EDUCATION IN ENGINEERING - INTERDISCIPLINARY APPROACHES REQUIRED

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Abstract.
Modern engineering courses are preparing highly skilled professionals, who are able to cope with a wide variety of engineering challenges. Nevertheless, some of society's problems which need to be solved by engineers involve aspects related to other areas, such as human perception, psychology or physiology. Examples can be found in biomedical engineering, sound engineering, food science, image processing, and many other fields. Unfortunately, engineering students, and also professionals, often encounter difficulties in analyzing such multidisciplinary concepts adequately and seek specific professionals for collaboration. This is often due to a lack of the integration of different areas at the university level, making the student prone to acquiring a limited perception. This article will show the importance of the integration of a at least multidisciplinary point of view, at least at the basic level, on the curricula of engineering courses, regardless of the type of engineering. Examples, mainly from other countries, show that this is possible, thus preparing engineers to cope with problems that involve aspects such as human psychology, physiology and perception.

Keywords: *education, engineering, interdisciplinarity, multidisciplinarity, philosophy*

1. INTRODUCTION

Engineering is very often seen, especially by non-engineers, as a science of number-crunching and many engineering students and engineers believe that engineering do not need to be concerned with anything other than numbers, measurements, numerical models and so on. Many engineering students, at all stages of their courses, and also lecturers, often do not recognize the value of non-engineering aspects and knowledge to engineering. Bazzo *et. al.* (2008) attempted to ascertain the reasons for such misconceptions in Brazilian education and their book can be considered as a milestone in the analysis of this issue in Brazil. They pinpoint some interfaces of interaction between engineering and the humanities, but concrete examples are scarce.

This article analyzes, in addition to the work of Bazzo and colleagues, the situation in Brazilian universities from the point of view of an engineer who graduated in Germany with a doctorate in engineering obtained in Brazil and a philosopher who graduated in Brazil with a doctorate in philosophy obtained in Germany. A comparison between Brazil and Germany reveals that the gap between engineering and other sciences is very large in Brazil while it is almost nonexistent in Germany.

The section following this introduction will discuss the interaction between engineering, human and exact sciences. This is based on some examples from history, engineering, philosophy and the introduction of some ideas from German universities. Generally speaking, it becomes evident in the current article, at least to the open-minded observer, that many projects and works in engineering, if not all of them, involve aspects and concepts from sciences other than engineering, such as human and natural sciences.

But even at a level usually associated with pure engineering there are a large number of interactions, especially when engineering is concerned with products made for humans, intended to serve humans or intended to be used by humans.

On analyzing the current situation it can be noted that the level of insertion of inter- and multidisciplinarity[1] into engineering courses is still very far from reasonable. As a solution for this dilemma a two-stage approach toward inter- and multidisciplinary education in engineering is proposed with the assistance of a third author in the last section.

[1] For a definition of the terms multidisciplinarity and interdisciplinarity see for instance Ertas *et al.* (2003).

2. ENGINEERING, NATURAL AND HUMAN SCIENCES

Probably the biggest gap at Brazilian universities is between engineering and human sciences. It is very common to hear engineering students voice queries regarding subjects which a student of human sciences, such as philosophy, psychology or geography, in Brazil usually belonging to the human sciences, deal with on a daily basis.[2] In the same way, philosophers do not usually understand the way engineers think and consider them as being machines that crunch numbers all day long, not being able to grasp abstract concepts. This point of view, not at all justified, but understandable to a certain point, can be explained by the traditional division of schools and universities in Brazil, where biological, exact and human sciences are spatially separated. In addition to this physical separation there is also a very strict separation in terms of thinking. This separation, principally into human sciences, exact sciences and engineering, is already implemented in basic education in schools and maintained throughout the examination system through which students gain access to the universities. It is probable that this, to a certain extent unreal, separation in school contributes significantly to a misunderstanding between students of engineering and students of human sciences, e.g. philosophy, and to the occlusion of certain aspects which they have in common.

The separation into exact or natural sciences, engineering and human sciences is not a phenomenon exclusively present in Brazil. In German universities one can also find a faculty[3] of mechanical engineering, a faculty of electrical engineering, a faculty of medicine, and so on. There are even universities that are extremely focused on engineering, such as the Rheinisch Westfälische Technische Hochschule at Aachen (RWTH), the Technical University of Berlin (TUB) or Munich's Technical University (TUM). In the case of universities concerned with all fields of science, let us call them integral ones, there is usually not a strict separation in terms of spaces allocated to a certain faculty, as is common in Brazilian universities. Engineering students at Berlin's Technical University for instance attend classes in nearly every building of the main campus, as shown by the red color in Figure 1. And students form Berlin's University of Fine Arts (orange buildings) will use the same university restaurant (brown) and the same open spaces.

