AC 2008-2316: TECHNOLOGY LITERACY AS A PATH TO "ENGINEERING SOLUTIONS IN A GLOBAL AND SOCIETAL CONTEXT"

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Introduction

A "device dissection" laboratory has been used by the author for more than a decade to instruct first year engineering students in "How Things Work." More recently, this lab has been combined with weekly lectures to create a course in technological literacy for non-engineering students. While this pair of courses neatly partitions the offerings into one for engineers and another for non-engineers, the argument has frequently been made that engineering students themselves need to have "Tech Lit" as well, so that they understand not only device construction and operation, but circumstances and forces which drive device evolution in the larger cultural and social contexts of the time.

The format of our Tech Lit course is important: each lab device and associated technical lecture ("engineering solution") is preceded by an historical survey lecture which provides not only prior examples of "engineering solutions" to the same or similar technical challenges, but also reflects upon the societal and technical settings of the time. While such a lecture pair was first created in order to show the evolution of the technology itself over time, it also naturally reveals the "global and societal contexts" within which each version of the device (engineering solution) was created, grew in frequency of application, and ultimately, perished or was replaced with a yet more modern version.

The evolution of such technical solutions over time thus provides a lovely platform for exploring one of the more problematic ABET/EC 2000 engineering criterion (h): that of providing the undergraduate engineer with "the broad education necessary to understand the impact of engineering solutions in a global/societal context."

We illustrate how such technological literacy lectures could be used to address EC criterion (h) using three examples drawn from our Tech Lit course: the PC and Jacquard's weaving machine, the electric guitar, and the bicycle. To focus more sharply, we summarize our lecture treatment of the French introduction of automation via Jacquard's programming of a silk weaving loom, the guitar and its history of amplification, and the invention and evolution of the bicycle.

The impacts of these engineering solutions remain with us today. Jacquard's conception of using punched cards to dictate a non-repetitive sequence of instructions to the weaving machine was adapted by Babbage for creating line-by-line programs for computers, a format still practiced today. The guitar has evolved technically through improved amplification, and socially from provision of courtly entertainment to modern concerts for mass audiences. The bicycle, invented as a result of a volcanic explosion, passed through multiple design phases, and today still transports more people than the automobile.

Years ago. Samuel Florman articulated in his book, Engineering and the Liberal Arts, the notion of building educational bridges between engineering and the liberal arts, in order to provide engineers, and engineering students, a more facile access route to such arts, and thereby bridge the "two cultures" chasm of the twentieth century. His civil engineering metaphors for such links included the following pairings[13]:

Liberal art	Bridge
History	History of technology
Literature	Engineer in Fiction
Philosophy	Truth of Science
Fine arts	Utility and Beauty
Music	Sound as Environment

If we are to understand, and to have our students understand as well, "the impact of engineering solutions in global and societal contexts," then we need creation of a similar bridge by which we can navigate from the engineered device to its impacts, as demanded by ABET/EC 2000. This paper suggests that the broader scope of technological literacy instruction encompassed in our weekly format of historical survey(lecture) followed by modern device (lecture and lab) allows for the desired educational bridge building. Widespread adoption of such an accessible instruction format could ameliorate the current difficulty in addressing criterion (h).

Three examples

Jacquard's invention of automated weaving, and the modern computer

A computer program is a non-repetitive series of instructions which can be executed by an appropriate machine to produced a desired outcome. The origins of the modern computer hark back to Charles Babbage and Ada Lovelace, his companion. At the base of all calculating machines is ultimately a binary system, typically represented as zeroes and ones. The earliest use of such an information encoding system occurred not in computing but in weaving, and was promulgated in Lyon, France, during the industrial revolution.

Lyon was Europe's silk capital, and the weaving of silk produced remarkably soft fabrics. The fineness of the silk thread meant that, at 1/20,000 of an inch in diameter, the order of tens of thousands of threads per linear inch of weave was required. The hand loom required the operation, since Chinese times of an earlier millennium, of three persons: one to toss the yarn carrying shuttle, one to feed the yarns of various colors, and a "draw boy" who lifted the appropriate warp threads for each successive pass. The latter's working position was both uncomfortable and long each day, leading to a permanent and characteristic spinal deformation.

