Epistemological Basis of Engineering for Curricula Innovation

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Abstract— This study presents an overview of different types of knowledge used in the engineering profession with the aim of identifying changes that can improve the education process in this area. To do so, it is presented the 5D model, a key reference for the distinct aspects of the profession, as a method of analysis of curricular strategies such as TU Delft and MEEC, in order to be able to clarify which educational fields are defective. The results include curricular proposals in both course and non-course form, capable of suppressing the discovered deficiencies. This reflection on engineering education aims to help keeping the university courses in this field attractive, but also to respond to the needs of the job market and society in general.


I INTRODUCTION

The purpose of this work is to stimulate a serious reflection about the contemporary engineering education. In order to do so, is essential, in first place, to figure out what kinds of knowledge are used in the engineering profession, to make possible the design of a complete model for that education. Descartes, Kuhn and Figueiredo are authors whose contributions had been shown to be useful for the understanding of the epistemological basis of engineering.

In order to develop a better education project, it is chosen, for it’s international relevance, CDIO Syllabus, where the goals of engineering education are exposed [1]. Also in a document written by the Education Director of Delft University of Technology, Aldert Kamp, it is reported eight targets of engineering education [2].

With this as a core, it is introduced a model to serve as a reference for an analysis of the curricula, to ascertain deficiencies of the courses.

Below, it is made some suggestions to the MEEC course, of IST, to fill the remaining gaps founded in its curricular plan.

Antique Greece was the cradle of occidental civilization and since that time two kinds of knowledge emerged: a theoretical one, without utilitarian items, – episteme – and a technical one, where was made use of tacit knowledge – techne[3].

Engineering seems to present all the required features to belong to the second group. However, the products and services offered by this profession change societies deeply, for example by means of transportation, of transmission of information or by medicine.

Therefore it is naive to believe in engineering as a simple practical application of science and it is dangerous to dismiss the human component present in that profession[3].

Environment, markets and human relationships are having moments of huge uncertainty, constantly changing, which generate a fertile ground to apocalyptic scenarios. Human race have never had so much facilities at the same time in such danger[3].

Education is the solution. This mantra by itself, despite the constant repeating, will not change anything. Higher education institutions and its methods have long roots and, nowadays, show the dark side of tradition: the inertia for changing, even when it is obviously needed[4].

II STATE OF THE ART

Epistemology

Modern science, the one known nowadays, had its origins in Renascence, with the geniuses Leonardo da Vinci, Galileo, Bacon, Descartes and Newton. In those times, began the search for maximum control of nature by mankind.

Bacon brought to us the belief that the only important knowledge is the one that becomes useful in practice, Descartes postulated that dividing problems in smaller ones, showing that any problem can be solved, and Newton almost proved a world ruled as a machine. From this ideas, began an unimaginable technological progress, which had strengthened the blind belief in them. When, in the beginning of 20th century, Bohr, Einstein and Schroedinger had excited all scientists with their discovers about the dimension of very little, renascence assumptions had suffered their first disillusion [4]. It was understood that the whole is more than the sum of its parts and that determinism fails, meaning that, despite the aware of initial conditions and regent rules, not everything is known [5].

Although more than a century has passed, the educational system continues underlined in a cartesian and deterministic spirit, compartmentalizing knowledge and treating students as deposits for information: as soon as containing the suppose important subject, they will be good professionals[3].

The new generation of epistemologists like Gaston Bachelard and Thomas Kuhn had written about the need of abolish cumulative knowledge belief, of creating news logics and reviewing the concept of scientific spirit. They had suggested that learning only from manuals is not the best way to educate and despite the history of science it will always brings a lot of disadvantages[4].
Engineering

However, the engineering profession has singularities that do not belong to science and is in that topic that Figueiredo focus his attention in his article “On the historical nature of engineering practice” [6]. The prehistoric men and women used an engineering base on intelligent action; Greeks invested their time in theoretical discussions and therefore they left valuable achievements for science; Romans were more practical people, they had developed technical and project management skills.

Engineering education began with master-apprentice style and started developing into a more theoretical basis, having as a result, in the 20th century, a transformation from a practical education to a majority based on sciences education. Despite that, some complaints emerged from employers about young engineers' disability for communication, management and business context[6].

Four-Dimensional Model

The four-dimensional model, proposed by Figueiredo[6], presents the possibility to recover the profession identity by pointing to the plurality of engineering. On the sciences dimension can be find the dedication to theory and investigation, and engineers who opt to follow this path usually possess rigor, methodology and analytic reasoning. On the opposite side there is the crafts component, responsible for handling real world ambiguity and to get things done. The other two dimensions are Design, with systemic and holistic reasoning, and Human Sciences, for management, business and communication contexts.