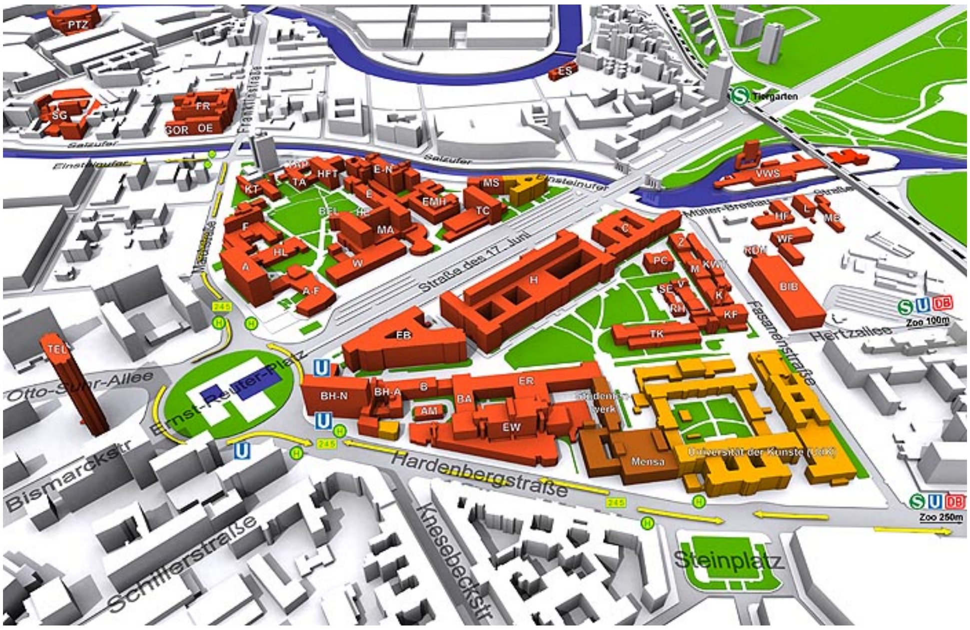


Figure 1: Main campus of Berlin's Technical University.

This division present at Brazilian universities also gives rise, at least at the university level, to comments such as 'the rich' and 'the poor' part of the university. And even technically-orientated universities, such as RWTH or TUB, maintain, not always without being questioned, at least some courses in humanities, sometimes for historical reasons. These courses have been proven to enrich of the portfolio, instead of being superfluous, counterbalancing the weight of engineering. In fact, the Technical University of Berlin is a reference not only in exact sciences and engineering, but also in human sciences, e.g. philosophy and psychology, and in inter- and multidisciplinary research[4]. This results from the fact that interaction between researchers from different areas within the same university can be easily provided. The organization into different faculties does not impede the interchange of knowledge, activities in education and research or

[2] According to Piva (2008) this opinion is also evident in college students and, probably, among parents, due to weak or nonexistent teaching of philosophy at school. However, it must be considered that philosophy is also not usually part of basic school education in other countries, such as Germany.

[3] Faculty means here a administrative unit of a, commonly public, university.

[4] For instance for some of the major automobile manufacturers, concerning a variety of man-machine interaction systems.

human resources. The TUB faculty I, faculty of Human Sciences, for instance, has strong connections with at least three other faculties, bringing important contributions to the scientific research.

Nowadays, after the implementation of bachelor's and master's degree courses, Technical University of Berlin offers at its faculty for humanities (*Fakultät für Geisteswissenschafen* `http://www2.tu-berlin.de/fak1/`) courses in humanities more orientated toward the relation between culture, society and technology. The faculty of Mechanical Engineering and Transport Systems, certainly a faculty of engineering, offers on behalf of the Institute of Psychology a master's in Human Factors (`http://www.humanfactors.tu-berlin.de/`). Human factors research is concerned, for instance, with ergonomics and the behavior of humans in technical systems, e.g. an aircraft cockpit or the nerve center of a powerplant.

Figure 2: Human factors meet engineering, in the nerve center of a powerplant, an aircraft cockpit or in perception based engineering.

