Knowledge in Engineering: A View from the Logical Reasoning

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***Abstract*—It is accepted widely that the work performed by the engineers fundamentally consists in detecting, identifying and solving problems, but most of the educational systems and related subjects seem to ignore the need of educating students for the development of logical reasoning in order they can properly perform this function. This article reviews the concepts of logic, abstraction, problem solving and logical reasoning, which are described and analyzed like a functional need for engineering and its professional application, by considering the requirements of today's Information and Knowledge Society, and making a relation fitted to the educational processes of current and future engineers.**

***Index Terms*—Knowledge, logic, engineering, logical reasoning, problem solving.**

I. Introduction

The work of engineers mainly consist in detecting, identifying and solving problems, but in this century, when the social evolution have leaded us towards the Information and Knowledge Society, this function has also become a comprehensive part of the work for most of professionals. Human beings lives in the middle of problems, from basic ones to the most complex, when these problems join together in social conglomerate they increase their complexity. This society, as never before through history, deal with complicated challenges that it must understand, analyze and solve to ensure its survival and to project the survival for the coming one [1].

To meet this requirement the information systems must maintain a permanent communication with reality, in order to prepare the future professionals for they perform themselves properly when they face reality. This objective has a basic feature: *the need for developing a logical thinking and a proper abstract interpretation, in order to achieve the efficient and effective solution of these problems*. When educating engineers for the 21st Century this need is a basic component, because engineer's performance will be greatly ruled by proper interpretation of problems even taking precedence over the solutions they give to them.

Engineering practice can be described like giving practical and optimal solution to physical problems by means of a logical, systematic and comprehensive analysis of scientific facts. However, the number, the complexity and the lack of clarity of they are so wide that to achieve it sense and invariability must be added. These components are active parts of personal intuition, which is considered like an art completely related with logic sciences and abstraction. Sense is recognized like a component of engineering practice, because the efficiency and effectiveness of the proposed solutions also depends on a set of intangible factors.

Engineering is a field of applied sciences that lies on the basis of mathematics, physics and chemistry. In order to their products respond to the social needs, these professionals must acquire a wide comprehension and functional of processes, as well as a proper control of technical skills [2], [3]. Among other skills, they must achieve a profound comprehension of abstract concepts, developing ability for algorithmic thinking and a proper logical reasoning [4], [5]. Different researches indicates that the ability for logical reasoning depends on the general intellectual ability, and that students that reason logically and which solve properly the problems tend to get better results in any scientific subject [6], [7]. Therefore, education in engineering, since scientific field, must include logic, abstraction, mathematics and problem solving at all levels; and besides, because since engineers is expected that they master and apply properly the logic thinking. Paradoxically, a few university programs around the world meet this educational need [3].

Engineers must develop the logic-interpretative and abstractive capabilities to achieve that thinking, because their educational objective, like the educational objective of scientists, is to be logical and systematic in their reasoning. However, again, almost none of the current educational models include these topics in their processes. The success of 21st century engineering depends to a large extent on the fact that students can live together, since their first years at the university, with logic and logical reasoning in order they could give them potential and could apply both of them properly. Developing this ability is not a process at last moment before becoming professional; the process must start from the school and gradually acquire maturity as increases the level of structure and complexity of the problems.

II. Logic in the Education of Engineers

Currently, in most of the institutions the educational processes are overloaded of information that teachers repeat in the classroom, most of the times based on a particular book**.** This do not contribute to the educational objective of developing a logical reasoning in the students, because they *learn*, or more precisely they get *saturated* with a number of equation and concepts which applicability is almost

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non-existent. In this way students acquire abilities for solving repetitive tasks and simple problems but they do not develop a reasoning for logically solving problems with some degree of complexity, because this type of problem contexts are not tackled in the classrooms, despite of the fact that teachers could have the knowledge for doing this. For instance, an engineering student takes a number of math courses during his education process, but because the course plan is not integrated, the equations and concepts he learn have no value when he really must solve problems which require integrating this and other fields of the university program [8].

Therefore, we require educational processes which involve logic in a parallel and integrating way throughout the entire plan course of the university programs. In engineering, knowledge without practical application is a mere, as called by students, academic *stuffing material* for completing the number or course credits. The problems of this century require innovative, creative and challenging solutions, but this could be possible if logic is *teached* in a different way and the most is made from logical reasoning which must have the students, to give it potential by using experimental, practical and integrating processes, but most important of all they can be applied in real life. The situation is critical but not desperate. From the experiments of Susanna Epp [9], if educational processes are slightly modified it could be possible to change drastically the comprehension and reasoning levels. During her research she asked the students not only solving the proposed exercises but also she asked them to add short comments. At first these comments were opinions for the teachers, because they were related to the fact that students did not understand the material, but later the comments become the basis for designing the comprehension and interpretation processes which they could use when studied individually. The results were promising because the students that participated became logical critics, even with their own work and for the work of their classmates.

