Revolutionizing Engineering Education: Adapting Curricula to Address Artificial Intelligence Challenges and Opportunities

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Abstract

Undergraduate university education is at an impasse, and the pandemic has merely highlighted its problems. There will be stark consequences if nothing is done to alleviate the issues. Mechanical Engineering is taken as an example, mainly because the authors are familiar with mechanical engineering, though it is suspected that the problems go beyond that. The issue currently faced is outlined, and one possible solution is offered. A new way to look at a course of study for engineering education is proposed. This is based on a different perspective on engineering education and considers that modern technologies have modified every aspect of knowledge retrieval and dissemination, particularly the dissemination of Artificial Intelligence as a tool for research and knowledge archive. The curriculum proposed here answers questions such as: Why should the course of study for becoming engineers begin by first dividing the required knowledge into a fixed and finite set of subjects; why should the courses last a fixed number of weeks with a certain number of hours each? The proposal is explained using the commonly used mechanical engineering curriculum, but it applies to any branch of engineering or any other field.

Keywords: Engineering Curricula, Artificial Intelligence, Education Challenges, Certification.

Introduction

This analysis is about undergraduate education (González and Wagenaar, 2008, Agogino, 2008), and we must be clear that when we talk of students, we only talk of undergraduates (graduate/postgraduate studies are something else, more related to research, publications, and external funding). Because of the authors' background, much of what we will discuss here will be specifically related to mechanical engineering. However, the basic ideas apply to other branches of engineering and other disciplines and areas of study in universities.

Books have been written about wasting time and money going through a university curriculum[3] (see, for example, Caplan, 2018). Sometimes, however, people are under the misplaced impression that the phenomenon occurs in disciplines that can be loosely called "social sciences," but not necessarily in the "hard or exact sciences" (including engineering). The authors fear that current trends of reduction in undergraduate enrollment (Aguilar, 2021), NSC Research Center, 2022) will continue and lead to something drastic that no one wants. Curriculum reform in universities must come from inside; otherwise, it will be imposed by other factors (such as racial diversity Adepoju, 2023), choice of majors Devereaux, 2023, and other possible characteristics). It is important to take action right away to alleviate the situation.

Ideas of the educational process have changed in recent years, most of the modifications coming from theories such as *competence training* and *constructivism*, among others. They all propose new teacher- student interactions to improve the learning process but provide no specific recommendations for a different perspective. Regardless of the pedagogy or the educational model, students always construct their knowledge base and skills individually and adapt to the environment by themselves.

Lately, there have been significant changes in information technology which must also be considered. The internet has redefined communication channels, information storage, and search. Artificial intelligence (AI) revolves around the search for information, and its easy availability leads to the need for a change in the formal educational process. This incorporation of technology opens up many questions regarding engineering education and how it should be modified:

1. The need to divide engineering knowledge into a fixed number of courses.
2. If information (that can be transformed into knowledge) is available almost everywhere, why do students have to receive it at a fixed location from a professor?
3. What should the role of universities be in the new engineering education?

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There are many ways to answer these and related questions. To begin with, the educational system must first define the knowledge and skills a person must have to be an engineer. We are not talking about a university system in any particular country, but worldwide; they are all similar or strive to be.

Furthermore, what did we learn from the pandemic? In addition to a partial change to the work-from- home concept and home delivery of groceries, universities have been profoundly changed, even though most would like to return to the way things were before the pandemic. Video classes have been shown to work somewhat, but they can be further perfected. And if this is so, what is the purpose of traveling long distances to attend brief face-to-face classes?

The Current Situation

The fixed and finite set of subjects and a specified duration for each course have shown many advantages, such as a progressive learning framework, a certain level of quality and consistency in education, an explicit schedule for covering material, and meeting academic deadlines. A structured curriculum ensures students are exposed to theoretical foundations and practical applications, preparing them for real-world engineering challenges and professional practice. Nevertheless, it is facing many limitations, particularly in the context of new technologies like Artificial Intelligence (AI) and the abundance of information on the internet. AI and other emerging technologies are advancing rapidly, often outpacing the traditional curriculum development cycles. This rapid evolution can make it challenging for structured frameworks to keep up-to-date with the latest technological advancements and their implications for engineering practice. Many engineering problems today require interdisciplinary knowledge and skills that may not fit neatly into traditional subject boundaries. For instance, AI applications in engineering often require knowledge from computer science, mathematics, and specific engineering disciplines, necessitating a more integrated approach that traditional frameworks may struggle to accommodate. Engineering education is evolving towards more flexible and adaptive models in response to these challenges.