Also RWTH Aachen, Germany's biggest technical university, have a faculty of medicine, a faculty of philosophy and a faculty of economics. The Philosophical faculty is formed by eleven institutes, concerned with research and education on language, literature, education, philosophy, sociology, hstory and other areas. This interaction, common for German universities, appears to provide sufficient mutual understanding to avoid that engineering students, in general, would view philosophy as being of no use to society, even without knowing exactly what philosophy means. In this context, it must be stated that the first author of this present paper also did not know what philosophy really meant before meeting one of the other authors at the Technical University of Berlin (TUB) and starting to read about the topic. The fact that the Technical University of Berlin does not impose a strict separation of spaces associated with certain faculties also contributed to the meeting of the two authors, one an engineer and the other a philosopher in Berlin in around 2002 and to begin some initial discussions on philosophy and the exact sciences.

Reading Heisenberg's papers and memories (Heisenberg, 1979) on his discussions with Albert Einstein, Niels Bohr and Erwin Schrödinger, all of them famous scientists, it becomes evident that the exact sciences, e.g. physics and chemistry, on the one hand, and philosophy on the other, are not as far apart as one might think. On reading Heisenberg's memories, the first author of the current article also remembered the very first lecture in thermodynamics he attended at TUB. The lecturer, Prof. Dr. Arlt, an engineer with a doctorate in engineering, mentioned that engineering students and engineers should be open to thoughts and ideas from other areas, calling attention to the fact that in the past engineering students were obligated to participate in a so-called *studium generale*[5].

The above-mentioned discussions, the reading of Heisenberg and the comments Prof. Dr. Arlt certainly led to reflection on the relation between philosophy and engineering, or the exact sciences. This reflection was further reinforced by the specialization area pursued by the author during the final two years of his engineering course, which was acoustics, a science based on physics but concerned with human perception and other fields of science.

In this respect, one could argue that the situation in German universities should not necessarily be exported to Brazil and some may argue that there are a large number of aspects in engineering that do not need any knowledge from philosophy or other human sciences.

A historical analysis of the relation between engineering and exact sciences on one side and philosophy on the other may prove the contrary. Greek philosophers, who certainly interacted with scientists, e.g., by analyzing their results, introduced concepts that were then called logic. Logic is now a branch in philosophy and mathematics. Without logic computers would not have been possible and engineers would not have important tools such as CFD, BEM, FEM or others for numerical simulations. The interaction between different fields of science continued for several hundred years. One of the most famous engineers in history, Leonardo da Vinci was, similarly, as engaged in painting and the study of natural sciences as he was in engineering. Doubtless, his interest in so many different fields covering mathematics, engineering, anatomy, fine arts, architecture, botany, music and literature, together with his technological ingenuity, made him also one of the most important inventors and engineers of his lifetime.

[5] The term *studium generale* has two meanings. Traditionally the term was the name of a medieval university which was registered as an institution of international excellence by the Holy Roman Empire. More recently the term was adopted to describe non-obligatory courses at universities. The same is also described by terms such as *studium universale, studium integrale, studium fundamentale* and general studies.

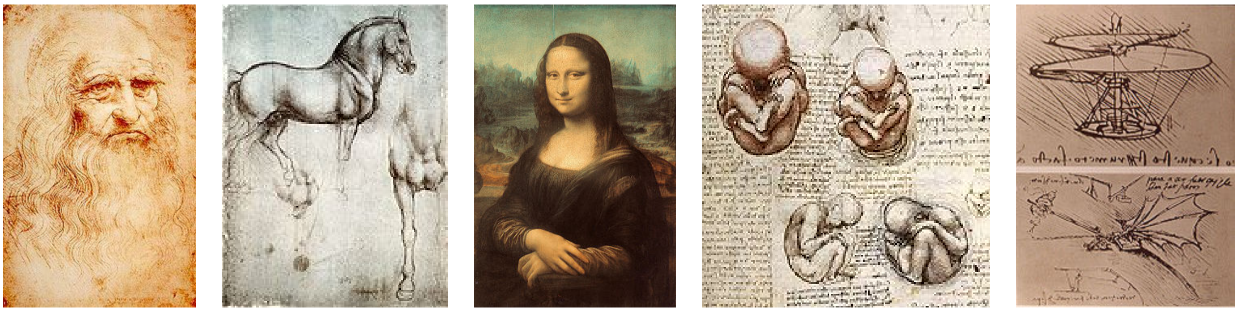
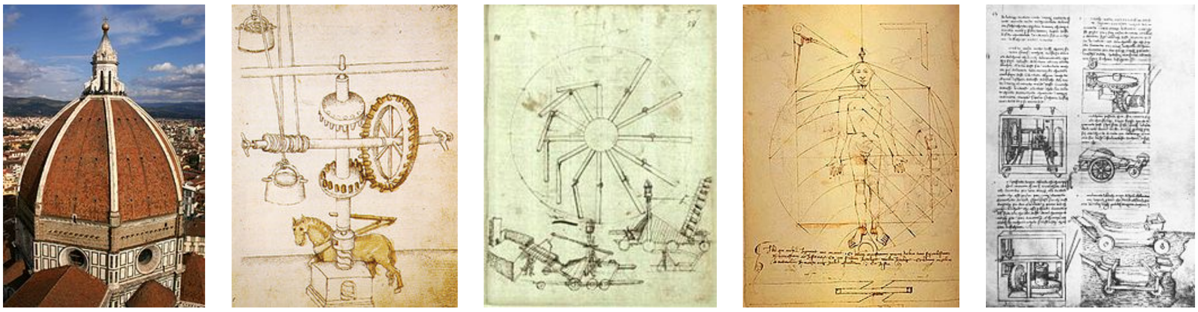


