by all those easily available books. Such learning certainly lacked the focus of a school education. We needed to find means for adding that focus to the books themselves.

By the 1830s, America recognized that France had something very effective going in its Ecole Polytechnique school (Lienhard, 1998). We began copying it, but with important changes. The École Polytechnique students were generally upper-class. Our variation would become today’s engineering school with far less respect for social status. And it would be richly served by these new cheap books.

The rise of correspondence schools was another variation of the way those books changed education ([Potter, 1946] [MacKenzie, Christensen & Rigby, 1968]). Anna Ticknor, daughter of a Harvard professor, pointed the way in 1873 by founding the Society to Encourage Studies at Home. Several large universities took up her idea. The University of California was a latecomer in 1910; and it soon had the largest academic correspondence school program in the country.

For engineering education, the International Correspondence School, or ICS, became a major force. It began in 1890 as a home study course offered by the Pennsylvania Colliery Engineer School of Mines. I first learned drafting from a friend’s ICS course on drafting. As I started doing drawings and asking him to check them, a world suddenly opened up. No instructor was talking at me and obstructing my view of the subject. I was on my own, and learning made sense.
Those old ICS books offered freedom to learn as rapidly as one was capable of learning. They fed by that freedom with the special beauty of beautifully drawn machinery (Figure 8). By 1900, the huge in-house high-speed printing presses of the ICS was producing four tons of course notes each week and could boast a quarter-million students.

We speak of distance learning delivered today, not by the postman, but by the Internet. Its form is still evolving and far from settled. Perhaps it can, one day, assume an importance comparable to the old correspondence courses.

The parallels here are clear. Each information revolution led people to dodge conventional education. That was true 2450 years ago when Socrates complained that all this writing was causing us to lose the grace, beauty, and responsiveness of an oral education. It was true when

Figure 8: The wonderful filigree detail of a bearing design in a 1904 ICS Pocket Memoranda book

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physicians complained that sixteenth-century medical students were not learning the old text material of Galen.

The best American universities of a century ago looked down upon the new engineering schools; then they looked down upon correspondence school students. But those students ignored them and went on building a nation. Now the Internet has been with us for a generation, and we have stopped looking down upon it. Yet we remain far from having determined just how to use it.

**Closing thoughts**

The common denominator in each information revolution is that it freed people to follow their own curiosity. As new wellsprings of information appeared, young people formulated new questions; then they set out to answer those questions. Each revolution destroyed the old concepts of education as it fostered new kinds of freedom and curiosity.

Therefore, we probably should think less about education and more about the mechanics of learning. Each of these revolutions dramatized the way learning occurs when curiosity demands to be fed. As I look back upon my own education, I realize that the teachers generally thought of as the best, taught me the least. Who among us did not learn most when we had to wage our own struggle to see what was going on? The adrenalin kick of having torn away the veil to find our own understanding is where learning really occurs.

In every one of these revolutions, learning gained new ground when student curiosity gained new traction. What then will cause today’s students to identify and surmount their own ignorance? The Internet certainly offers us clues, but not clear answers. One thing is certain: We will not solve the riddle by creating over-arching strategies because that means predicting a future in a world too fluid to be predictable.

Rather, we need to do the only thing that has succeeded in every previous information upheaval. We need to read the present, and experiment with it. We must try new ideas and be prepared to drop them when they do not work out, or change them when they work poorly. The creation of engineering education in the 21st century will evolve from the bottom up. It always has. It will come from people directly involved with harnessing the new technologies as they spring up daily.

All engineering design yields unpredictable results. No new technology is finished until the users show us how they fit into their own lives. We struggle to design engineering education; and no design can ever be complete until students tell us how it works in their lives. No one is closer to the new information technologies than our students. They will ultimately point our way for us. They always have; they always will.

**Sponsor acknowledgements**

Maersk Oil Qatar is the exclusive sponsor and industry partner for Engineering Education Letters, an open access, peer-reviewed journal that promotes the advancement of engineering education in the Middle East, North Africa and beyond. Publication costs for this manuscript are supported by Maersk Oil Qatar, which has no influence on journal content or editorial decisions. For further details, see the Engineering Education Letters Transparency Statement.
Source materials
Some of the books that I refer to above are rare or even singular. They may be found in the University of Houston Libraries. See: http://library.uh.edu/search/t?SEARCH=engines+of+our+ingenuity+res

[11] T. P. Jones, New Conversations on Chemistry in which the Elements of that Science are Familiarly Explained and Illustrated by Experiments. (Philadelphia: John Grigg, 1833): Jones was one of the many men who made minor editorial changes to Marcet's books, then added their own male as the author, to improve book sales.


I offer no sources on today’s information revolution. We are in the middle of it and we are the sources.