From a learning point of view, the current engineering curricula present several limitations and drawbacks. It imposes rigid timelines for learning specific topics, leading to superficial understanding or memorization rather than deep learning and conceptual mastery. Students may feel constrained in their ability to delve deeply into subjects that interest them or are critical for their career aspirations. They need help connecting knowledge that represents different engineering aspects with similar fundaments and mathematical models, for example. Engineering is a field where lifelong learning is essential due to rapid technological advancements; thus, the current engineering curricula may not adequately prepare students for continuous learning and adaptation throughout their careers, as they might focus more on completing predefined syllabi rather than developing skills for self-directed learning, or may limit opportunities for students to explore creative solutions and innovate within their coursework. There is a growing movement towards more flexible educational models in engineering, such as modular courses, competency-based learning, project-based learning, and interdisciplinary programs. These approaches aim to provide students with greater autonomy over their learning paths, accommodate diverse learning styles and paces, foster more profound understanding and critical thinking, and better prepare students for the dynamic and complex challenges they will face in their engineering careers. (Chiu, 2024; Chiu et al., 2023; Gunawardena et al., 2024; Tavakoli et al., 2022)

Some characteristics of the current old curriculum

In its basics, educational activities currently follow an evolutionary cycle, as shown in Figure 1. Cycling from deductions based on previous knowledge, using analogies to understand physics-based models with similar mathematics, and reinforcing the knowledge with repetitions. For example, looking at the specific case of the mining industry in Mexico, the *Real Tribunal de Minas* appointed experts, and the *Colegio de Minería* started formal courses for teaching future mining experts. The process for appointing mining experts ended when an academic jury examined each candidate and decided to nominate one or more. Over the years, the procedure for appointing experts has changed, but it is the origin of the current engineering degrees.

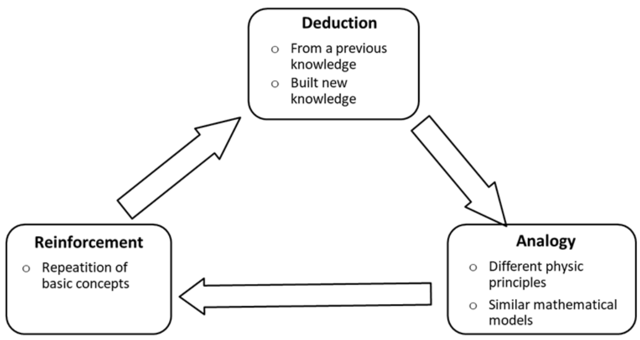

Figure 1. The situation as it is now (Jauregui-Correa, 2022)

A major "revolution" (to give it a name) in engineering education came after the Second World War. The curriculum changed from studying geometry, mensuration, surveying, and topology to calculus and physics-based mechanics. That approach has served us well for the decades since then, but it is time for another revolution. One source (Lattuca et al. 2006) says that "by the 1980s ... new graduates were technically well prepared but lacked the professional skills for success". Technology detonates societal changes, or perhaps it is the opposite; in any case, they are closely related.

Networking with other students is one of the strengths of the current system. The students come to know their peers, who may sometimes help them in some way in the future. On-campus lodgings are a few ways to achieve that since lifelong friendships are often born there. The students also greatly benefit from internships in industry, and in any change, a way must be found to keep that. Another issue is that of specialization. One of the main roles of universities is to create a multicultural space for sharing experiences beyond specialization. Society has a problem in that even the well-educated (like people with Ph.D., for instance) know only a small fraction of today's knowledge. Surely someone like Newton or Galileo knew a larger proportion of scientific knowledge of their times than a Ph.D. does of knowledge today. When the population of the Earth suffers a COVID-19 pandemic, antibacterial gels abound, but few know the difference between a bacterium and a virus. We have already mentioned that, even within universities, it is difficult for experts in one discipline to talk to those in another. An expert in one field is a beginner in the rest of human knowledge. However, it is hard to know what to do with the problem of specialization: by its very nature, it *must* exist if knowledge is to advance, but it is also, in some ways, counter-productive. Like most professors, the authors go to conferences where they meet and talk mostly to others who can understand them and rarely meet or talk to those who do not.

