AC 2011-1816: REVERSE ENGINEERING MODERN ENGINEERING EDUCATION AND ITS SCIENTIFIC APPROACH: WHAT WOULD STEPHEN TIMOSHENKO SAY ABOUT THE CURRENT ENGINEERING EDUCATION?

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Introduction

One of the most profound transformations in engineering education may have occurred after World War II, especially in the U.S. According to Jørgensen, in the post war period, engineering education shifted from "encyclopedia stages," focused on national and industrial infrastructure development, to "scientific stages" characterized by achievements such as semiconductor, electronics, and computing[1]. Hence, where instructors were once mainly practitioners, since the 1970s the majority of faculty are academic scientists[2]. Along with this shift, the first concerns about the lack of professional skills of the new graduates appeared in public opinion, concerns that have strongly increased during the 1990s[3]. Sciences, in particular physical sciences and engineering sciences, have become the essential component of the engineering curriculum, giving a higher status to analytical courses than intuitive and practical-oriented courses[4]. This predominance of sciences in engineering seems to be a barrier to developing the new set of skills that new engineers need, now that industry has become the main employer and an important supporter of engineering schools, more so than federal funds[5]. A further challenge resulting from this shifts is that globalization has generated a global and open market of engineers, resulting the creation of multicultural engineering workplaces around the world[6] and requiring a new set of professional competencies[7].

In the current era, the design of new products and systems for new markets has become the context of engineers, requiring skills such as teamwork, creativity, social context understanding, environmental awareness, and competence in foreign languages[8]. Therefore, the scientific and technical approach to engineering education now conflicts with the current predominance of the "market world" and the new skills required for many professions[9]. Thus, nowadays, when the scientific approach seems to be in question, a closer historical analysis of the transformations prompted by Stephen P. Timoshenko, an engineer who was called "the father of engineering mechanics in the United State"[10], might illuminate the current discussion and lead to better appreciation of modern engineering education.

Timoshenko was born in the Ukraine 1879 and studied engineering in the St Petersburg Institute of Way of Communication, Russia. In 1922 Timoshenko moved to the U.S and in 1927 became a professor of engineering at the University of Michigan. According to Seely, Timoshenko was one of the most important European engineers who arrived in the U.S. in the early twenties, and while at the University of Michigan he transformed engineering education through a rigorous mathematical approach, inspirational lectures, fundamental textbooks, and innovative initiatives, such as summer schools[11].

The University of Michigan is relevant for the study of engineering education not only because it was the first American university where Timoshenko worked, but also because it is an institution with one of the oldest traditions in engineering education in the U.S. The first engineering degree at the University of Michigan was awarded in 1857. Thus, the University of Michigan was the sixth university that gave a degree in engineering in the U.S. after Rensselaer Polytechnic, Union College, Harvard, Dartmouth, and Yale. The Department of Engineering at the University of Michigan was established in 1895, enrolled 331 students, and its first dean was Charles Ezra Green, a Harvard graduate. In 1920, seven years before Timoshenko's arrival the now called College of Engineering enrolled about 2,000 students[12].

Timoshenko left a huge legacy in mechanical engineering, specifically in relation to topics such as strength of materials and theory of elasticity, and much has been written and analyzed about his contributions in this field. However, little has been said about his educational approach together with his vision of how engineering education should be. This paper makes a contribution in this direction through providing possible answers to questions such as: what was Timoshenko's general vision of engineering? What made him a "brilliant lecturer" and an inspiration to new generations of engineers? What would he have said about the current discussion about engineering education?

Methodology

Since this study is mostly based on historical books and documents, it is important to keep open and alive the historical questions that provoke us in analyzing those texts. Thus, I follow a hermeneutical approach as a methodological tool to "speak" with the texts. Hans-George Gadamer states that it is possible to understand a text as an answer to a question; "Thus interpretation always involves a relation to the question that is asked of the interpreter. To understand a text means to understand this question."[13] To ask this question of the texts is to open the possibility of new answers in which the interpreter participates from his or her own perspectives and traditions. Hence, in this study, the analysis of the texts written at the time of Timoshenko is similar to a conversation through which we bring our own current concerns and experiences to the authors' tradition at that particular historical moment. Consequently, I cover a body of literature from two veins: texts and documents written by Timoshenko and his colleagues about engineering education at the first half of the twentieth century, and a selected corpus of current reports and papers that argue the necessity of change and for new directions in engineering education in the twenty first century.

The first and foremost source of study is the historical texts that were written by Timoshenko and his colleagues, in particular those related to the College of Engineering at the University of Michigan. Timoshenko not only was a prolific and outstanding writer about revolutionary engineering theories but also an author who wrote about engineering education and about the turbulent stage of the twentieth century's first half. Two particular books are critical in this study. *As I Remember* is the autobiography of Timoshenko, published in English in 1968. The other important text is *Engineering Education in Russia*, which was published in English at 1959, a sort of short report about the evolution of engineering schools in Russia until that time. Both books represent a rich source of Timoshenko's vision of engineering education and a window through which to observe the transformations that occurred in American engineering education during the interwar period. Although some of the texts were translated from Russian to English during the cold war period, the translations expose Timoshenko's severe critiques toward American engineering education.

To capture the interaction of Timoshenko with his colleagues and the discipline at that time in the U.S., I explore other sources such as engineering reports and minutes of discussions about engineering curricula, obtained through the Bentley Historical Library of the University of Michigan. I will also examine papers and books about the history of higher education. Some of them focus on the history of engineering education and others include references to engineering within a general context.

Contemporary reports, papers, and books about the current state of the art of engineering education are the second source of analysis. Most of them state a critical vision about today's current engineering education or suggest a period of important shift from the "traditional" perspective to new approaches shaped by the global economy. These texts are crucial in a sense that it is possible to formulate questions about the history of how these changes have been produced and discussed in the past. Moreover, in these texts, there are some statements and assumptions about the changes produced during Timoshenko's times that are reviewed in this study.