A series of inventors Vaucanson, Falcon, and Bouchon achieved construction of programmable looms, for which the weaving pattern or sequence was stored perforated paper (Bouchon), rectangular punched cards (Falcon) or cylinder (Vaucanson). While functional, none of these sold widely. Jacquard

> “combined two principles: one established by Vaucanson, the other by Falcon. Bauconson’s cylinder was replaced by a prism (known as a square or rectangular cylinder) which, when pushed by a carriage, pressed against the needles, and at each quarter revolution, presented a new card. Vaucanson’s cylinder, with its limited size, was replaced by a chain of cards, with a theoretically unlimited capacity. The system was actuated by a single treadle, leaving the weaver’s hands free to deal with the passage of the shuttle and the beat-up mechanism.[1]”

Charlin[1] notes that Jacquard’s machines sold poorly, and were only rescued by the (today) unknown Breton who created a remarkable reduction in the complexity of the beat-up mechanism. The final version of Breton was widely adopted. While Jacquard and Breton “were equally famous during their lifetime, with the passing of the years, Breton’s name has been supplanted by that of Jacquard.” It is not impossible that Jacquard’s fame was as much due to his public recognition by Napoleon as to his inventions.

On the societal response side, “The Revolt of the Canuts” or weavers is a well told story in France. Lamartine, the historian, wrote that

> The looms to which Jacquard gave his name spread throughout the city. Every new loom adopted saw jobless weavers and their wives and children – whole families- thrown onto the street, with no work and nothing to eat. People began to realize that while this machine might be a miracle from the cloth manufacturers’ points of view, it was a disaster for the proletariat. Jacquard’s name had initially been praised to the skies, but it now became the subject of murmurings, and was cursed by the people: workers and their families banded together to smash his machines, and lynch him, to satisfy the resentment felt by those to whom his genius had brought only starvation.[2]

Charlin reviews other historical viewpoints, discounts Lamartine’s as an exaggeration, and concludes instead that the high cost of shelter in the silk weaving district, Croix Rousse, was the true cause of the revolt.

> This rise in rental costs, combined with the rise in town dues and the slump in manufacturing consequent upon the slowdown in business after the Paris revolution of 1830, was partly responsible for prompting the weavers to seek higher prices from the cloth merchants, and demand a ‘fair and equitable’ price for their labors. Having failed to obtain any satisfaction despite the promises made, the silk workers revolted on 21 November 1831. 150 people were killed.

> This uprising was the first clear case of a social insurrection, at the beginning of the industrial era. It marked the birth of a social consciousness among workers, heralding their great battles in the late 19th century...

Longer term technical consequences.

In Jacquard's Web[3], the author recounts that Charles Babbage kept a portrait on his wall, and would entertain guests by demanding how it was constructed. Following the inevitable "painting" response, he informed that the portraits were woven of silk on a Jacquard machine. Given that the resolution was approximately 20,000 threads per inch, the length of the program of punched cards which had achieved the encoding of the picture must have been remarkable. The punched cards indicated for each warp thread whether on the next shuttle pass it should be raised or lowered, and thus the position of each warp thread on each pass was represented by the equivalent of a one (hole) or zero (no hole).

Today, Charlin notes that the more recent electronic version of the Jacquard machines has triumphed: "Thanks to the efficiency and performance levels they offer, it has taken electronic Jacquard machines just fifteen years to conquer a market which for two centuries had been the preserve of their mechanical counterparts."

The impact of Jacquard's machine has been remarkable, in the textiles industry, and in its inspiration for creation and evolution of computer programming, beginning with Babbage's utilization of the punched card approach, an obvious predecessor of the punched computer card systems which dominated large computers in the 1960s. Thus the Staubli weaving history and the "Web" book reveal much about the "impact" of engineering solutions (Jacquards loom) in global and social contexts."

The credit for the invention of the programmable weaving loom is thus distributed beyond Jacquard, yet his name trumps the others in recognition. A similar story often appears in other inventions, and a pertinent example is explored by Alice Rowe Burks in her recent book: Who Invented the Computer: The Legal Battle that Changed Computing Histroy.[4]

The Jacquard loom represents automation of an old technology, the loom. The next example, the guitar, also follows a continuous evolution, punctuated by an abrupt shift to electronic versions. The final example, the bicycle, represents an invention de novo.