Figure 3: Leonardo and some of his most famous works

At the time Leonardo da Vinci lived, no mutually exclusive polarities between the sciences and the arts were considered, and Leonardo's studies in science and engineering are as impressive and innovative as his artistic work. According to an article by Bjerklie (1998) da Vinci was not the only great artist-engineer of the Italian Renaissance, other no less important names were Filippo Brunelleschi, Mariano di Iacopo and Francesco di Giorgio.



(a) (b) (c) (d) (e)

Figure 4: Famous works of Filippo Brunelleschi (a), Mariano di Iacopo (b-d) and Francesco di Giorgio (e)

Moreover, the famous G.W. Leibnitz, inventor of differential calculus, was not only a mathematician, as usually inferred by engineers. Leibniz also made major contributions to other fields such as physics, technology and philosophy. He also anticipated notions that surfaced much later in biology, medicine, geology, probability theory, psychology, linguistics, and information science. He anticipated Einstein's theory that space, time and motion are relative, contradicting Newton. He also wrote on politics, law, ethics, theology, history, philosophy and philology, and even occasional verse. Besides the great artist-engineers of the Italian Renaissance and Leibnitz many other examples of persons expressing genius who contributed to a variety of fields may be given.

In the late nineteenth century, important findings in science started to be published with great frequency in journals using the term 'philosophical' in their names, such as *The Philosophical Transactions of the Royal Society* or the *Philosophical Magazine*. Famous scientists, such as Newton, Thompson, Faraday, Joule, and others, published their results and findings in such magazines. According to Davis (2006) the very first paper published in *The Philosophical Magazine* carried the title "*Account of Mr Cartright's Patent Steam Engine*", certainly an engineering-based issue. And many other famous scientists such as Davy, Faraday, Joule, James Clerk Maxwell, or Rutherford published as, often frequent, contributors in the issues of The Philosophical Magazine.

Another relationship between engineering and philosophy worthy of note is the famous title of Doctor of Philosophy (Ph.D), which many engineers work hard for on postgraduate courses. This simply means teacher of philosophy, or teacher of science, when using the more modern interpretation of 'natural philosophy'.

On analyzing the situation in Brazilian universities (UFSC, UFSM and UFPA provide good examples), it can be observed that the most important factor that has contributed to the gap between human sciences and engineering is the fact that the students of engineering simply have no notion of what human sciences, e.g. philosophy, are concerned with. In general, one can affirm that Brazilian engineering courses lack education in terms of giving credit to other sciences. But an understanding of philosophy, at least at a very basic level, can provide an important contribution to the development of analytical and critical thinking, capacities certainly required by engineers. Philosophical education can enhance these capacities, because philosophy is basically reflection on presuppositions of problems and their possible solutions.

The same misunderstanding may, although less pronounced, occur between engineering and the natural sciences. Once again Leonardo da Vinci might be cited as an example of an engineer also capable of investigation into natural sciences. Nowadays, bionics or bioengineering are examples of an interface where engineering and biology meet once again in a very pronounced way.

The division in science we find today, contrary to the time of Leonardo da Vinci, can be associated with the fact that metaphysics and its search for eternal and total truth has lost credibility since Newton. From the XVII to the XVIII century there was a general attempt to unify science, which was considered to be impractical during the XIX century. Since then a process of fragmentation has begun, which continues today. It must be acknowledged that it is now impossible to find a general and unifying approach in science, but this does not pose a problem, because modern science should not be based on knowledge that does not change over time. On the contrary, it is accepted that knowledge, and therefore concepts, may change. In this context of changing knowledge it must also be acknowledged that science is always inserted into a cultural context, and interacts with it.

