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ENGINEERING EDUCATION:
MASS PRODUCTION AS A QUEST FOR EFFICIENCY?

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Abstract: *Education, especially higher education, is in trouble today. There are more people in the world than ever before and a far greater part of them want an education. The demand cannot be met simply by building more schools or training more teachers or cramming more students in already crowded classrooms. Education must become more efficient, and it is crucial for Engineering Education, because this dynamic world the changes quickly, and Engineering Education is now at a crossroads, it has reached this moment of truth very late. While mass production benefited manufacturing and service industries alike, engineering education still lags behind existing potentials for improving its efficiency and productivity. In this article we compare both worlds, and we argue that the computer, even with its immense possibilities, still needs a professor to make the recalcitrant education more efficient at last.*

Palavras-chaves: *Engineering. Education.*

1. INTRODUCTION:

Education, especially higher education, is in trouble today. There are more people in the world than ever before and a far greater part of them want an education. The demand cannot be met simply by building more schools or training more teachers or cramming more students in already crowded classrooms. Education must become more efficient, and it is crucial for Engineering Education, because this dynamic world the changes quickly. Since the Industrial Revolution, a demand for increased production has led to the invention of labor saving capital equipment. This is true with the automobile and the automated hamburger. Moreover, many services continue to be improved by automation and mass production principles. However, it is not clear how the masses can pursue higher education today without incurring an enormous debt that will take a long time to be paid. Indeed, in America, for example, increases in tuition have made colleges and universities less affordable for most American families, and, in Brazil, the access to higher education continues to be deficient Engineering education is now at a crossroads. It has reached this moment of truth very late, a long time after the automobile, and the hamburger, possibly through a misconception of its task. While mass production benefited manufacturing and service industries alike, engineering education still lags behind existing potentials for improving its efficiency and productivity. In this article we argue that the computer, even with its immense possibilities, still needs a professor to make the recalcitrant education more efficient at last.

1. THE AUTOMOBILE

Before Henry Ford, there were just a handful of firms producing automobiles in the world, notably in Germany and France. By the early 1890s, the existing firms were producing several hundred automobiles a year using the craft-production system. The most sacred assumption of mass production that cost per unit falls significantly as production volume increases wouldn't hold for craft production. If those companies tried to build half a million identical cars annually, the cost per unit wouldn't have fallen much below the cost of making 5 or 50 units. And, the cars wouldn't be identical either, because their contractors didn't employ a standard gauging system and the machine tools of that time couldn't cut hardened steel. Henry Ford overcame these barriers in the early 1900s.

For these reasons, engineering education must be aware of the following situation: yesterday, craftpersons didn't think about what they were producing nowadays, students didn't think about computer results they are generating. The computer can be viewed as a machine that conveys information instead of raw materials.

We all love the idea of craft production, but the problem with it is obvious: Goods produced by the craft method – as automobiles once were exclusively—cost too much for most of us to afford. Also fatal to the craft age was the inability of the small independent shop owners to develop new technologies.

Like the old craft producers, educational institutions experience today many of the same problems. Education costs are high and increasing instead of dropping with volume. This means that not in a distant future, only the very rich will afford to have an education. Indeed, in America, while only the wealthiest families have seen their incomes keep pace with increases in tuition, the lowest income families have lost the most ground and this is a major factor in their lower rates of college attendance (1). In Brazil, the Ministry of Education is pursuing the university reform for trying to solve this problem, although the Ministry of Treasure has raised crucial barriers to the project. Like the independent contractors of craft production, universities and colleges are having difficulties to develop new cost-saving teaching technologies.

At this point in the history of the automobile, Henry Ford found a way to overcome the problems inherent in craft production. His new techniques would reduce costs dramatically while increasing product quality. Ford called his innovative system mass production (2). Henry Ford invented neither the automobile, nor the assembly line, but recast each to dominate a new era.

The first Ford automobiles were craft produced. The company purchased most of its major components for its new models. Teams of mechanics built cars individually at work stations, gathering parts as needed until a car was complete. In 1903, Ford's 125 workers made 1,700 cars in three different models. The cars were expensive, and their high-profit margins pleased the stockholders. But Ford was not happy at all.