TU Delft

Aldert Kamp, Director of Education Aerospace Engineer TU Delft, wrote in 2014 about important aspects to keep in mind when the subject is engineering education in a rapidly changing world[2]. His ideas value horizontal thinking, as opposed to a vertical approach, synthesis instead of analysis, teamwork instead of independence and engineering design instead of research. The accuracy and rigor should never be ignored, but neither should critical thinking and unstructured problem solving. Due to the nature of engineering and the outsourcing trend, Kamp states as essential features the systemic thinking, imagination, creativity and initiative. The information era and globalization bring a constant need for mobility, diversity, communication and collaboration. For university to be a context for integral learning, student engagement in a professional educational community, which promotes employability and lifelong learning, should be present.

CDIO Syllabus

Aligned with the UNESCO Four Pillars of Learning – learn to know, learn to do, learn to live together and learn to be – CDIO Syllabus [1] creates a rational, complete and consistent set of goals for undergraduate engineering education. Syllabus can be used to design new educational initiatives or can be employed as a tool for rigorous outcomes-based assessment process, such as that required by the Accreditation Board for Engineering Technology (ABET), and increasingly by other international accreditation processes as well.

The first section of Syllabus, Disciplinary Knowledge and Reasoning, is where the needed knowledge to master the engineering fundamentals can be found. Secondly, in a section called Personal and Professional Skills, are contained the three ways of thought most professionally practiced by engineers: Analytical Reasoning and Problem Solving, Experimentation and Investigation and System Thinking, and also personal values as Ethics, Equity and Other Responsibilities.

Section 3 Interpersonal Skills is divided into three sets called Teamwork, Communications and Communication in Foreign Languages. At last, Syllabus section 4 is Conceiving, Designing, Implementing and Operating Systems in the Enterprise, Societal and Environmental Context.

Knowledge Ecology

University students around the world protested against education marketization and bureaucratization[7], and about the weak presence of social aspects in the courses[8].

On the other hand, there are some universities with innovative programs and teaching methods, like Stanford and Harvard, where students are invited to freely choose their own projects, which usually are correlated with other study fields, which is also aligned with the current interdisciplinarity lived in engineering world[9][10]. The crucial topic is the shift of perspective upon students. This universities believe that students can not be seen as hollow boxes where professors will introduce some information. They are different of each others and with a lot of creative potential that will only flourish if universities give them the right context[11].
Nowadays, mindfulness is a trend between big companies like Google and General Motors. MIT and Harvard also have some contemplative programs in order to train the mind of participants. This is happening because science can now prove that meditation has some powerful implications in people’s brains, reducing anxiety and stress and increasing productivity, focus and memory, making this a highly important matter to be included in higher education programs[12].

Authors like Morin and Figueiredo[13][14] reminded the urgency for knowledge ecology, transdisciplinary approaches and appreciation of features like intuition and creativity, as a way to compensate the cognitive tendency for reductionism and compartmentalization.

III. METHODOLOGICAL OPTIONS

To make a connection between the epistemological basis of engineering and the curricular innovation, Figueiredo’s four-dimensional model is used as a starting point of historical nature, and a new one is created, adapted to improve the engineering curricula. It was achieved through the use of five-axis radar diagrams, which were used to analyze epistemological preferences of the CDIO Syllabus, Kamp suggestions and MEEC curricula. Taking Alfredo Bensaude’s approach into account (the founder of IST, who questioned alumni about the degrees and quality of teaching methods [15]), it was also addressed several questions to alumni and the answers show several interesting possible solutions for better education.

IV. CURRICULA COMPARISONS

In order for the renewed model to be aligned with the present literature, a fifth dimension named Human Skills is suggested, in which ethic, cultural and empathic abilities are developed, as well as environmental and social awareness, and educational skills. Aptitudes related to communication, management and business belong in the dimension of Human Sciences as far as Figueiredo’s model goes, but they are essential to Management and Entrepreneurship (ME) contexts, so this is a renamed axis. All other dimensions (Crafts, Design and Sciences) remain unchanged.

CDIO Syllabus and Kamp suggestions were made in order to compensate science-orientated engineer education, and because of the Sciences dimension is under-represented.

CDIO Syllabus

In a Syllabus appendix[1] there is a set of detailed skills and competences that should be developed in engineering students. It was through the analysis of that document that the following graphic was obtained:

Graphic 1: CDIO Syllabus epistemological model

CDIO Syllabus highlights student Management and Entrepreneurship skills, in order to be able to communicate with clients, public or institutional entities, and also to be aware of business concepts, strategies and to have a creative and innovative mind.

TU Delft

The following diagram was obtained by adding up the skills pointed by Kamp in relative five axis model.

Graphic 2: Epistemological Model of Kamp Suggestions
Kamp is a keen supporter of Human Skills in engineer education, as he believes it is the only way to create good solutions for world problems and to prevent an automation of engineering abilities, which would lead in the end of the profession.