Finally, it is important to mention that the hermeneutic approach of this study does not have the purpose of achieving a complete revision of the reviewed period, nor a comprehensive description of the events that occurred in Timoshenko's period. This paper pretends to formulates questions to the history and to obtain answers that can be a source of further discussions about the apparent problems of engineering education. As Gadamer states, "The critique of the concept of the problem that is conducted with the means of a logic of question and answer must destroy the illusion that there are problems as there are stars in the sky."[14]

Analysis

Timoshenko allows us access into a detailed and rich history of engineering education's development during the first half of the tumultuous twentieth century. Universities, research institutes, laboratories, scientists, faculty members and students have the most relevant place in the Timoshenko's autobiography *As I Remember.* In his narration, the Bolshevik Revolution, World War I, and the rise of Nazis in Germany are the context through which engineering and the sciences go forward into a new technological era. Timoshenko also devotes many episodes to explain his teaching and learning experiences and his vision about comparisons among engineering curricula in different countries. He taught in Russia, Yugoslavia, and in the American East, Midwest, and West, and gave lectures around Europe and the U.S. These comparisons represent Timoshenko's scientific vision, describing clearly the strength and weaknesses of each national system. In many chapters, he became very critical of American engineering education of the early twentieth century. As a result, many are the possibilities of dialog in terms of the Gadamerian logic of question and answer within Timoshenko's texts. In order to organize this dialog and to achieve the aims of this paper, I divide the analysis into three general findings: I) The indissoluble union between science and engineering, II) the global impact of the engineering curriculum setting, and III) the vital interchanges between industry and engineering colleges. Around these topics, I bring contemporary discussions about engineering education and about the role of engineers in society.

I) The origins of the indissoluble union between science and engineering

Timoshenko visited the U.S.S.R. in May, 1958, after almost four decades of absolute absence from his birthplace. The American engineering educators were very interested in Timoshenko's impressions about the Soviet engineering educations system, and the scientists of the U.S.S.R. were very excited about receiving this prominent figure and knowing more about the American system. Timoshenko is by that time over seventy, lives permanently in Palo Alto, California, and is dedicated to prepare new editions of his books. He has become a well-known figure worldwide in engineering and sciences mainly due to his books and papers, which have been translated into many languages. Due to these accomplishments, Timoshenko received many important prizes and honors, such as member of the academies of science in the U.S., France, and the U.S.S.R. Thus, he easily arranged many tours of different Soviet engineering schools. In many of these schools he had studied or worked in as a researcher and instructor before he left the country. Visiting one of these schools, the Mechanics Institute of the Ukrainian Academy of Sciences, he notes:

> The basic idea of marrying science to engineering, which had so inspired me when I organized the mechanics department at the Kiev Academy of Sciences, was a living reality here. This laboratory that I had planned was now actively participating in solving the country's important engineering problems.[15]

The work in this laboratory was based on theories developed by Russian scholars specialized in bridges. Timoshenko has not seen anything like this in the U.S. or in Europe. As he mentions, he started his studies of engineering in Russia at a time when the presence of science in engineering became increasingly important. Since that time, he truly believed that the future of engineering depended on a marriage with science. Timoshenko will hold this belief during his whole life.

The nineteenth century was witness to remarkable advancements in mathematics and physics, as well as other basic sciences. Particularly in France, many scientists had a crucial role in this development, such as Lagrange and Laplace. Soon, these developments were carried over to engineering. French engineers and scientists highly influenced the beginnings of engineering schools in Russia.[16] One of the most important schools was the St Petersburg Institute of Ways of Communication, opened in 1809, which was staffed mainly with French engineers. Clearly, Timoshenko's idea of "marrying engineering and science" was shaped in his early studies at this institute. Thus, mathematics and physics, taught by mathematicians, had a central role in the Russian engineering curriculum:

> The main subject in the first year was mathematics-analytical geometry and differential calculus. In these courses we had six lectures a week. The lecturer was Professor Grave, then still a young mathematician, who had just received his doctor's degree and who always appeared for the lectures wearing his doctor's insignia. Later Grave transferred to the University of Kiev, acquiring a reputation as a mathematician. [17]

Timoshenko was also influenced by the work of researchers who used mathematics to solve engineering problems. This mathematical background allowed Timoshenko to explore new ways to teach and conceive engineering curricula. To some extent, Timoshenko polished the relationship between mathematics and engineering. In other words, he was one of the first in "consummating the marriage." Although he worked intensely in this union, he acknowledges that applying mathematics is different from working abstractedly with it. "I was not born to be an abstract mathematician. But mathematical applications in the engineering sciences did interest and naturally attract me," Timoshenko states.[18] In his 1958 travel to Russia, he could realize the fruits of the seed of his work as a young faculty member. Forty years after his first innovations connecting mathematics to the engineering curriculum, Timoshenko remarks on the number of "mathematical engineers" that graduate every year from the Petersburg Polytechnic:

> The idea of using mathematical analysis to solve engineering problems was, of course, not new. I arrived at it under the influence of Krylov's works in Russia, Stodola's in Switzerland. Under their influence too, in 1916, I offer and I evolved a curriculum for the Department of Physic and Mathematics at Petersburg Polytechnic. I was guided by these same ideas in 1918 when I drew up my program for the mechanism section of the Ukrainian Academy of Sciences. And then forty years later, in 1958, I had a chance to revisit both the Petersburg Polytechnic and Mechanism Institute of the Ukrainian Academy of Sciences. Both are flourishing. The Department of Physic and Mathematics at the Polytechnic turns out every year about two hundred mathematical engineers.[19]

One of the reasons explaining the impacts of mathematics in Russian engineering, which even reached more influence there than in France or Germany, was the highly competitive exams for admissions into the engineering schools[20]. At the beginning of the twentieth century the demands for engineers in Russia had been growing quickly, mainly for necessities of national infrastructure, such as, bridges, roads, and railroads. Consequently, the number of applicants also grew quickly, but the number of engineering schools did not increase at the same pace. Thus, the exams, which included complex problems of arithmetic, algebra, geometry, and trigonometry among other requirements, such as Russian composition, were the main instrument of selection. When Timoshenko was examined for being admitted in the Institute of Way of Communication there were more than 700 applicants, 150 of whom will be admitted.[21]

Taking into account Timoshenko's background, his negative impression about the lack of mathematical knowledge and the lack of interest in science of American engineers when he arrives to the U.S. is easy to understand. During the Bolshevik Revolution, Timoshenko left Russia and obtained a position at the Zagreb Institute in Yugoslavia, and then he emigrated to the U.S. in 1922 to start work in American companies. He first worked for about one year in the Vibration Specialist Company of Philadelphia, and then he moved to Pittsburg to take a position at Westinghouse where he worked until 1927. His first years in America were difficult. He realized that his prolific life as a scientist in Europe would not continue in the U.S. were he would not be able to have access to European Journals, participate in scientific conferences, and have the opportunity to do theoretical work. On the other hand, the life conditions in Europe were precarious, far from what in America he and his family could have. In this moment, Timoshenko faced a dramatic dilemma of pursuing a fertile scientific life or bringing stability to his family.[22]