After introducing a new cheaper model with a lower profit margin, the model N, Ford pressed forward with the car he really wanted---- "a motorcar for the great multitude "---the model T. With a few colleagues, he devoted two years to the design and planning of the model T. The car that finally emerged from Ford's secret design section at his plant on Piquette Avenue in Detroit would change America and the world forever. The model T went to the first customers on October 1, 1908. In its first year, over 10,000 units were sold, a new record for an automobile model. For $825, a model T customer could take home a car that was light and easy to drive, Simple, sturdy, and versatile, the little car would excite the public imagination.

However, growing demand for the new Ford overwhelmed the old craft production method. Ford realized that he not only had to build a new factory, but *a new system* within that factory. This is what education needs today-a new system within a new mentality. Ford began to implement factory automation in 1910. Experimentation would continue every single day for the next seventeen years, under one of Ford's maxims: "Everything can always be done better than it is being done." Ford was already talking about "continuous improvement" in 1910! Somehow, continuous improvement was re-discovered in the 1980s, by the total quality management crusaders…

In the Highland Park plant, the new factory, which opened in 1910, production increased by 100% in each of the first three years, from 19,000 units in 1910, to 34,500 in 1911, to an incredible 78,440 in 1912. It was still only a start. "I'm going to democratize the automobile", Ford said in 1909.When it sold for $575 in 1912, the model T for the first time cost less than the prevailing average annual wage in the U.S. Ford demonstrated that a strategic, systematic lowering of prices could boost profits, as net income rose from $3 million in 1909 to $25 million in 1914.As Ford's U.S. market share rose from a respectable 9.4% in 1908, to a formidable 48% in 1914, the model T dominated the world's leading market.

Is it the same thing the government to say: "I'm going to democratize the education"? If so, the number of students will go exponentially, but what will happen with the professors? In engineering education, this aspect is very, very critical, because a good engineering professor needs professional experience, experience that is not conquested not in one or two years, but during a lifetime.

Mass production at last (or why the assembly fitter disappeared)

The key to mass production was not the moving assembly line. Rather it was the complete *interchangeability* of parts and the simplicity of attaching them to each other (3). Ford insisted that the same gauging system be used for every part all the way through the entire manufacturing process. Ford also benefited from advances in machine tools able to machine pre-hardened metals. He was also able to develop creative designs that reduced the total number of parts needed and made them easier to assemble.

In 1903, Ford was still using craft production methods to assemble his cars. Assembly stands were set up where the whole car was built by one assembly fitter. In 1908, the amount of assembly work totaled 514 minutes (or 8.56 hours) as the average task cycle. Shortly before introducing the model T, the first thing Ford did to make the process more efficient was to deliver the parts to each workstation. Now the assembler could remain at the same place all day. Then, around 1908, when Ford finally achieved perfect part interchangeability, he decided to that the assembler would perform only one single operation and move from vehicle to vehicle around the assembly hall. By 1913, on the eve of the introduction of the moving assembly line, the task cycle time for the average assembler went down from 514 to 2.3 minutes! Perfect part interchangeability saved more money than the next step, the introduction of the moving assembly line at Ford's new Highland Park plant in the spring of 1913. With the Ford model T, no fitting was required anymore and so the assembly fitter disappeared. Like the horse, which became dispensable with the advent of the farm tractor, so did the assembly fitter with the introduction of Ford's assembly line.

In engineering education, the concept of interchangeability is similar to the concept of the need of an engineer student to know not only engineering subjects, but also computers, management, law, and environmental analysis. Nowadays, the interchangeability is not regarding parts, but knowledgement, and the effect is completely different. While in the machines product reduces the cycle time, in engineering education the amount of new information causes a lack of time for the professors transmit what there is in the textbooks, but also the experience they have, many times more important than the authors´ theoretical point of views.

The moving assembly line

Ford claimed to have found the inspiration for the moving assembly line on a trip to Chicago. The idea came in a general way from the overhead trolley that the Chicago packers use in dressing beef. At the stockyards, butchers removed certain cuts as each carcass passes by, until nothing was left. Ford just *reversed* the process. The moving assembly line brought the car past the stationary worker. Ford's moving assembly consisted of two strips of metal plates---one under the wheels on each side of the car---that ran the length of the plant. At the end of the line, the strips mounted on a belt, rolled under the floor and returned to the beginning. The device was similar to the long rubber belts that now serve as walkways in many airports. Since Ford needed only the belt and an electric motor to move it, his cost was minimal. This innovation cut cycle time from 2.3 to 1.19 minutes.