A proper education in logic allows developing and applying creativity processes. This relation can be understood through a comparison between the functioning of brain, during the thinking process, and this of a computer when calculating [10]. When a person thinks he store his remembers like related information in the same way that a computer stores data in files for its subsequent retrieval. When some information is needed, both brain and computer search for the data in the stored files and order them logically to transform them into information, and if they collect new data they assign them easily to the respective file. This task gets more complicated when the required data are not stored or when they are corrupt. The computer only will say that it does not find related information or that it cannot processing because any hardware or software error; on the contrary, the brain uses creative capability for correlating, combining, mixing, testing, abstracting and representing data from other files, and it will try to respond the request by applying an algorithm like this shown in Fig. 1. It is clear that to achieve this person needs to have had a proper education in logic, if not he will respond like a simple computer: *they didn't teach me that*.

Problem solving logically is a search process through known data, information is added to data in order to complement the basic file of this particular subject. For example, to solve a math problem the brain applies logical reasoning: first it searches for the file *how to apply mathematics*, until it founds the information related with the problem, but if it does not find the information the requirement itself guides brain to make science in order to find and discovering information, thus it will fill the blanks it has in its files. This process is possible because the person has been educated in logic and he has developed a reasoning that allow him following or constructing a road, through steps carefully structured and taking care that all of these steps is supported firmly on previous knowledge [4].

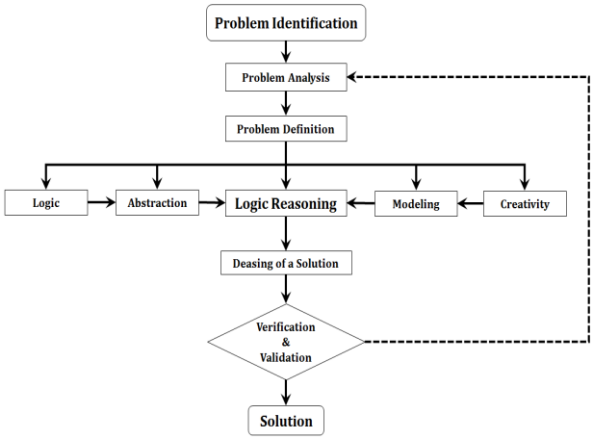

Fig. 1. Creative capability for problem solving.

The skills and engineering principles on which are educated the engineers must be guided by means of logically related processes, and it cannot be performed at the last moment, that is to say, at the university; it is a comprehensive process that starts from primary school and that gradually develops as the student progresses through the different educational levels. In higher education the process structure becomes finished by means of more sophisticated applications, but if the student still does not have developed that ability, is very probable that him drop his university program and searches for another one in which that lack of skill does not become so evident [1]. This is because a big extent of engineer's work requires calculation and analysis, tasks which greatly depends on logical reasoning, therefore, these professionals must be logical for achieving success.

III. Logical Reasoning

This reasoning is a rational process of brain by which people find correct conclusions, but it is one of the learning concepts being the most difficult to achieve [11]. It is achieved through the development of the logic capability and a rational relation between the different factors involved in every particular situation. Logical reasoning depends mainly on the skill for structuring and formulating logical procedures and applying inference processes using a precise language.

Smith [12] describes in the results of his researches that exists a relation between the concepts of reasoning and logical thinking. He considers the reasoning like a common definition of thinking, which sometimes is used like a synonym in the broad sense of the word *thinking*.

Additionally, he explains that sometimes reasoning is used for: 1) justifying a conclusion that have been reached and 2) persuading someone to accept a conclusion. This implies that this term could be used to talk about the past, like the said above in 1, or about the future, like in 2. Smith emphasizes that thoughts or actions can be strongly tied by *reasoning chains*, which acts as linking elements. However, he also says that reasoning skills comes with the comprehension of that one is trying to reason about, for this reason is needed logical capabilities to interrelate both issues.

Nigel [13] considers that logical reasoning can permit constructing effective arguments to respond to the problems. Another question is that people belonging to different cultures can reach dissimilar conclusions, because they reason in a different way [1], [12], but Smith [12] states that this difference is not because they belong to different cultures and have different skill levels, instead of that this is because they have different visions of the world, according to the way they have been educated. Because the culture is the way of rationalizing the world, but is logical-interpretative ability by which the world is transformed.