A fresh, new start on the curriculum

Current undergraduate engineering syllabi in universities and polytechnics worldwide are not exactly working: they do not do what they claim to do for the students. It is important to make a stronger link between engineering education and what the graduate actually does later. Rarely does a graduate of such a program after, say, 20 years of working at a job affirm that "I have really used all my education at some point in my career." And if he or she has not used a particular course, then it seems that it can be removed without much argument. Why is it there? However, the issue is not that simple: it seems to us that some mental maturity is associated with spending time sitting in a course and following a train of argument, not to mention other benefits like regularly taking exams or doing the assigned homework. However, much of that can be absorbed without any emphasis on, say, Newton's Laws of Motion; in fact, the student comes to believe that it is Newton's Laws and their application that we are teaching when it is all about being able to think straight about mechanical processes and relate *cause* and *effect*. A more profound question as to whether an equation such as $F = ma$ is a definition of force F, mass m, or acceleration a is worth considering but rarely studied. What is true, however, is that budding engineers learn how to use the equation. More than that, however, they should *feel* it in the sense that any force results in an acceleration, independently of the quantitative relation between them. Statics is, of course, a special case of this dynamics. If tweaking, or making small changes to the curriculum, does not improve the educational system, what will? If we gave each of us a blank sheet of paper to write down the knowledge base that we think a mechanical engineering graduate should have, we can only be sure that they would all be different, and most will differ from what is currently taught. For a fresh approach to education, one has to begin by asking what the students use in their jobs. However, there are also many difficulties with curriculum change. Faculty like to teach what they have learned as students and what they have taught before. Usually, likes and dislikes are formed early in their careers and do not change over their working lifetimes. For various other reasons, faculty currently in the educational system cannot be expected to change it radically, and it is easier for those outside to make suggestions that may, unfortunately, cut to the bone.

What the students really need to know! (Harris and Krousgrill 2008, McCahan et al. 2015)

The first thing to find out is what the students really need to know. It stands to reason that engineers must have enough knowledge and abilities to solve problems in the field. However, what should they be taught to get there? Many students are proud that they do not use all the math they are taught ("I am good with my hands but not good in math," they may say, "that is why I am in engineering"). So should math be eliminated from the curriculum? It is easier to say what is superfluous in the curriculum than what should be in it. Some aspects are, however, obvious. Students need to know how to think rationally, which is really hard to teach. However, that is what we assume we are teaching in traditional courses, even though the take-home message for the student is more like how-to, i.e., how to solve particular problems given to them in assignments or exams. Engineers must develop the ability to solve problems with the available tools within a limited time. Mathematics plays a crucial role in forming this ability. These courses must be treated as a calculator for children: very useful in reality but totally useless if they do not know what the results mean. The internet has tools to derive equations or to solve complicated algebraic formulas, and engineering students continuously use them to do homework assignments but do not necessarily develop the abilities described in Figure 1. When an engineer uses a math tool, for example, to find the derivative of a function, they expect a specific solution. In general, mathematical modeling leads to understanding. However, AI has become very strong today because we have been unable to model complex mechanical systems from the ground up completely. What has happened in the past serves as a basis for predicting the future. In contrast, engineering students have no previous knowledge of what they expect. Therefore, for the student, any answer will be correct, even if they have input a wrong function. This example illustrates the risks that modern computational tools can create if engineering abilities are not developed properly during education. These types of problems currently occur because breaking the curricula into a set of curses does not guarantee that the knowledge evolves from subject to subject.

A concrete proposal for the future

Other techniques have tried to solve learning problems by modifying the teaching process (without questioning the root problem or even identifying it). Examples are the education model based on competencies, and the inclusion of project-oriented learning, among others. None of them have questioned the need to modify the entire curriculum and dissolve the rigid structure of a fixed number of courses with a fixed number of classes and specific hours per week. Plus, there is the issue of accreditation and grading.

The main task is to develop an ability to reason, such that students will be able to analyze, evaluate and synthesize any problem (that could be solved using engineering skills) regardless of the time frame. The proposal compiles different thoughts and ideas discussed in our communities and presented in other forums (Berlanga et al. 2022). The effectiveness of non-synchronous education and the application of assessment tests has proven to be effective in many educational systems; therefore, this proposal is an evolution of teaching engineering experiences that have broken the traditional framework. In the new model, teachers would no longer be needed to instruct students; their role would be to curate the reading material and select the appropriate sources of information. They also have to prepare laboratory exercises to reinforce theoretical knowledge, and the relationship with students must be through coaching and advising them in preparing for exams. The proposed model is based on the idea of self-formation. Instead of breaking engineering knowledge into a fixed number of courses, every student must approve a set of examinations, laboratory procedures, and the development of projects to receive an engineering diploma. The tests must be organized sequentially and can be presented at any time; in this way, each student will determine their own rhythm based on their abilities and needs. The universities will become spaces for sharing knowledge and experience, coaching (if online coaching is not effective enough), and laboratories for hands-on work and research.