MEEC

Now, in a more specific context, the epistemological inclinations of the MEEC course are analyzed. This work is more targeted toward the second course period, the last two years of specialization, because the purpose of the first three years is to create a solid scientific base for engineering so, for definition, it is, mainly, Sciences dimension. In order to achieve a ‘fair’ evaluation, the courses taken into account were ones finished by the author. However, the institution and MEEC degree identities tend to be preserved, regardless the chosen courses, so is a reliable analysis.

The timid representation of Management and Entrepreneurship components and the absence of Human Skills developing courses shows a gap between MEEC curricula and international trends for engineering education.

Survey

In this survey, a set of questions were addressed to alumni: Which changes should be introduced in the course? Which subjects should be introduced? And removed? Which practices should be explored?

Alumni unanimously condemned the deep theoretical approach in most of their teachers, asked for more practical exercises and complained about the lack of connection between subjects and the real world. They suggested more flexibility on the choice of subjects, professional internships integrated in the course, more projects and market oriented subjects. Another aspect alumni referred was a weak pedagogic teacher motivation.

V. CURRICULAR PROPOSALS

The first proposal is aligned with a method already used by TU Delft and suggestions from alumni: to increase more freedom on the choice of subjects in the last years so that students can enroll in a master area more related with their preferences. If a student enjoys investigation, he should be able to learn in-depth subjects of his interest and learning how to write articles. On the other hand, if the student’s personality claims for working in the market, the student should have subjects that stimulate project or management skills. Regardless of the choice, there would always be present a common core, dedicated to critical reflection on technology in order to develop social, environmental and ethical awareness.

It is proposed four course units that would have a greater impact if the method was done by case studies, by inviting important entities to speak about the subjects and by asking students to do projects that they are passionate about, instead of traditional exposition of theory.

History and Culture of Societies and Engineering would be an opportunity to develop skills of empathy with other cultures, of understanding the engineering mission and capacity to work with different cultures and also to understand that huge steps in science and technology were achieved thanks to intuition.

The second suggestion is Cyberspace Safety and Legislation, where students would understand how to protect data and distinguish safe and dangerous software, and would also develop sensibility for ethics and law in the cyberspace.

The more serious failure in the MEEC curricula, through the optic of the 5D model, is the Human Skills component. In order to be able to communicate or to manage our lives and our work is essential to discriminate our feelings and thoughts. Based on the Google program, a curricular unity entirely dedicated to Emotional Intelligence is proposed, where social and emotional skills are developed through meditative exercises and debates about self-awareness, self-regulation, empathy and interdependence.

The last one is MEEC Portfolio II, and it would be where students could acquire oral, written and digital communication skills in a formal and informal manner, where they could work out their rhetoric capacities and

![Graphic 3: MEEC Epistemological Model](image)
have lifelong learning.

Like the alumni said, more practical approaches are necessary in engineering education. So an integration of transdisciplinary projects in MEEC curricula is proposed, where students would choose what they want to do and where it would matter if the student was passionate about the subject of the project.

Another proposal is to stimulate students to do professional internships and are presented two options for that: students that preferred a more practical masters program could have an internship as a basis for their final course assignment, instead of the current compulsory investigation-oriented thesis; the other suggestion is to make students answer an annual self-assessment questionnaire, in order to determine if they are developing skills from all engineering dimensions.

Nowadays, collaboration and empathy are valuable skills for the engineering profession. In that way, it is suggested to establish fostering spaces for students to help each other, developing a sense of union and training their educational capacities.

The interdisciplinary dimension is enriching as long as there are contexts for technological, social and political debates and for cultural and artistic experiences. I propose a delegation, composed by students, responsible for organizing this kind of activities, in order to achieve not only a scientific and technical, but also social, cultural and human learning experience.

**Comparisons**

In order to demonstrate how the proposals presented are effective to transform the second cycle of MEEC in a complete engineering program, a radar diagram contemplating the suggestions made in the previous chapter is presented.

![Diagram of MEEC with suggestions epistemological model](image)

**VI. CONCLUSIONS**

This work has proven the importance of the engineering education debate, not only because many authors and universities are focused on it, but also because of the students complaints and the decrease in searching for engineering courses nowadays.

The 5D model can be used in any engineering course, but, taking into account this rapidly changing world, it should be subject to continuous updates.

The survey answers demonstrated how fruitful it would be if the institution took into account the students opinions and suggestions. This inquiry should be done every year and the structure of courses should be more flexible in order to have opportunity to implement some of these ideas.

The proposals presented should be taken as inspiration, in the hope that MEEC educational managers reinvent or maybe even implement some of them. As such, there are hopes that this work rouses will and initiative, so that the institute could join the international trend for a more complete engineering education at all levels: scientific, technical, professional and social.

**VII. REFERENCES**