Ancient Greeks, for instance, believed that only things that do not change could be true. This led them to disregard nature and to search for purely logical principles. They also did not acknowledge zero, because Greek philosophy came from a rationalization of myth, and the concept of zero does not enhance the idea of creation but rather of the organization of the universe. The idea of 'from chaos to order' does not accept the conception of 'nothing' and therefore philosophers like Parmenides thought that the *Being* must be something and absolutely could not be nothing. The thoughts of Parmenides, and later Aristotle, gave origin to the principle of identity ($A = A/A \neq B$) which was, and still is, important in western thinking and is a basic logic relationship.

[5] ἡ δ' ὡς οὐκ ἔστιν τε καὶ ὡς χρεών ἐστι μὴ εἶναι, τὴν δή τοι φράζω παναπευθέα ἔμμεν ἀταρπόν· οὔτε γὰρ ἂν γνοίης τό γε μὴ ἐὸν - οὐ γὰρ ἀνυστόν - οὔτε φράσαις·	5 for truth is its companion. The other, namely, that *It is not*, and that something must needs not be, - that, I tell thee, is a wholly untrustworthy path. For you cannot know what is not - that is impossible - nor utter it;
III	III
... τὸ γὰρ αὐτὸ νοεῖν ἐστίν τε καὶ εἶναι.	For it is the same thing that can be thought and that can be.

Figure 5: Part of the poem of Parmenides: on nature. Original Greek text: Diels; English translation: John Burnet (1892), Source: http://philoctetes.free.fr/parmenides.pdf

This shows that even logic is not absolutely independent of historical or cultural context. Another example may be given for the exact sciences. Whereas for classical physics, in the historical context of the XVIII century, the universe was a thing organized by God in a logical manner, and thus describable by mathematics and logic, our understanding of it in modern physics is different. For modern physics, as described by Heisenberg, nature isn't something completely predictable and our reasoning must therefore include the acceptance of non-determinations. This is not only due to the complexity of things, e.g. the subatomic universe, but is also caused by the way we understand certain phenomena. One way to understand complex phenomena is the simplification of the phenomena by a complex model, an approach commonly used in engineering. In other words, engineers interpret nature daily by means of limited models, and in this way accept non-determinations.

For Heisenberg our interpretation of reality, e.g. with a model, also depends on our logical expectations and of the things we learn when doing so. In the word of Heisenberg (Heisenberg, 1979) : "*the progress of the science is brought into effect not exclusively by knowledge and understanding of new facts, but also by learning again and again what the term 'to understand' means.*

The exact sciences and engineering also search for objectivity and neutrality, but history shows that the contrary is true. After the explosion of the world's first hydrogen bombs a profound discussion started regarding the intended objectivity and neutrality of physics and engineering, and many physicists involved in the their development acknowledged at the time that such intended objectivity and neutrality does not exist. It was thus perceived that technical knowledge is not independent from cultural and ethical questions and that technical knowledge is always embedded in a context. Currently, stem cell research, research on implantable brain chips or proposed solutions for carbon dioxide neutralization lead to similar discussions. From historical and current examples one must draw the conclusion that technical solutions that do not accept ethical and ecological criteria are not only dangerous, but also less efficient.

It is thus interesting to observe that the enormous mutual misconception that exists between engineering and philosophy is much less pronounced or almost absent between physics and philosophy and mathematics and philosophy. This is most probably due to the very different concepts of education in physics or mathematics, where the student is stimulated to ask whether a concept he is studying is true or not, a thing the student of engineering apparently does not do anymore. Also, an adequate study of the history of engineering would lead a student to discover many of the facts described above, and it is very likely that he then would be more open to 'philosophical' questions.

In this context one must ask also what type of professionals are required. Do we want "*Brotgelehrte*", a term coined by the famous German philosopher Friedrich Schiller when giving his first lesson at Jena University in 1789 (Grigat, 2002), or do we want "philosophical heads"? According to Schiller, to the "*Brotgelehrte*" the studies only serve as a form of professional training, an inevitable, toilsome investment, that should amortize as rapidly as possible (. . .). In contrast 'the philosophical head', the scientist, sees science for its own sake, for the joy of the realization and in the light of the connection to a universal synthesis. Even if universal synthesis is no longer the aim of science, as discussed above, a university should be a place with aims of higher value than simply producing professionals ready for a certain job.

3. MULTIDISCIPLINARY AND INTERDISCIPLINARITY IN ENGINEERING

Beside the discussion on the relation of engineering, the exact sciences and the humanities, with examples from basic scientific research, one can also show that there are branches in applied engineering that are strongly related to concepts and aspects that are subjects in other sciences, such as human perception, ergonomics, logic, biology, anatomy and many others.