The guitar: Music and amplification

Stringed instruments have a very long history. For the guitar, Chapman[6] notes that that stone reliefs in Asia minor which date back to 1350 BC exhibits an instrument which resembles a guitar, having “a body with incurved sides, a neck with frets, and a number of frets.”

A 13th century frescoe shows a musical group including two violins, a guitar, and a singer in a royal court setting. The instrument, with flat top and back, is a *guitarra Latina*, or Latin guitar. Its shape differs from that of the ‘ud, a round backed lute, brought to Spain by the Arabs. The latter back is more fragile than the flat back; this feature, combined with the Arabs 1492 expulsion from Spain, may have combined to cause its decline and disappearance.

Like other string instruments, the loudness is modest. In consequence, guitars of the middle ages often had two identical strings to increases volume, installed in courses of four, five, or six. In an early instruction book by Luis Milan, the *Libro de Musica de Vihuela de Mano*, the instrument shown had both string and frets made from catgut, the later ties across the guitar neck to create a fingerboard.

In the seventeenth century, the guitar was played by men and women alike, and was popular among families of wealth. The decoration of the guitars of the time was substantial, as they were considered as a work of art.

The reception of the guitar in different areas of European is illustrated by several quotes from Chapman[6]:

French painter Antoine Watteau (15684-1721) represented the “guitar as an instrument for the amorous or frivolous”.

A German wrote in 1713 that “the flat guitar with its strum, strum we shall happily leave to the garlic-eating Spaniards”

The ongoing Napoleanic wars of the nineteenth century moved many performers north to London, Paris, and east to Vienna.

Conditions for playing could be taxing: The famous player Fernando Sor from Barcelona studied early on in a Monserrat monastery, where he was forbidden to play guitar. Moving later to Paris, he published both studies and original compositions.

The modern classical guitar was the design of Antonio de Torres (1817-1892) whose “guitars have more volume and projection, with a larger, deeper body.” Improvement in internal bracing, and the larger body, enhanced the instrument’s tone and volume.

The twentieth century saw the guitar became again a major classical instrument, due to the efforts of Andres Segovia. In parallel, the guitar and other instruments were seen often in Cubist style paintings. The classical and avante garde camps both espoused the instrument as its popularity rebounded.

In performance, the guitar remained relatively soft spoken, as suggested by Chapman's description of a Segovia concert, wherein Segovia "demanded silence and concentration from his audiences[6]"

Like the piano, the guitar has been adopted for use in virtually all types of music: classical, flamenco, blues, country, folk, jazz, rock and pop, and Latin.

The electric guitar emerged slowly throughout the 1930s. An early inventor's version featured a phonograph needle stuck into the top of an acoustic guitar, and later versions utilized the present day electronic, rather than mechanical, signal pickups.

These conversions led to several results:

- Loudness of the instrument was open ended, and much larger audiences could be reached. The limit today is simply the level of sound when can be tolerated without ear damage.
- The musician himself had complete and instantaneous control of the instrument volume and tone.
- In addition to volume and tone control, the use of distortion became common, and could be achieved directly on the guitar itself, or in subsequent electronic amplification.
- The guitar "box" was no longer a device for amplification of the guitar strings, and the box design was freed to become whatever form was desired.

Despite such freedom of form, one modern industrial engineering[7] analysis of current popular electric guitars indicates that there is still considerable room to achieve design of an electric guitar which is ideal from the players point of view.

In sum, the current popularity of the guitar appears due to the follow features:

- Acoustic versions have been adapted by composers of virtually every type of music and culture
- Electric types have found popularity in both media (radio, TV) as well as large concert settings. Its tenor s an instrument of "revolution" has kept it popular with youth today, just as it was at one point popular with the traveling gypsies of a much earlier era.

The guitar, and the loom of the previous example, are both devices which date in ancestry back to antiquity, well before the AD era. The incorporation of their products, music and textiles, into societies has therefore long and rich histories. The next and last device for discussion is an early modern instrument, the bicycle, which was invented largely because of a natural disaster

The bicycle[5] : "Necessity is the mother of Invention"

Wilson informs us that the bicycle is modern, and is a device with three distinct periods of development: invention in 1817 but short lived (1817-1821), re-invention in France as a pedal powered device, and later made safe by both redesign to place the rider securely between two equal wheels, and the addition of pneumatic tires to render the ride softer.