Not only in engineering education, but in higher education in general, the continuous education taught in modules is similar to the moving assembly line. The education belt offers a myriad of courses with variable duration. and the students (even professionals) choose the best one for them at that moment this life for crafting a better human being.

Characteristics of mass production

What are then the characteristics of mass production, as pioneered by Ford in 1913 and continuing in many businesses today? To put it simply, mass production was made possible by the division of labor at its ultimate extreme; by a complete set of novel tools that were capable of producing parts with incredible accuracy leading to complete parts; by interchangeability; by vertical integration and by making a single standard product.

Ultimately, Ford attempted to mass-produce everything. His idea was that by making everything---from food to tractors to airplanes, in a standardized way, at high volumes, he could dramatically reduce the cost of products and make the masses rich. He was well aware of the learning curve phenomenon and its implications for production management. Ford had never attempted to apply mass production principles to education. Would he have succeeded if he had ever tried?

2. **THE AUTOMATED HAMBURGER**

The production line approach pioneered by Henry Ford made McDonald's Corporation famous. The McDonald's story began in 1940 when Dick and Mac McDonald opened a highly successful car-hop barbecue restaurant in San Bernadino, California. In post-war 1948, aware that growing families were more and more concerned about value, and with a growing roadway system making customers more interested in speed of service, they temporarily closed their restaurant, built a simplified menu around their best-liked products, designed a more efficient interior and re-opened with self-service at the former car hop windows.

Thus, they invented the self-service, drive-in concept that was a limited –menu, paper-service, hand-out operation, featuring 15-cent hamburgers, 19-cent cheeseburgers, 20-cent malts and 10-cent French fries. After a slow start, business boomed. In 1952, American

Restaurant Magazine ran a cover story on the phenomenal success of the brothers' new concept. The McDonald brothers proceeded to franchise and open, in the West, eight of the concept drive-ins they had originated.

Two years later, a food service equipment salesman named Ray A. Kroc came into the picture. He owned the national marketing rights to the five-spindle multi-mixers the brothers used to make their milkshakes, and the brothers had purchased ten of the machines to keep up with their soaring business. Ray formed McDonald's System, Inc. in 1955 and opened the 9th McDonald's, his first, in Des Plaines, IL, in April 1955. In 1961, Ray bought from the McDonald's brothers the proprietary rights to the McDonald's system, including all rights to the rest of the world. The organization that Ray founded – today's McDonald's Corporation— proceeded to add more than 23,000 McDonald's restaurants and 4,500 franchisees across more than 111 countries around the world. Just like Henry Ford's black model Ts, the automated hamburgers changed the world. The production – line approach, meticulously applied to service made it possible.

3. EDUCATION: THE SEARCH FOR EFFICIENCY

In its erratic search for efficiency, education has been introducing more audio-visual aids. It was not long ago when a textbook publisher would focus on publishing textbooks, sometimes accompanied by an instructor‘s manual and a study guide. The publisher's life has become more complex today. Now the publisher not only publishes textbooks but has to provide numerous ancillaries like instructor's manual, study guide, computer software, CD ROM for class presentations, transparencies, videos and DVDs, films, internet sites where more materials are placed and so on. Textbooks and all the modern ancillaries are more colorful and attractive than never, on the assumption that if sufficient interest is elicited, the student will learn.

What would have happened to mechanization and automation if Ford had decided to bring more assembly fitters and more of the same craft tools to help increase efficiency of the craft production process?

Audio-visual aids like films and projections have been around since the 1920s.They serve to supplement lectures, demonstrations, and textbooks. They serve to *present* material to the student and, when successful, make it so clear and interesting that it can help the student learn.