The research laboratories in the American companies were not what he thought of in Europe. Timoshenko used to read articles about the American machines in the laboratories of large companies, but then he realized that "the descriptions were to a large extent advertising."[23] In 1927, Timoshenko left Westinghouse, accepting a position at the University of Michigan. Although he had spent most of his remaining time training new engineers during his last period working at Westinghouse, he could return to teaching in an academic environment. However, his experience in Michigan was also daunting: the laboratories were "not suitable for scientific work,"[24] the instructors did not have mastery in mathematics, and the students were absolutely underprepared.[25] "Clearly, under these conditions the training received by American engineers was inferior to that given engineers in Europe," Timoshenko points out.[26] This conviction was so strong that his son and one of his daughters were sent to study engineering in Germany because of the superiority of the European programs.[27]

Historians agree with Timoshenko's impressions. George Emmerson, acknowledging the productive capacity of engineering in the U.S., points out that "the American engineer who threw railroads across rivers and mountains, devised myriad machines and mass-produced them was by no means an applied mathematician."[28] Earl Cheit states that American engineering was a "practical and creative art" concerned more about economical factors than "refined method of design."[29] Timoshenko had the same judgment about the lack of sophistication in the engineering design when he saw for first time the elevated railroad in New York City that "had been built so stupidly."[30] French development in sciences was substantially ignored in the U.S., and engineering education remained based on apprenticeship.[31] John Oliver takes another perspective in his book *History of American Technology*. In this book, Oliver emphasizes the rise of the U.S. as a world power at the end of the nineteenth century. This author states, "Americans were especially interested in the great new scientific thought that was developing in Europe […] and in the curricula of the great universities in [Europe]."[32] John Thelin remarks the rigorous training in mathematics that the first American engineers received at the military academy West Point, the first institution in the U.S. that officially imparted engineering education in the 1830s.[33]

How interested were Americans in European sciences at the beginning of the twentieth century? It seems an arguable question, but certainly the discussion about science in engineering was present in American universities prior the arriving of Timoshenko and other European scientists.[34] For instance, at the University of Michigan in 1914, a physics professor, Karl E. Guthe, complains to dean of College of Engineering about the idea of reducing the amount of credits dedicated to physics. Guthe claimed that the University of Michigan was getting behind the physics education in other good engineering schools, such as Columbia, MIT, and Purdue, and he wrote, "in the interest of the reputation of Department of Engineering of this University we must strongly object to the present tendency of transforming your Department into a better trade school."[35] According to Professor Guthe, engineering without science is just a trade school. By that time, a trade school was not well considered in academia.

The analysis of sciences in engineering is incomplete if we do not consider the general debate in American higher education about the tension between the liberal traditions and the rise of the useful professions, such as engineering and business and administration. At Columbia University at the beginning of the twentieth century, the discussion was synthesized for either the option of to "make professional men" or to "make men."[36] In other words, to prepare men for professions in university was considered a deficient way to prepare men for society. Similar discussions were taking place at the University of Chicago and Harvard.[37] Cheit suggests, "The new professions on campus were perceived more as a threat to higher learning than as a part of its adventure […] the new professional schools were isolated from the academic enterprise."[38] Thelin illustrates this discrimination against professional schools during the 1910s through the example of engineering students that were required to sit in the back in the college chapel at Yale because they were considered "second-class students."[39] Clearly, by the time of Timoshenko's arrival to the U.S., engineering education was not a priority of the higher education discussion.

In many ways Timoshenko noticed the lack of concern within American colleges and universities toward applied sciences. For instance, one of his constant critiques was the nature of the work and career of faculty. According to Timoshenko, the chairs in an engineering department must be filled by people who have demonstrated scientific achievement, but in America he found other criteria. Professors were promoted based on the years of service and teaching experiences, a "worse method." In the U.S., they were distancing young people interested in sciences, who have the "energy" necessary for the classroom, from research and teaching. As he suggested:

> All my subsequent experience showed me that the Council's choice of new professors on the basis of written appraisals, from experts, of the candidates' scientific work is the best method of filling a chair. Promoting assistants and teachers to professor on the basis of length of service and teaching experience is an incomparably worse method. So long as American schools employ that method, they cannot acquire satisfactory teaching staffs**.** Under that system the talented young are held back, become professors only when they are older-when the energy and enthusiasm of youth, so important in teaching, are gone.[40]

During a conversation with another European instructor in the U.S., Timoshenko agrees with him about how odd it seems for them that the administration of universities was directed by people without background in sciences. Timoshenko reports, "He was particularly annoyed by the fact that the university was run by people who had no connection with science."[41] Timoshenko also makes an interesting observation after an audience with Vannevar Bush, prorector of MIT and one of the most important advocates for sciences in the U.S.[42] "American life does not favor the flowering of scientific talent but draws the capable people away-into administration," Timoshenko commented.[43]

Timoshenko was a passionate advocator for the marriage between science and engineering, but he acknowledged that this union was not totally perfect, and one of the main problems was related to teaching methodologies. Usually scientists, especially mathematicians and physics, were poor lecturers. Timoshenko started to observe this problem since his first year at the Institute of Way of Communication. He and his classmates in Russia used to study from books instead of setting in a large classroom with one of these lecturers:

> The first lectures were a big disappointment to me. I remember the first lecture on geodesy. It was given by a Professor Buguslavskiy, author of a voluminous book on the subject. He was poor lecturer. A descriptive course is ill-suited to the lecture method on teaching, especially in a large lecture hall. The physics lectures were even worse […] After reading some of the book, I quickly decided that I could assimilate the subject sooner and better from the book, without attending the lectures.[44]

Those scientific instructors were disconnected from instructors of technical courses. Thus, they were teaching without knowing what "future engineers needed to know."[45] On the other side, technical professors "were unable to formulate the requirements that courses in theory ought to satisfy".[46] These problems were not only presented in Russia, but also in the U.S. In a meeting report at the College of Engineering at the University of Michigan, while discussing whether or not increase the credits of mathematics in the engineering curriculum, Professors Wilson and Good point out that the problem is the abstraction in which mathematics were taught and the lack of connection to engineering problems.[47] Even, Timoshenko, trying to strengthen the mathematical background of his students at Stanford, asked Professor Uspensky to teach partial differential equations. It turned out that Uspensky's lectures were "purely theoretical" not what his engineering students really needed.[48]

Realizing this gap between science and engineering in the classroom, Timoshenko took some actions to reduce the gap. The strategy that he found more effective was a careful preparation of problem collections. These problems were engineering problems that requires the use of high level mathematics. He continues the effort of Russian colleagues that connect classes' problems to the real engineering problems. Later, many of these collections of problems were translated and used for many generations of engineers around the world. Timoshenko spent a lot of time creating many of these problems in Russia and Yugoslavia, and they were a key element in his teaching in the U.S.[49]

One barrier, which Timoshenko faced in American engineering education, to increase the use of these problems in the U.S., was the mechanism of examination. American professors did not use problems that require a longer development during exams. According to Timoshenko, the well spread system of true-false or alternatives in engineering schools do not allow a deeper understanding of the subject. He points out that "the only advantage of those methods is that they require a minimum of the time and effort from the teacher."[50] Despite these obstacles, many young people were trained by using Timoshenko's problems in his courses at the University of Michigan and Stanford.