The new engineering learning process is based on a new paradigm (González and Wagenaar, 2008, and Mina, 2013). The roles of those involved are different from before; students would have to acquire new knowledge and thinking abilities by themselves. They would have to read textbooks, review videos, and do exercises at their own pace. They would not have to attend classes. They would progress in the program at their own pace. The idea is represented in Figure 2, where the examination structure is shown. Each circle, or node, represents a certification test of a set of common concepts and skills and is a prerequisite for the following nodes. Evaluating subjects has become a complex issue; the first question is grading. What does grading mean? Every country has its particular grading system, which distinguishes each student individually; nevertheless, the grading system cannot determine individual knowledge; thus, students must prove their knowledge and the engineering abilities they acquired during their studies. In the proposed method, there is no grading, every node has to be approved, and the distinction among students is the time they spend approving all the certifications, which are the nodes.

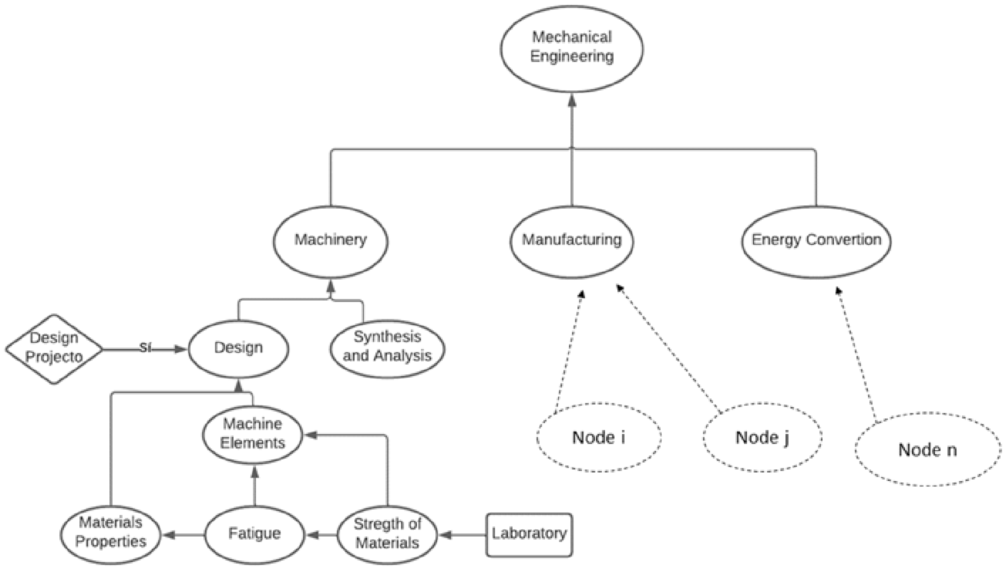

Figure 2. Outline of the alternative proposed curriculum.

The proposed method defines three types of nodes: theoretical, practical, and projects. Theoretical nodes are closely related to developing thinking skills and basic engineering concepts, from physics and mathematics to specific engineering subjects. Practical nodes are designed as laboratory activities with well-defined experiments and specific outcomes; students must fulfill a set of laboratory activities with their corresponding technical reports. Laboratory activities must be designed to develop testing skills, using logbooks, writing technical reports, using specialized instruments, and so forth. Before any practical nodes, students must have approved the theoretical prerequisite nodes. Project nodes are designed as complementary activities, where students combine theoretical and previous practical knowledge to solve real problems.

Additionally, teachers can organize short courses to reinforce individual studies. These classes should not be mandatory; they must be designed to support the learning process and could be taught at any time. The length of the courses must be adapted to the specific needs and requirements of the students. Table 1 is a summary of the roles in this new engineering curriculum.

Table 1. New Roles

Actor	Role
Student	Self-study Prepare for examinations Attend coaching sessions when needed Carry out joint projects and laboratory activities Involvement in extra-curricular activities within the university Network with other students
Professor	Curate certification material Design and update certification exams Coach students in specific subjects Monitor students' evolution Prepare and coordinate projects and laboratory activities Organize short courses Research
Staff	Organize and support cultural activities Administer student enrollment Procure laboratory and project materials Coordinate examinations and certification

Conclusions

The university system is headed for a crossroads, at which point some choices must be made. The pandemic has helped make it painfully clear that business as usual will not work, and some alternative must be found. *When* that happens is anyone's guess. The organizational structure of current universities is not flexible enough to change as needed. This, of course, is not the only line of business in trouble. In the restaurant business, for instance, people have realized that they go to restaurants not just for the food, and the waiters do not want to work for pittance either.