Human legs contain the body's largest muscles, yet Wilson notes the relatively rare use of these as a source of power. Early examples include use of multiple capstans for raising a stone obelisk, an inclined treadmill to power a mill, and a treadmill geared winch for raising water from a well.

In 1815, the Indonesian volcano Tambora exploded, ejecting into the atmosphere something like seven times the mass of the more famous, later volcano Krakatoa (1883) The result was "the year without a summer" in Central Europe and New England as well. "Starvation was widespread, and horses were killed for lack of fodder, the price of oats then playing the same role as the oil price today." Historian Lessing argues that the resulting shortage in the supply of horses led Baron von Drais , student of mathematics and mechanics, and inventor, to create a two-wheeled "running machine." His device included front wheel steering, side pockets for documents or freight to be delivered, and a cloak behind the seat to protect the rider from both weather and mud from the rear wheel. Lessing notes that while the bicycle had no prior history, von Drais had previously invented several four wheel, human powered "driving machines" in 1812. These , along with von Drais' experiences with balance on inline supports for both ice skates and roller skates, and even wheelbarrows (balanced load over a single wheel) arguably provided the background from which von Drais was inspired to create his "Draisienne", two wheeled vehicle with 27 inch wheels.

The next stage was transfer of human power to rotate the front or back wheels, and included examples using hand power (Gompertz) and pedal power (Michaux and Lallement). These early versions involved heavy wheels using thick, weighty wooden spokes. Development of wire spokes lessened the wheel weight dramatically, enabling use of larger front wheels, and thus delivering greater maximum speed. The ultimate version was the "high-wheel" or so-called "ordinary". The greater speed allowed came at the price of safety, as the seat installation moved much closer to the front wheel axle. In consequence, a rider hitting an obstacle or bump could be ejected over the front wheel, arriving headfirst on the ground.

Before this configuration was abandoned, it saw incarnations with treadle action front wheel drive, and the invention of the bicycle chain within a front wheel drive configuration.

The safety problem led to the ultimate appearance, in the late 1890s, of safety bicycles, so called due to their use of two equal wheels and the return of the rider to a midpoint between the two wheels or even further back.

Bicycle design remained surprisingly unchanged thereafter, the Starling safety bicycle of 1896 looking surprisingly familiar to twenty first century cyclists. More modern innovations included development of geared cycles, and of all-terrain "mountain" bikes. The former allow cycling under circumstances which provide maximum power transmission from the legs to the cycle at all speeds, and the latter brought a of the older, heavier framed bikes albeit for new uses. The author Wilson notes dryly that the lack of a chain guard on the all-terrain bicycles serves no useful purpose, and clearly leads to faster chain and gear wear than would be found with a chain cover in place.

While in western societies the bicycle is largely a recreational vehicle, around the world it is a primary mode of transport for many. Today, more people travel by bike than by car, and even in the US, sales in the 1970s, perhaps coincident with the oil price hike, rose rapidly to exceed those of car sales. As the present day oil price approaches $100/bbl, it is not difficult to imagine a similar resurgence of bike popularity for commuting, not just for recreation.

Overview

Technology evolves to serve society, as these examples of weaving, guitar, and bicycle indicate. In parallel, society changes as new technology arises: more people could afford woven fabrics as the automation of weaving grew, the use of the guitar has spread across all walks and varieties of music, and the bicycle will be operating long after oil has disappeared.

We have illustrated, with three examples, how the history of devices can be used to illustrate the "impact of engineering solutions in a global and societal context." The automation of weaving led to the first strikes against such technological advance, to be followed by worker reactions in a host of other industries, including automobile manufacture and transportation. The guitar has not only evolved in form, but society has found an increasingly broader fraction of the population engaged in its use for various forms of music. The bicycle has enabled the underdeveloped world and developing world inhabitants to own mechanized transport, and continues to provide commute capacity for probably more people that the automobile, even today.

"Those who cannot remember the past are condemned to repeat it" wrote Santayana in justifying the study of history. Nonetheless, as history is a liberal art, Florman[13] long ago argued that "unless the arts can be shown to be intimately involved with engineering, they will seem frivolous" to our students. The format for technology literacy instruction which we have designed here provides not only technical content, but historical context, would seem a perfect vehicle to address Florman's 1968 concern along with the more recent EC 2000 criterion (h) of our focus.

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