Summarizing this section, Timoshenko saw in the "marriage" between sciences and engineering an indissoluble union and believed that "there is no doubt that the future of engineering is destined to become more and more closely connected with the development of pure science."[51] This union occurred in Europe during the nineteenth and at the beginning of the twentieth century. The role played by mathematics was extremely important in Europe, especially in Russia. Many European researchers, who were well-trained in mathematics, after World War I emigrated to the U.S. and fought for a better awareness about the role of sciences in engineering. By that time, in the U.S., the training in sciences was poor, and engineering education was absent in the main discussions in universities. This effort to bring together science and engineering was not absents of problems, which certainly were present for many years. Scientists seemed to be extremely theoretical and totally disconnected from engineering education, and on the other side engineering practitioners and professors were unable to understand the most advanced sciences. Timoshenko devoted many years of his life applying theoretical knowledge to real engineering problems, and this legacy, without doubt, had a deep impact in the further development of sciences in engineering in the U.S. after World War II.

II) The engineering curriculum did matter; it made a difference in a global scale

The cohorts of engineers who graduated in the late nineteenth century and at the beginning of the twentieth century in Europe, not only played a crucial role in their countries, but also they were a workforce that spread their knowledge and capabilities all around the world, contributing to a development of infrastructure and technologies in remote countries[52]. Before World War II, an important group of European engineers emigrated to the U.S., and they were fundamental in the big transformation of engineering education in American colleges and universities. Timoshenko was part of this wave of newcomers. For example, he remembers a group of European engineers that used to gather in Pittsburg on Sundays. All of them participated first in industrial development and later in important changes in major universities, such the University of Michigan, Columbia, and MIT:

> On Sunday mornings at nine o'clock, at a designated corner, our "hiking club" assembled. It was a small group, usually fewer than ten. The only American was J. Ormondroyd, later mechanics professor at the University of Michigan. All the others were foreigners, from different European countries. The Russians were I and G. Karelitz, my pupil at the Petersburg Polytechnic, who was to become professor of applied mechanics at Columbia. A frequent participant in the walks was J.P. Den Hartog, my very close associate at the Research Institute, who afterwards became mechanics professor at M.I.T. Another of our hikers was Soderberg, who also became a professor at M.I.T., and subsequently dean there. Who could have imagined at the time that within some ten years this group of young engineers would be playing leading roles in the development of mechanics in America? We were all really interested in mechanics.[53]

Timoshenko also notes that after World War II when large amounts of resources were allocated to enhance engineering and science in the U.S. and the expansion of Ph.D. programs, the develop of engineering still depended on groups of European scientists, especially from Germany, who arrived to the U.S. before and after World War II. As Timoshenko mentions, "money alone was not enough. People were needed too. The prewar teaching staffs of U.S. engineering schools were in general untrained for such a job. […] Conditions of life in Germany were hard, and many scientists left, thus enabling America to expand rather rapidly its research in engineering."[54]

Who could have imagined the impact of Timoshenko's "hiking group" and other Europeans in American Engineering? In this section, I suggest that the innovative curriculum that these engineers experienced in Europe was a crucial part in the leading role that they played in the U.S. These engineers were well trained in mathematics and physics. They acquired a scientific vision of engineering and brought new methodologies to solve problems. The curriculum in Europe made a difference in cohorts of engineers that had a large influence around the world. In the nineteenth century, in the U.S., a different idea of curriculum took place and produced a different engineer from the European conception. In Europe, and especially in Russia, the engineering students received rigorous training in mathematics. According to Timoshenko, this training made a difference in him and his classmates. This training gave them a capacity to resolve "non stereotyped problems" and a way of success in the U.S. Despite the limitations of language and cultural differences, they had an advantage over American engineers:

> We all expected to be fired as useless within six months. But that did not happen. We all went on to become very successful at Westinghouse. Now some forty years later, thinking back over the reason for our achievements, I come to the conclusion that not a small role was played by the education that we had received at Russian engineering colleges. The thoroughness of our training in mathematics and the basic engineering subjects gave us an enormous advantage over Americans, especially in the solving of non stereotyped problems.[55]

Timoshenko strongly believed in the power of the scientific approach. He and others like him succeed, to some extent, due to the Russian curriculum. Was this curriculum, which stressed the scientific approach, intrinsically superior to other curricula? This question is an open debate especially when, since the 1980s, there exists an inclination to believe in a curriculum with a more liberal tradition as its basis rather than a curriculum designed with a "vocational mentality."[56] Certainly for Timoshenko, the evidence of the power of science in engineering comes from the capacity to resolve complex problems; with a scientific approach, engineering will achieve more efficiently its purpose of serving society. However, this faith in the power of sciences can be described as an intrinsic characteristic of who practices sciences and resolves problems using its theories and methods. Thomas Kuhn suggests that a "normal" science has the capacity to establish paradigms and more rigid definition of its field and its problems, rejecting the vision of other disciplines and problems that are "just too problematic to be worth the time."[57] Upon these assumptions, engineers could have projected an idealistic scientific engineering that overlooks other essential parts of professional work, such as creativity, and other social science knowledge. As Eugene Ferguson, analyzing the role of design and drawing in engineering, points out, "The myth that the knowledge incorporated in any invention must originate in science is now accepted in Western culture as an article of faith, and the science policies of nations rest on that faith."[58]

To think that the curriculum was the most important factor influencing these American engineers could be somewhat naïve. There were many other factors that explained the rise of science in the U.S. For instance, the industrial revolution in the U.S., which did not require scientific engineers at its beginnings, and especially after World War II, the spending on research in national defense allocated large amount of resources for the advancement of sciences and technology and training of scientists and engineers. Moreover, Timoshenko and his European colleagues did not arrive to the U.S. with their learning process concluded. They received significant influences from American society. For example, the democratic environment that they experienced in different companies gave them new approximations to engineering problems and new capacities of innovation. The results of this meeting between these scientists and the American culture will be analyzed in the next section. Nevertheless, although it is clear that the conditions in the U.S. nourished the scientific development in engineering, to explain the rise of the influence of science in American higher education without acknowledgment of the effect of European curricula would be inaccurate.