The present paper has proposed a new paradigm to prepare engineering schools for adapting to the technological revolution. The new curriculum model would eliminate the need for classes, courses, and grading and would force the students to acquire theoretical and engineering knowledge by themselves. The new curriculum is organized as knowledge nodes that guide and support students to construct engineering skills and knowledge for professional practice. In them, professors will have new roles. Instead of teaching, they will help students, individually or in groups, develop the necessary skills to fulfill the certification requirements, curate the material being studied, and update exams. They will organize laboratory activities and design specific projects. Networking is crucial for engineers; thus, students will participate fully in project development and laboratory practice, without the need for attending other classes at the same time. The methodology will use newly developed technologies and take advantage of AI, the internet, and the experience of working at home during the pandemic. Although not specific to engineering, we offer practical strategies for assessing (Marzano et al. 1993) and improving student learning, including developing competencies and skil.

References

Adepoju, O., (2023), The Economist this weekend: "A special edition on universities." https://groups.google.com/g/usaafricadialogue/c/gmjlpQeijTc?pli=1, 2023. accessed online June 26, 2023.

Agogino, A. (2008), "Educating the Engineer of 2020" Proceedings of the 9th Biennial ASME Conference on Engineering Systems Design and Analysis ESDA08.

Aguilar, J. (2021), "High school students' reasons for disliking mathematics: The intersection between teacher's role and student's emotions, belief and self-efficacy." International Electronic Journal of Mathematics Education, 16(3), 11 pages, Art. No. 0658.

Berlanga, F., Vallejo, M., Borrego, J., and García-Prada, J. (2022), "Influence of continuous assessment test methodology on the learning of basic mechanical physics knowledge." In J.C. García-Prada and C. Castejón, editors, International Symposium on the Education in Mechanism and Machine Science, pages 103–109. Springer.

Caplan, B. (2018) "The Case Against Education: Why the Education System Is a Waste of Time and Money". Princeton University Press, Princeton, NJ.

Chiu, T. K. F. (2024). Future research recommendations for transforming higher education with generative AI. Computers and Education: Artificial Intelligence, 6(December 2023), 100197. https://doi.org/10.1016/j.caeai.2023.100197

Chiu, T. K. F., Xia, Q., Zhou, X., Chai, C. S., & Cheng, M. (2023). Systematic literature review on opportunities, challenges, and future research recommendations of artificial intelligence in education. Computers and Education: Artificial Intelligence, 4(December 2022), 100118. https://doi.org/10.1016/j.caeai.2022.100118

Devereaux, B., (2023) "Colleges should be more than just vocational schools." https://www.nytimes.com/2023/04/02/opinion/humanities-liberal-arts-policy-higher-education.html. accessed online June 26, 2023.

González. J., and Wagenaar. R. (2008) "Developing competency-based learning in higher education: Evidence from the tuning approach." In Tuning Educational Structures in Europe, pages 33–41. University of Deusto, Bilbao, Spain.

Gunawardena, M., Bishop, P., & Aviruppola, K. (2024). Personalized learning: The simple, the complicated, the complex and the chaotic. Teaching and Teacher Education, 139(March 2023), 104429. https://doi.org/10.1016/j.tate.2023.104429

Harris, D., and Krousgrill, C. (2008) "Distance education: New technologies and new directions". Proceedings of the IEEE, 96:917–930.

Jauregui-Correa, J. (2022) "Flipped learning applied to machine design". In J.C. García Prada, C. Castejón, and J.I. Pedrero Moya, editors, Trends in Educational Activity in the Field of Mechanism and Machine Theory (2018–2022), pages 55–63, Cham, 2023. Springer Nature Switzerland.

Lattuca, L., Terenzini, P., Volkwein, J., and Peterson, G., (2006) "The changing face of engineering education". The Bridge: National Academy of Engineering, 36(2):5–13.

Marzano, R., Pickering, D., and McTighe., J., (1993) "Assessing and improving student learning in college: A practical guide." Mid-Continent Regional Educational Lab., Aurora, CO.

McCahan, S., Anderson, P., Kortschot, M., Weiss, P., and Woodhouse, K. (2015) "Designing Engineers: An Introductory Text." Wiley, 2015.

Mina, M. (2013), "Liberating engineering education: Engineering education and pragmatism." In Proceedings of IEEE Frontiers in Education Conference, pages 832–837.

National Student Clearinghouse Research Center. (2022), "Current term enrollment estimates: Fall 2022". https://nscresearchcenter.org/current-term-enrollment-estimates, accessed online June 26, 2023.

Tavakoli, M., Faraji, A., Vrolijk, J., Molavi, M., Mol, S. T., & Kismihók, G. (2022). An AI-based open recommender system for personalized labor market driven education. Advanced Engineering Informatics, 52(November 2021), 101508. https://doi.org/10.1016/j.aei.2021.101508