However, audio-visuals contribute little or nothing to the interchange of ideas and interaction between teacher and student like in the small classroom or tutorial situation. Much of that interaction has been lost in engineering education, in order to teach larger and larger numbers of students per class. With widespread use of equipment designed simply to present material, the student is becoming more and more a passive receiver of instruction. Computers can do much more than just present material. A powerful idea came about in the 1920s but unfortunately the time was not right to fully appreciate it.

Pressey's teaching machines

In 1926, Sidney L. Pressey designed several machines for the automatic testing of intelligence and information. This was about the same time when Ford was reaping the benefits of mass production. This kind of capital equipment would make the student to take an *active* role in the instructional process (4).

In using the device, the student refers to a numbered item in a multiple-choice test and presses the button corresponding to the chosen answer. If the answer is correct, the device moves on to the next item; if it is wrong, the error is tallied and the student must continue to make choices until the answer is correct.

According to Pressey, such machines could not only test and score, they could also *teach*. Moreover, the immediate response supplied by a self-scoring device, can have an important instructional effect ----- *immediate* feedback. These machines would also increase efficiency by allowing each student to proceed at his or her own pace.

Pressey seemed to have been the first to emphasize the importance of immediate feedback in education, and to propose a system in which each student could move at his/her own pace. And above all, the teaching machine, in contrast with the audio-visual aids that were beginning to be developed at that time, permitted the student to play an active role.

In part due to cultural inertia, the "industrial revolution in education" which Pressey envisioned, refused to materialize. In 1932, he gave up the idea, bitterly disappointed (5).

Skinner, programmed instruction, and computers.

In 1940, B. F. Skinner developed further the idea of machine instruction, and his work spans thirty years. His ideas had far greater implications for the design and operation of social systems and organizations than just the teaching machine and programmed instruction in general.

According to Skinner, instead of the machine pioneered by Pressey, another kind of teaching machine would be needed, with important features (6). In education, the behavior to be shaped and maintained is usually verbal. Towards this end, the student must *compose* the response, rather than select it from a set of alternatives as in multiple-choice questions. The reason is that we want the student to make a response as well as to see it is right. Another reason is that multiple-choice material must contain plausible wrong responses, which are out of phase in the process of shaping behavior because they strengthen undesirable forms.

A second requirement is that, in acquiring complex behavior, the student must pass through a carefully designed sequence of steps, often of considerable length. Each step must be so small that it can always be taken yet in taking it, the student moves somewhat closer to fully competent behavior. The machine must make sure that these steps are taken in a carefully prescribed order.

Computers can do easily and effectively the work teaching machines of the 1970s were doing in teaching spelling, arithmetic and other subjects to lower and higher grades, from junior high school through college, by programmed instruction.

The computer, of course, does not teach. It simply brings the student into contact with the person who composed the material it presents. It is a labor saving device because it can bring one programmer (instructor) into contact with an indefinite number of students.

Paradoxically, while computer teaching is mass production, the effect upon each student is like that of a private instructor. Let us see why.

1. There is a constant interaction between program and student
2. Like an effective tutor, the computer insists that a given topic be completely understood.
3. Like a good tutor, the computer presents just the material for which the student is ready.
4. Like a dedicated tutor, the computer helps the student to reach the correct answer.
5. The computer, like the tutor, reinforces the student for every correct answer by providing *immediate* feedback.
6. Prompt feedback is also crucial in holding the student's interest for the subject. It plays an important part in motivating the student to make the effort (7).

We argue that with the modern computer and the internet, the present generation of students is ready for machine instruction and the industrial revolution in education.

The programming task

While computer teaching can be considered labor saving, programming the material to be taught by machine is certainly labor-intensive. After all, mass production eliminated the expensive craft workers but it created new professions and introduced new actors like the industrial engineer, responsible for “programming “ the work to be done in the production lines.

The task of programming a given subject for machine teaching is at first sight rather formidable. Nevertheless, many helpful techniques can be derived from a general analysis of the relevant behavioral processes, verbal and nonverbal.

The computer can also make sure students understand graphs, diagrams, charts, or pictures, by asking them to identify and explain its features---- correcting them immediately whenever they are wrong.

The student can also have access to auditory material. Computers can be used to teach foreign language skills as well as music, speech, literary and dramatic appreciation, and many other subjects. A typical program would combine many of these functions.