Joan Stark and Lisa Lattuca, define "curriculum" as an academic program with at least eight elements: purpose, content, sequence, learners, instructional processes, instructional resources, evaluation, and adjustment.[59] Using some of these elements, I will present some of the relevant features of the curriculum that shaped Timoshenko's generation and the difference that existed at that time between the European and the American curricula. As we will see, many of the tensions and discussions presented by Timoshenko and his colleagues are still alive in current discussions.

Who the learners of the curriculum are defines the structure of the curriculum. In this analysis, two main differences are easy to appreciate between European and American engineering students: their knowledge before initiating their program and their social and academic background. Regarding knowledge, mainly shaped by their former education in high school, Timoshenko mentions several times the huge gap between European and American secondary education. Even in the late 1950s, when Timoshenko acknowledges the improvement of American higher education, he still points out that if the U.S. maintains "poor secondary school preparation", American engineering will stay behind Soviet engineering.[60] It turned out that in 1961, two years after Timoshenko's book *Engineering Education in Russia,* the Soviet Yuri Gagarin became the first man to go around the world in orbit. This event was considered by the U.S. as a fact of certain superiority of Russian technology.[61]

According to Timoshenko, the lack of mathematical knowledge of American students was caused by the scarce number of mathematics teachers in high schools, and those teachers who taught mathematics were "ill-trained." Timoshenko realized this situation many years after his arrival to the U.S. while he was teaching in university. During his work in companies, he did not notice the absence of mathematical knowledge as clearly because all the positions that required a more theoretical knowledge base were filled by European engineers:

> Geometry was limited to planar problems, while trigonometry usually was not taught at all. Even sadder was the training of the mathematics teachers. In knowledge of mathematics they could not compare with the teachers in Europe. Yet even of the ill-trained ones there was a complete insufficiency. I was once told, for example, that 40 per cent of the high schools in California had no mathematics teachers at all! Whether this was true or not, I do not know. However, I did not learn all this till later. When I started at Westinghouse, I merely noticed that all the jobs requiring any theoretical knowledge whatever were filled mainly by engineers educated in Europe.[62]

Certainly, with this poor training in mathematics, it is difficult to be ambitious about what is possible to achieve with an engineering curriculum. According to Timoshenko, in the late 1930s, even after many years of improvement in the engineering curriculum, the problem still persists. Timoshenko points out that doctoral students are far weaker prepared in mathematics than third-year engineering students in Russia.[63] This problem will remain permanently in American higher education. Nowadays, almost one hundred years after Timoshenko's arrival, many reports indicate that one of the main barriers to the advancement of engineering and technology in American higher education is the poor preparation in science and mathematics of young people throughout the K-12 and post secondary education. As the U.S Department of Education mentions, "According to the National Assessment of Educational Progress (NAEP), only 17 percent of seniors are considered proficient in mathematics".[64]

In Timoshenko's time, the second characteristic of learners that differenced European and American engineering students was their socioeconomic background. According to Cheit, although the American engineering curriculum has changed a lot over more than a century, engineering still attracts the same kind of students. They mostly come from working class families and see in engineering programs a chance of social mobility. As Cheit points out, "Engineering comes closer to the land-grant ideal of access for the sons and daughters of ordinary parents than any other field."[65] In the University of Michigan, Timoshenko notices in the late 1920s that students "were strikingly coarse and ill-mannered […] A student would come into my office in his hat and coat, and without even saying hello start talking of his affairs. I tried to train them at least to take off their hats, with poor results."[66] Later, comparing these students with Stanford students, he suggests that students in Stanford have better manners and are better prepared that in Michigan because they come from more prosperous families.[67]

In 1926, the General Committee on the study of engineering education of the College of Engineering of the University of Michigan presented a complete analysis of engineering students in the *Report of [the] Sub-committee on engineering students at the time of entrance to college*. They studied thirty-two institutions: nine state universities, six privately endowed universities, six state land grant colleges, three privately endowed polytechnic institutes, and another eight representative institutions. They concluded that the possibility to get a job after graduation was the main reason to study engineering, and that most of the freshmen had little knowledge of the field. At the University of Michigan, the freshmen were on average, 19.5 years old, half of them came from out-side of the state, 94 percent were born in the U.S., and most of them came from middle-class families.[68] Interestingly, the perception that engineering represents a special opportunity to respond to the low-income students' necessities persists until today. The so called Spellings Report, the last official governmental repost of American higher education, suggests that there might be matter of policy to "encourage the progression of low-income and minorities students through STEM fields (sciences, technology, engineering, and medicine).[69]

In Europe, especially in France and Russia, the students' socioeconomic background was somewhat different. They also came from middle-class families, but their aspirations differed from American students. As Emerson states, "In both [France and Russia] there were great social pressures for the aspiring middle class to move into the civil service and to regard commerce and manufacturing as social inferior pursuits."[70] Thus, while the European engineering students' motivations were oriented towards a civil service, in America it was more akin to that of a job-seeker in the industry. Knut Sørensen studying the Norwegian engineers' transformation, remarks that in Norway as well in France, Germany, and Sweden the "engineering education became a kind of elite education", and that at the Norwegian Institute of Technology (NTH), between 1910 and 1925, most of its students came from the "upper-middle class."[71]

In his 1958 travel to the U.S.S.R., another important difference that Timoshenko noticed between the composition of American and Soviet students was the percentage of women in engineering. In the U.S.S.R., women had a much greater participation in engineering than in the U.S. Timoshenko pointed out that in Russia women started to participate in 1909 and that in 1956 they were a third of the total enrollment.[72] Anecdotally, one of Timoshenko's daughters studied engineering in Germany. In the twenty-first century, the small numbers of women in engineering is still an important issue and a matter of policy in the U.S. and many other countries.[73]

Learner characteristics might influence the program's content, the second element of this curriculum analysis. As discussed in the last section, mathematics, physics, and other basic sciences were predominant in European engineering education, but what were the predominant elements in American engineering education before World War II? In the U.S. the science instruction had to share room with subjects of the liberal art traditions, especially English. Emerson presents a table that compares the engineering curricula of the French École Centrale and the American schools of Rensselaer, MIT, and the University of Illinois at the second half of the nineteenth century. Rensselaer and MIT had three years of English and foreign language, the University of Illinois had two years, and the École Centrale had no French or foreign language requirement.[74] One explanation of this difference can be found in the inclination of the U.S. towards the liberal arts, which was discussed before. This inclination has always been present in American engineering education. In 1926 the General Committee of the College Engineering at the University of Michigan stressed the increasing importance of the non-technical knowledge in engineering as a fundamental piece to understand the modern world and to training the thinking:

> To show more clearly and convincingly the fundamental dependence of sound engineering upon science, the increasing importance of human relationship in engineering, and the high value of well written and spoken English as an aid to success in the practice of engineering, and thus to broaden and deepen the student's interest in the non-technical elements of his curriculum; and finally, to present to the student some of the main human problems of the present day, as mean of cultivating his intelligent interest in extra-engineering natters and of training him to think.[75]

To understand the complexities of the contemporary professional world, to work in multidisciplinary and multicultural teams, to acknowledge the impact of technology and engineering in society, to incorporate social necessities into the design process, among other reasons for including more of the humanities and social sciences in engineering are usually stated in almost all contemporary reports, books, standards and criteria about engineering education that were used in this study.[76] This concern about a broad education of engineers has been present since the beginning of American engineering education. Interestingly, Timoshenko never made any reference to this discussion. According to Timoshenko, in the U.S., the inclusion of languages and humanities in engineering curriculum has its origin in the poor preparation of high-school graduates. Language and literature remain in the curriculum because higher education is solving problems that high schools are unable to solve.[77] In Russia, this training was not necessary due to the work of secondary schools, and the competitive entrance examinations that included Russian compositions and humanities. An interesting Timoshenko's commentary is the perception that he and his classmates had toward humanity courses. They considered these courses as "superfluous":

> "In the curricula Russia we notice the absence of humanities courses. American engineering schools usually allocate up to 20 per cent of instruction to such courses. Very often they are courses in the English language and the history of Western civilization, which have compensated for insufficient training in these subjects in the secondary schools. In Russia, after substantial training in languages and history in secondary schools and after competitive entrance examinations, the introduction of humanities courses into engineering curricula is considered superfluous."[78]

Did Timoshenko overlook the importance of languages and literature in engineering education? Was he influenced by his strong belief in the power of science in engineering? What it is possible to mention is that Timoshenko needed all the abilities that advocates for a broad engineering curriculum claim as fundamental in the twenty-first century, and it seems that Timoshenko was able to succeed in difficult and complex times, using more abilities than an exceptional understanding of sciences. Although to learn a new language was always a difficult issue for Timoshenko, he was able to understand and communicate in Russian (his first language was Ukrainian), French, German, and English. Was he interested in literature and humanities? Certainly, he was. In several episodes he comments his passion for Russian literature, his interest for politics, and his desire to knowledge more about the culture and history of the countries that he visits. Also, we know that his youngest daughter studied arts in Philadelphia encouraged by him.

In the preface of a book dedicated to commemorate Timoshenko's sixtieth birthday anniversary, the editorial committee writes about Timoshenko, "Being of an artistic temperament he loves the music and painting of all lands and derives benefit and pleasure from his frequent travels."[79] Timoshenko also dedicated part of his life to research about the history of the theories which he researched. One of his most successful books was the *History of Strength of Materials: with a brief account of the history of theory of elasticity and theory of structures*, a comprehensive history from Galileo to the first half of the twenty-first century.[80] Finally, in his autobiography it is easy to appreciate his capacities to analyze in detail the social and cultural contexts in which he was involved. Did he believe that a broader knowledge might be included in engineering education? I did not find evidence of that. However, as described in this paragraph Timoshenko would pass the test of what it is considered the engineer of the twenty century even though he studied and believed in a very specialized and scientific curriculum.

Another long lasting and unresolved debated in engineering education is related to the sequence, another element of an academic program tightly linked to the content. In particular, the debate is about how long the sequence of content in engineering curriculum should be. In other words, how many years an optimal engineering program should last. In the U.S., the engineering training has been traditionally conceived in a four-year curriculum, but from the beginning it has been questioned and even some schools experimented with a five or six-year curriculum. In 1858, DeVolson Wood, the founder of engineering education at the University of Michigan, asked, "Should the entire [engineering] course be included, in point of time within the present undergraduate course of four years, or should a fifth or University year be added to complete the course."[81] This question still remains open after more than 150 years.

In 2008, James Duderstadt, president emeritus and professor of science and engineering of the University of Michigan, proposes in his report *Engineering for a Changing World* to consider the Master of Engineering degree as the first professional degree in engineering, which should be "awarded on completion of an integrated program of at least five years."[82] Thus, the bachelor's degree would be considered a pre-engineering degree. Duderstadt suggests that engineering might be understood as a profession similar to medicine and law. Duderstadt's main concern is the capacity to add value of American engineering threatened by globalizations and the phenomena of outsourcing and off shoring. "To compete with talented engineers in other nations with far greater numbers and with far lower wage structures, American engineers must be able to add significantly more value than their counterparts abroad," Duderstadt points out.[83] The logic is that in order to add more value, it is necessary to have better-trained engineers, and a better trained engineer is one who has received a rigorous and longer formal education. Also, a five or six-year trained engineer would have a more prestigious position in society. I will return to the issue of the engineer's social prestige later.

Timoshenko also was an advocate for longer engineering training. Along with the claim of a better preparation in high schools, he proposes a longer curriculum as the way to achieve what the Russians are doing in their engineering schools:

> "Admittedly the situation in America has improved greatly in the last 20 years, but with our poor secondary school preparation and our four-year engineering school curricula, we cannot possibly accomplish as much as the school of Russia are doing today."[84]

Not only Timoshenko promoted a longer curriculum but also other professors from different specializations. Indeed, in the U.S. there were certain failed experiences of longer engineering programs. In 1924 at the University of Michigan, Professor of Chemical Engineering Alfred White in a letter to Dean Cooley comments, "I am really sorry that Columbia could not maintain its six year courses and win the fight."[85] Columbia had recently decided that they would reduce the chemical engineering program from six to five years. The editorial of Chemical and Metallurgical Engineering (May 26, 1924) also regrets this decision. "Six year men were obviously better trained and worth proportionately more to industry" and also better paid, the editorial comments.[86] Despite these advocators for longer engineering programs, the U.S. kept the four-year formula, offering other arguments. For example, neither graduates nor employers ask for longer programs, the industry needs recruit a great number of young and affordable engineers, and longer programs will increase the cost of education. The vision of those who advocate for longer programs is seen as "idealistic." In 1926, the Wickenden's report of the Society for the Promotion of Engineering Education states:

> As to the normal length of the curriculum, we find no peculiar sanctity in the four-year standard. […] Its more glaring defect is its inflexibility. It is long enough to afford a reasonable general training without specialization or a narrow training with specialization. There is no evidence that a majority of the graduates find it inadequate or that they desire a longer program. Nor is the employer asking for a longer normal program. Industry is seeking a greater supply of recruits for its line or operating activities, but specifications call for a sound general training, […] and for entrance to active live at an age which afford the margin of time needed for a thorough grounding in rudimentary experience.
> The urge toward a larger normal program is largely idealistic. We are tempted to apply to education the principle that if some is good, more is inevitably better. [87]

In Europe, the length of the engineering curriculum followed another history. It always has been considered more than four-years taking into account the virtues of its secondary schools. In Russia, it was considered by at least five years,[88] and in Norway, a clear two levels of engineers was implemented where the "sivilingeniører" had a longer education (six years) and had the highest positions in Norwegian industry.[89] Nowadays, the Bologna Process, which aims a more comparable higher education in Europe, adopted for engineering programs a 3+2+2 model, which means three years for a bachelor degree, five years for a master degree, and seven years for a doctorate degree. According to Duderstadt, in this model "the three year undergraduate program would provide only a pre-engineering degree, while the first professional degree would be a two-year Master of Science."[90]

What are the consequences of a longer or shorter curriculum? Certainly there are differences between a four-year and a five or six-year model. A four-year program reduces flexibility, or in other words it increases the trade-off between a general and a narrow training. Therefore, in many cases, the industry has to assume part of the training of new engineers. To have experience in the field was considered important by Timoshenko, but he saw a different value when this experience is obtained through practices included in the curriculum. Timoshenko regrets that American students do not have the opportunity of engineering practices:

> Recalling now my experience on the railroad, I see that it played a large role in my engineering education. It's a pity such opportunities for practice do not exist in American schools, that most of the students are graduated without real acquaintanceship with work in their field.[91]

Another element of the Russian engineering curriculum that Timoshenko remarks is the diploma project or capstone at the end of the program. In the last semester of the fifth year, Timoshenko worked on three different projects: bridges, railroads, and harbor installations. He had to do the preliminary designs by himself, and then he worked on a detailed analysis with the guidance of a professor. "The extent to which the quality of a student's work depends on the interest shown in it by the instructor, was here completely obvious," Timoshenko asserts.[92] Later, in the U.S.S.R., the engineering schools kept and polished the idea of diploma projects. Students were not asked to use a more specific knowledge, but combine different engineering fields that they learned during their studies.[93]

> The work on this project [diploma project] was not considered as a narrow specialization but rather as a pedagogical method by which the student could be shown how a practical engineering problem could be solved by combining information already acquired in the study of various engineering sciences. Very often the subject of the diploma project was selected by the student himself, which naturally contributed to his interest in the work.

Another consequence of the length of the curriculum is whether or not a longer program increases the social prestige of engineers in society. Certainly, it is a question difficult to resolve due to the influence that many variables have in this issue. For instance, as I mentioned before the students' socioeconomic background, the structure of national economy and country's necessities, and the quality and content of instruction are variables that also play a role in the prestige of engineers in society. The fact that by Timoshenko's époque the engineers were an elite profession in Europe is clear, especially in Russia, and through this section I have discussed that the curriculum had a positive effect on these cohorts of European engineers. Nowadays, Duderstadt connects directly the structure of the American engineering education to engineering prestige. According to this author, the step "to enhance the capability and prestige of engineering continues to be strongly resisted in the United States. As Schowalter notes, our engineering schools are simply not in the business of providing pre-professional education."[94] However, the prestige of engineering is not only a problem in the U.S. but also in Europe. Sørensen demonstrates that Norwegian engineers have been displaced from leader management position in the industry to middle management positions or to technical consultant.[95] Jeffrey Pfeffer suggests a similar tendency in American and global companies: engineers have been ceding power to experts in finance or commercial laws.[96] Thus, the position of engineers in society is affected by more complex and global tendencies that are not purely related to the curriculum and the soundness of engineering education. The current structure of markets and new dynamics in corporations that pursue quick opportunities in constant flow rather than principles of durability, technology, and planning have moved engineers from power positions in society.[97]

Through this section I have suggested that the way in which the engineering curriculum in Europe was conceived at the end of the nineteenth century and at the beginning of the twentieth century had a global impact in the advancement of engineering and technology, especially in the U.S. The main characteristics of these curricula was a strong basis in mathematics and physics, as well as other basic sciences, highly qualified students, and an orientation of engineering toward national development. The analysis of this rich historical material allows a reflection on many discussions that are present in current debates in engineering education. Thus, contemporary questions about the role of sciences and liberal arts in engineering education, the impact of the socioeconomic background of students, and the length of the curricula were illuminated with old discussions and points of view. Most of the current issues in engineering education seem old and unresolved problems, and probably they will stay in permanent debate for many years more. Perhaps, these permanent tensions in engineering education are a key element of the potential of future engineers. The discussion keeps alive the vibrant desire of engineering to respond to emerging challenges of the humankind. So far, the extraordinary advancement of science, engineering, and technology has been possible despite of these permanent and problematic debates.

III) The virtuous relationship between industry and engineering colleges and between engineers and machines

The process through which the arrival of European engineers influences American engineering during the first half of the twentieth century was not unidirectional. The impetus of the U.S. a new super power also influenced these newcomers not only in their daily life or in personal issues, but also it shaped their visions about engineering and technology, and Timoshenko was not immune to this effect. In particular, Timoshenko was surprised by the dynamic that he saw in American companies. In the U.S., he discovered that although the work of engineers was less glamorous than in Europe, the possibilities of applying scientific knowledge were unique. In America, engineers were close to problems in the factory. Engineering teams worked in close contact to workers on the production line. Timoshenko remarks on the role of the chief engineer who always kept his door open to any employee. There was a certain "democracy" in the factory that enhanced the process of research:

> Members of our section were on those teams, thus assuring a close link between the theoretical research and its practical application. Only this close contact between researcher and man in the factory made the research contribution to the engineering advances fully effective. Largely responsible for this contact was chief engineer Eaton, He spent a great deal of time discussing the new problems with us. His office door was always open to every factory employee. This factory democracy greatly favored our research.[98]

Comparing these research teams and research teams in Germany, Timoshenko points out that in Germany despite of its well-equipped and well-trained engineering teams, their capacities of innovation were affected by the distance from workers in the factory. German teams had a large ability to resolve problems, but there was little capacity to put these solutions into practice. On the contrary, in the U.S. the "communication" between researchers and workers was better. Thus, scientific results can be rapidly implemented on the production line. As Timoshenko noted:

> [In German the] plant had a marvelously equipped research institute, headed by a well-known scientist. His closest associates were also people known for their scientific work. But between the scientist and plant engineers no communication existed. The scientist successfully worked the problem given them by the engineers, but the results of their work did not reach the men in the factory.