Traditionally engineering courses in Brazil are extremely focused on purely engineering questions and are trying to be fully autonomous courses. In Germany, to the contrary, there is a greater integration and interaction even between the students from different engineering courses. As fundamental disciplines in engineering, such as calculus, thermodynamics and the like, are attended by virtually all students of engineering in the same class, an interaction between students of many engineering courses during everyday university activities is facilitated, which is enhanced by the physical structure of German universities, which do not impose a strict division of physical space for different faculties.

In Brazil engineering courses, such as mechanical engineering, attempt to give a notion of everything that might exist in classical engineering. However, an analysis of current problems shows that the market increasingly requires special solutions and special types of engineers, able to cope with problems that not only involve tools from mechanical engineering or engineering at all.

In Section 2. man-machine-interaction has been discussed from a general point of view. Besides this point of view, which is concerned with insertion into a cultural and social background, there are other aspects that are much closer to elementary questions of engineering. Engineering must consider that many products and solutions, from very simple ones like a can opener to the most complex ones such as a space station in orbit, are subject to man-machine-interaction. Thus, aspects such as human perception, action, performance and others play a significant role in the intended use of such a product.

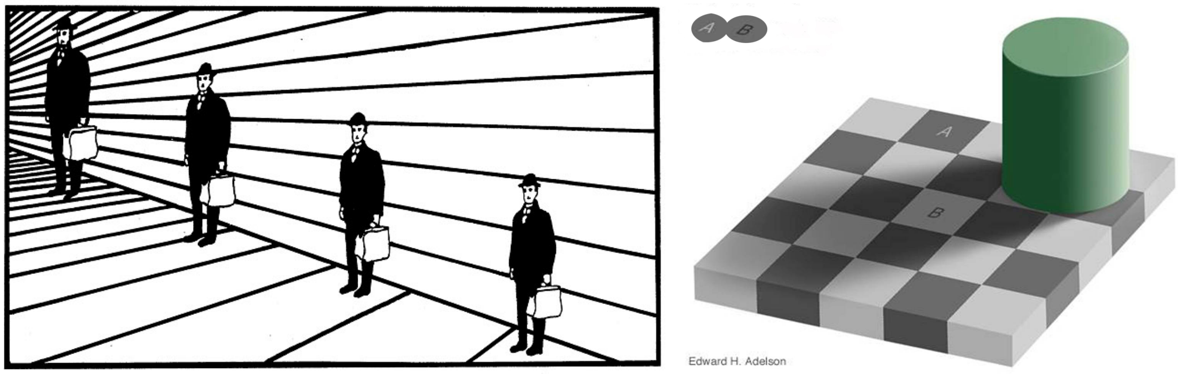
Therefore, the engineer, and not only the designer of the product, should have an understanding of how humans perceive a product by means of visual, haptic, or acoustical information and how humans use such a product, for instance, in terms of ergonomics. In some cases an engineer must also have a notion of human behavior in emergency situations in order to design adequate tools for the prevention of accidents or disasters. This is the case when designing break assistance systems, autopilots and many other systems for the control of technical systems.

3.1 Engineering for human beings - perception-based engineering

For this article let us consider the aspect of human perception and its relation to engineering. When optimizing printers for instance, one must know that image quality does not only depend on numbers of pixels per square inch, but that human visual perception is dependent on many other factors and is highly non-linear. The same knowledge is necessary when trying to copy human perceptive abilities for computer aided diagnosis of medical images. One must consider, for instance, that human perception usually depends on background information, as one can see in Figure 6.

Visual perception, as well as the perception of sound, taste and smell, is non-linear and the Weber-Fechner law describes this non-linear relationship between sensation and physical stimulus with a coarse approximation.

The perception of sound is studied in more detail in psychoacoustics, a discipline of acoustics that deals with concepts and knowledge in physics, mechanical and electrical engineering, psychology and human physiology. Acoustics and psychoacoustics are important aspects in engineering, because products are also perceived by means of their acoustical footprint. Modern automobiles and home appliances are generally designed to a certain degree with respect to their acoustical output. In automobiles, for instance, doors and trunks are modified to attend also acoustical criteria, in addition to criteria such as crashworthiness. This is because door slamming sound is an important contributor to the overall quality impression of a vehicle. But door slamming noise, and thus a 'good' or a 'bad' door, cannot be described by means of sound pressure or sound pressure levels, the latter a logarithmic magnitude derived from sound pressure and based on the Weber-Fechner law. Here, a broader perceptual approach is required, taking into account, for instance, the nonlinear properties of human hearing, such as pre- and post-masking in the time domain. Another interesting application of psychoacoustic knowledge, especially masking in the frequency and time domains, is the mp3 compression algorithm developed at the Technical University of Berlin (Brandenburg, 1999) .