However, it is a challenging task to construct effective engineering software. Whether a confuse passage in a textbook can be forgiven, because the teacher can always explain it in class, computer material must be self contained and entirely appropriate. In composing a program, the programmer must go directly to the point.

Continuous feedback from students will allow the programmer to improve the program. It is possible to discover which frames led to wrong responses and the answers are always available for analysis. But the professor is not an engineer, and an engineer is not a programmer. For this reason, it is difficult to know if a program will work correctly in the real life, because we don’t know how the engineer and the programmer will exchange their knowledgement.

If we control the effect of the machine in confronting the instructors-turned-programmers with the full scope of their task will certainly contribute to greatly improve education.

This new vision of engineering education can also be adapted for different kinds of communication, e.g., for blind, deaf-mutes, spastics and other with special needs. Education fails many times because students have special needs making a normal relationship with an instructor difficult or impossible. Many blind students are treated as feeble-minded because no one has had the time and the patience to communicate with them in regular classes. A teaching machine can be adapted to special kinds of communication, e.g., Braille—and above all, machines have infinite patience.

4. CONCLUSION

We all worry that our role in society may be abolished one day by social change. The crucial question “Will machines replace teachers?” was left to the end of the article.

We already know that in the face of the farm tractor, the horse simply was not able to pay its keep and so it disappeared. Can the same happen to the human worker as automation proceeds? Can teachers, without making use of new technology, produce enough to pay their keep as demand for education increases?

We think not. The role of the teacher may well be changed for machines will affect several traditional practices. This already happened with numerous services that have been industrialized. The electrocardiogram, for example, reliably substituted a lower paid technician for the higher paid doctor listening with a stethoscope. The credit card replaced a time – consuming manual check for each purchase. Supermarkets and other establishments

like cafeterias, restaurant salad bars, open tool rooms in the plants and open –stack bookstores and music stores enabled customers to serve themselves, rapidly and efficiently.
Fast food restaurants like McDonald's, Burger King, Pizza Hut and others adopted the same rational system of division of labor, and specialization, to produce speed, quality, cleanliness, and low prices.

Income tax preparation service was transformed into a fully systematized , assembly – line, yet personalized service on a walk-in basis, performed at low cost with remarkable accuracy and guarantees. Fast, low-priced repair facilities such as national muffler, brakes, and transmission shops, appeared in the market, featuring high volume, specialization and special purpose tools, which combine to produce fast, guaranteed results. And we could go on and on, with numerous examples of machines and organized work systems at work in what was always done before as an extension of the craft culture.

The fact is that to enhance their opportunities and realize their educational aspirations we work more hours than in the past, incur greater debt, and devote larger portions of their income to paying for college. And-what is worse-tuition is increasingly financed by student borrowing.

What to do then? There is a lot a promise ahead in information technology. States could explore the potentials of information technology to improve both educational effectiveness and cost-effectiveness of on and off-campus instruction. Also alternatives to full-service campuses, such as learning centers and distance education, can provide more responsive, flexible, and cost-effective education to underserved communities (8).

Naturally, in the process, many jobs, positions, titles, specialties and fields of expertise will disappear, while many new jobs and professions will be created. Historically, industrialization and increased automation have consistently and persistently been accompanied by rising real wages. It was not really the tractor that destroyed the horse, but humans themselves. While the supply of horses and capital were responsive to market forces, the supply of labor was not. Humans (limited in number) found that they could earn higher real wages in symbiosis with tractors than working with horses. And so they abandoned their old friends for the new ones.

The new symbiosis of teachers and teaching machines will certainly displace the traditional teachers and their old teaching methods and technology. Computers are capital equipment to be used by teachers to save time and labor. In delegating certain functions to machines, the new teacher emerges as an indispensable human being. He/she may teach more students heretofore. This is inevitable if the worldwide demand for education is to be satisfied. Hopefully, teachers will be able to teach with less effort and with fewer burdensome chores. In return for their greater productivity, they can ask society to improve their economic condition.

Finally, the computer may have all the information in the world, but it lacks experience in the real life, because the valued engineer des not do repetitive tasks as a computer, but, in essence, thinks about as problem and s/he"*engineers*" the solution.

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