> The success of a research department in an engineering enterprise depends largely on how the achieved scientific results are transmitted to the people directly engaged in production. Communication between scientists and engineers, according to my observations, is better in America than in Europe.[99]

Timoshenko had a similar impression when he visited for first time England. English engineers had a different relationship with machines. Their laboratories looked like "workshops," very different from German laboratories. "A laboratory in German resembled a physics institute; this one looked like a workshop," Timoshenko states.[100] English engineers had a close contact with machines, without the assistantship of a technician. They prepared their instruments with their "own hands." Thus, English engineers obtained a much better observation of what happened with their experiments:

> The engineers working in the laboratories there were not so dependent on the aid of technicians as in Russia or Germany. An engineer carrying out test did not expect a technician to get the machine ready for him, insert the specimen, and set the measuring instruments. The researcher did all of that himself with his own hand and therefore he observed much more than when everything is prepared by someone else.[101]

Interestedly, at the beginning of the twentieth century, English engineers had a lower social status compared to engineers in other European countries.[102] However, Timoshenko appreciated this relationship with machines because it allows the capture of better information and the possibility to apply and generates knowledge. Nowadays, the idea of workshop spaces and sophisticated machines of productions in engineering schools is identified as an essential standard in contemporary engineering education.[103]

As mentioned, Timoshenko believed that his scientific career lost momentum when he arrived to the U.S., but he acknowledged that he "gained greater experience in applying scientific analysis to solving engineering problems."[104] Although Timoshenko had very successful positions at the University of Michigan and Stanford, he always maintained as a consultant a link to different companies, such as Westinghouse, Babcock and Wilcox, the Pennsylvania Railroad, and the Detroit Edison Company.[105] According to Timoshenko, the status of professor in Europe was much higher than in America. Therefore, in the U.S. the best engineers preferred to work in private industries instead of serving as a researcher in some university, which was a right for the best students in Europe. "The average quality of the engineers, for example, at the Westinghouse Research Institute was higher than that of the engineering professors at the University of Michigan," Timoshenko states.[106]

Another aspect of the work in American companies was that they complemented the training of young engineers, because these new engineers had no experience in the field and a lack of practical knowledge. This situation meant that some companies had to include internal engineering schools. For example, Timoshenko had a crucial role in the training of new engineers at Westinghouse. This kind of company usually was better suited with laboratories and conducted much more advanced research than in the universities.[107]

However, Timoshenko also contributed to transforming the university into an attractive place for the industry as a source of knowledge and actualization. Timoshenko was part, for several years, of the successful Summer Session of the College of Engineering at the University of Michigan. The brochures of the Summer School promised the opportunity of taking advanced courses, working with faculty members in laboratories of the university, and enjoying the features of the life at the university and in Ann Arbor. The sessions were designed to meet the need of advanced students, research engineers, and teacher in technical schools and colleges. Here, Timoshenko conducted the courses "Vibration Problems in Engineering" and "Applied Elasticity and Strength of Materials."[108]

As a result, by the time of Timoshenko's arrival, the engineering was a dynamic discipline in American companies, and American industry saw engineering schools only as source of new engineers. During the 1930s, some companies started to see engineering schools as an opportunity to bring new knowledge and new capacities to their factories. This change was motivated by the work of Timoshenko and many other outstanding faculty members that could apply advanced scientific theories to industrial problems. Timoshenko discovered that when the engineer is close to the production line, its machines, and its workers, the potential of innovation increases.

Conclusion

This paper focused on the transformation of engineering education that occurred at the beginning of the twentieth century prior to World War II, analyzing the trajectory and vision of Stephan P. Timoshenko, a Russian engineer who arrived in the U.S. in 1922 and was considered the father of American mechanical engineering. The methodology used in this study was text analysis based on the hermeneutic tradition of Gadamer and his logic of question and answer. Under this methodology, the analysis of historical texts seems a conversation with the texts, through which researcher's traditions and questions are brought to "talk" with the traditions and contexts in which the texts were written. For this reason, this paper mainly used and mixed contemporary reports and books about engineering education, Timoshenko's books, other text written by Timoshenko's colleagues, and historical books that refers to engineering education at that time.

This study obtained three major findings. First, the origins of the indissoluble union between science and engineering started during the ninetieth century, but it was consolidated at the beginning of the twentieth century, and the trajectory of Timoshenko is an outstanding example of this process of consolidation. The "marriage" between science and engineering was originated by the progress of mathematics and physics in France and consolidated by schools of engineering in different European countries. Then, especially German and Russian engineering had a large effect in the U.S. However, this "marriage" was not absent of problems, particularly problems related to teaching methodologies. Mathematicians and scientists were criticized for being poor lecturers in engineering schools. Second, the engineering curriculum did matter, and it made a difference on a global scale. The cohorts of European engineers trained in this scientific approach in engineering had a large influence in Europe and in the U.S. They were key pieces in the radical change of engineering education during the twentieth century. Despite the influence of science in the engineering curriculum, many of its elements are still debated. For instance, the length of the engineering curriculum, and the role of humanities and social sciences in engineering are old discussions that continue with similar arguments until today. Third, Timoshenko and other European engineers learned new ways to use the scientific knowledge to solve real engineering problems and to advance the capacities of innovation from American companies. In these companies, they saw a closer relationship among engineers, workers, and machines.

This study confirms the Seely's proposition that understanding the big transformation of engineering education during the first half of the twentieth century might illuminate many of the current discussions about engineering education.[109] Many are the actors interested in shaping tomorrow's engineers: industries, governments, universities, and professional agencies. And many are the missions attached to engineers, such as competitiveness, national defense, environmental sustainability, medical solutions, among others. Whether engineering will be taught with more or less sciences, or whether the curriculum will last four or more years are still open questions. Perhaps, as discussed, engineering will be conceived differently for different countries and regions, and any effort of homogenization will have a limit. Despite this debate and questions, if engineering continues attracting and preparing people like Timoshenko, able to adapt to changing contexts and able to pursue passionately new frontiers of knowledge, we will continue witnessing the amazing advancement of engineering during this new century.

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