(a) (b)

Figure 6: Two examples of the dependence of the visual perception of objects on background information: a) Physically, all persons have the same height, but background information contributes to the perception of different heights, b) fields A and B on the chessboard are perceived to be clearly different, A is clearly gray and B is clearly white. But cutting out samples of A and B shows that they have the some coloration.

Another important aspect to be considered when working with perception in general is the time-invariance of human perception. This applies to all kinds of perception of intensity, such as (intensity of) weight, sound, color or light, odors, and so on. This gives rise to the phenomenon of adaptation. Adaptation might split up into purely physiological adaptation (electrical impulses delivered by hair cells in the inner ear decrease with time and, similarly, the cells responsible for perception of light in the eyes send less information when stimulated over a larger period of time with the same intensity) and psychological adaptation. Both aspects must be considered when attempting to modify continuous stimuli, e.g. automotive powertrain sounds or interior noise in aircraft, or when designing signals that should be perceptible within such stimuli, e.g. warning sounds.

By way of these examples, the importance of an engineering approach based on an understanding of perceptual questions should have become evident. As many engineering students will later work with the conception, fabrication or commercialization of products and solutions to be used or operated by humans, a student of engineering should be introduced at least to the most basic terms in man-machine-interaction and should at least have the possibility to study psychophysics, learning about the most basic laws of human perception at undergraduate level.

Other examples of where knowledge from a broad field of disciplines needs to be incorporated into engineering solutions are bioengineering and geoengineering. The engineering of medical prostheses requires a basic understanding of human anatomy and some basic principles of human biology. Classical geoengineering, concerned with prospection of petroleum, for instance, similarly requires knowledge from other areas. Currently, geoengineering is also concerned with providing technical solutions for the problem of climate change, requiring a knowledge of biological processes.

3.2 The engineer and its products as acting elements in a society

Regardless of the branch of engineering, or even education, where the future engineer will be working, it has to be considered that the engineer will be acting in and interacting with society. Also, the products and solutions that are the fruit of his work interact with and transform society.

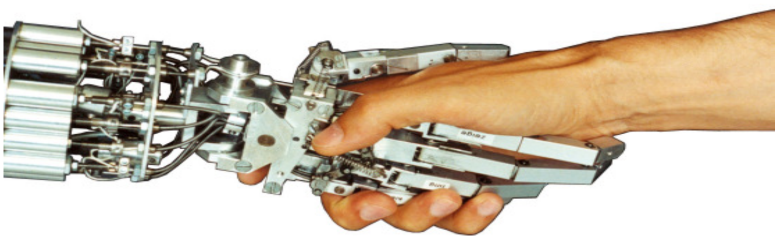


Figure 7: Symbolizing man-machine interacion

Even with a knowledge of where the interfaces with other areas of science lie, the engineer must learn to work and communicate fluently at these interfaces. Furthermore, the future engineer's abilities must be founded on ethical and socio-economical aspects which need to be taught.

4. A PROPOSAL FOR BASIC MULTI- AND INTERDISCIPLINARY EDUCATION IN ENGINEERING

In this paper it have been shown that applied engineering may require some tools and knowledge that is not part of the curricula of traditional engineering courses such as mechanical engineering or electrical engineering. Considering that such interfaces exist and that the solutions for current problems require that the engineer has at least a basic notion of the interfacing sciences, adequate education is required. In summary, a broader vision of a certain problem is necessary and the engineer should be able to apply knowledge from areas other than classical engineering.

These conclusions are not new (Ertas *et. al.*, 2003), not even considering engineering education in Brazil. In the case of Brazil, Pereira and Bazzo (1997) warned, more than a decade ago, of the need for interdisciplinarity. Nevertheless, few such aspects seem to have been implemented, or at least borne fruit, in terms of engineering courses. Particularly at UFSC, the university of Pereira and Bazzo, things have not really changed since then, and this is very likely the case in many other universities as complaints from industry show.

In order to complete the theoretical approach to the problem used by Pereira and Bazzo (1997) and also Bazzo, Pereira and Linsingen (2008), the current article used concrete examples of interaction between engineering, the exact sciences and human sciences and also concrete examples from applied engineering where interdisciplinary knowledge, thinking and action are required. The examples given, although many others can be found, may be applied in an educational approach in order to finally achieve a change in the perceptions of engineers and engineering students.

To achieve this, different approaches may be taken. One possibility is the implementation of so-called 'transversal academic projects', where a complex theme is treated through joint efforts from different disciplines. Naturally, this requires the search for an adequate theme, the elaboration of an integrated work plan for all participating disciplines and a considerable integrating effort from the lecturers.

Another approach, more independent from the existence of a complex theme and the joint efforts of the different disciplines, will be proposed herein. This approach, divided into two stages, is based on experiences from some European universities, especially those that have implemented the "*Freiberger Erklärung*" (Manifesto of Freiberg). Even through a more generalized education in terms of classical sciences certainly has its appeal, see for instance the course at St. John's College, Annapolis, Maryland, USA (`http://www.sjca.edu/`), the proposed approach is not intended to generalize the education in engineering or to weaken the fundamentals of engineering. Instead, education in engineering should be carefully enriched.

The first stage is certainly related to the discipline 'Introduction to engineering', already implemented in most, if not all, undergraduate engineering courses in Brazil. It is considered of essential importance that the students not only learn about the things an engineer will do, but also learn to be open to ideas and points of view from other areas of science. A short introduction to the history of science for instance, citing examples such as Leibnitz, da Vinci and Newton, can be used to show the relation between engineering, natural and human sciences. Thus, the students will learn to accept knowledge and research in areas other than engineering as valuable for their own personal and professional development, both during after the engineering course. One may argue that the concepts of the exact sciences and philosophy and their interaction, as demonstrated in Section 2. and 3. should be taught in schools and that there is no space to do this in university. Even though some schools do so, their success is rather limited (Piva, 2008). Another may argue that there is no space available for such 'experiments'. But often an analysis of the curricula of engineering courses shows that some concepts introduced in the first semester course 'Introduction to Engineering' will be repeated in other disciplines during the semester and other concepts will be entirely forgotten until being of use to the engineer. By way of a thorough analysis of the needs of the first semester students in order to understand the objectives of the course and the scientific methodology, some space could very probably be made available for an introduction to the relation between engineering and other branches of sciences.

If the introduction to engineering given at university level enables the student to be more conscious of the relation of his particular area of engineering to other areas, he may learn to acknowledge that areas such as philosophy, sociology, biological sciences and others have contributed, continue to contribute and always will contribute to the development of society and science, and also to the development of engineering. Thus, the objective of the first stage of the proposed approach would be reached. An enriched vision of engineering and science will certainly aid an understanding of the most of the concepts to be studied during the engineering course.

During the undergraduate course the future engineer is usually identifying the subarea in which he would like to act professionally and this may include areas where knowledge on subjects not covered in engineering courses is important. It is therefore desirable to stimulate the student to seek such knowledge and to offer disciplines that teach it adequately. This is where the second part of the proposed approach comes into play. It is proposed that the university should offer such possibilities in the last semesters of the engineering course, not as part of a predefined curriculum, but as a collection of options from which the student, almost an engineer by this time and sufficiently conscious about his professional career, can choose, representing a wide variety of disciplines offered by different departments of the university. Unlike current practices, the disciplines available to the engineering student should not be restricted to engineering disciplines, but should include disciplines offered by departments and faculties other than those of engineering or technology. In addition the student should be encouraged not to choose disciplines from engineering, but rather to search knowledge in other areas, according to his interests.

This certainly complies with the idea of a *studium generale*, as offered in some European Universities. In this way, the university, not only the department or faculty where the course is offered, should offer a variety of disciplines from different areas. Naturally each of these disciplines should be given by the respective departments, but they will be offered by the university itself and therefore accept students from other departments. Thus, the interchange of students between the courses will also provide an interaction between the different areas, departments and courses, this interaction being of fundamental importance for the actions of intended professionals and also for social interaction, as shown in the previous sections.

The proposed second stage, with its possibilities to choose disciplines from a wide variety of options, and the inclusion of disciplines related to human sciences, will also contribute to the development of knowledge and abilities required for advanced studies, such as post-graduate activities. In such activities, as well as in professional life, multidisciplinary knowledge and abilities acquired at university must be continuously updated.

5. CONCLUSIONS

In this article the relation between engineering and human sciences was discussed, starting from the perspective of Brazilian universities on the one hand and German technical universities on the other hand. It was suggested that the location of human sciences and engineering in different physical spaces in Brazilian universities contributes to a gap between these areas, which is not justifiable. An analysis of historical facts, from Parmenides through Leonardo da Vinci to Heisenberg, showed that human sciences and engineering have several factors in common and that strict separation of the disciplines is therefore not appropriate. Through several other examples it was shown that engineering is often concerned with man-machine interaction, which involves, for instance, human perception and psychology. The importance of the integration of an interdisciplinary, or at least multidisciplinary, point of view on the curricula of engineering courses, regardless of the type of engineering, was discussed. Finally, a two-stage approach to such integration based on the idea of the *studium generale* was proposed.

6. REFERENCES

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