When performing a profession differences can be created in logical reasoning [12], for example, engineers could reason in a different way than doctors or philosophers; even within the same profession reasoning can vary, because of the position from which reasoning is made. This is researched by Smith and he concludes that these differences have as basis a number of factors, among which we found culture, principles, roles, tasks and personalities, but above all, the ability for understanding problems by using logical reasoning. However, when the logic issues cause conflicts with individual principles, usually the principles have the supremacy, because they are stronger than logic; although this do not happens very frequently because people come from different educational processes and therefore they reason differently. Smith states that the only items that people must develop in a better way than logic must be these of principles and common sense, but currently it seems that education will be guided for using these items to nullify it.

In the same sense, the principles and the common sense are consequences of experiences accumulated by people and therefore they create inferences and disagrees in logical reasoning, in part because the different points of view people have for making decisions and reaching conclusion, and because they are the result of approaches about the world that are not governed by logic rules [12]. However, the fact of accepting a conclusion is itself a reasoning approach. Although Smith emphasizes that logic can't be a leading principle supporting all the decisions and conclusions about the world, Baron [14] suggest that it would be more useful if logic had a most relevant role in daily logical reasoning, that is, the ideal situation is to put the brain to work before putting to work the mouth. This would be very valuable for an engineer, because if he is educated to reason logically, surely he will apply the processes depicted in Fig. 1 before presenting solution to daily problems.

Therefore, logic would be included since the early stages of educational process of all students. The use of simple logical relations to express the use of some simple expressions allows students linking logic with activities and daily dialogues. It would be convenient structuring an elementary logical system embedded in the program course plan, in such a way that students starts developing or giving potential to their logical-interpretative capabilities from their early years of age [15]. But this is a matter that seem not to consider the current *education systems*, in which come first issues like principles that, although important and necessary, do not have importance if are not rationally understood. Educating in logical thinking and developing it must be a well-planned objective. Engineers need logical thinking for making decisions which allow them solving social problems, and in the same way researchers like Wason and Johnson [15] have proposed sophisticated methods by using logical descriptions, which can be relevant like simple logical relations in the dialogues or daily activities of students. These proposals would be considered, because they promote the simplicity and give importance to logic in the daily contexts of educational processes; and besides, it could be used for developing the logical thinking in the students, obviously through activities that catch their interest.

A. Reasoning and Logic

Logic is related to the standardization of thinking laws and is focused in the formulation of normative theories for describing the way the people would think. Cognitive psychology also deals with thinking, but is almost exclusively focused on descriptive theories that study *how* people think in practical situations, not considering if it is correct or not. The two theories above mentioned have developed themselves in an isolated manner and not having a direct known relation, however during the last years psychologists have developed the *dual-processes* theory, which can be understood like combining descriptive and normative theories [16]. Traditional descriptive theories are focused on intuitive thinking, which is associative, automatic, parallel and subconscious, while the normative theories, on the contrary, are focused on deliberative thinking, which is based on standards, requires efforts and is serial and conscious. Based on these principles we can argue that logic is a matter related with dual-processes, because it combines the intuitive thinking with the deliberative one, but that is not only related to thinking in abstract but also symbolize the thinking represented by sentences, and the thinking like the manipulation of statements for creating new thinking. Therefore logic, from this perspective, can be considered like the standardization of human thinking [17].

Logic and reasoning are cognitive skills by means of which can be reached solid conclusions for making decisions and problem solving in daily life. People reach conclusions based on the processes performed on the information they collect through senses. However, despite of the fact they apply constantly both skills, even though many times they are not conscious about they are doing. When they receive stimulus and apply logic to achieve correct conclusions, they are performing the mental task of reasoning, however, unlike instinctive decisions, that is, those made from the basis of emotional responses, cognitive reasoning tend to require longer response times [18].

Logic and reasoning are closely tied, and frequently they work together to help people to *work* correctly, and without these two cognitive components it will be difficult for people

rationally controlling their lives [17]. Both, logic and reasoning are part of mental processes and are necessary for mental processes that engineers apply to solve problems, and given that engineers' environment is constantly bombarded by complex stimulus involving many variable features, they must develop the logic-interpretative ability for answering to these requirements. Education on these concepts will help engineers for developing the required skills for facing the dynamical environments, that is, engineers need education in logic and other concepts for developing logical reasoning in order to identify and to understand the problems, but also for solving them. When engineers reach this development they get the ability for combining multiple cognitive processes, like memory, attention, process speed and flexibility that they need for recognizing patterns, giving conclusions and making decisions [19].

B. Logical Reasoning and Problem Solving

Problem solving in engineering can be funny, but also can help for determining the direction of engineering programs, because when doing this the students must test their logic and their reasoning abilities [20]. Reaching a strong critical thinking and proper logical reasoning skills will help engineering students for making better decisions and for solving problems more efficiently. In any case, when engineers face problems they must be sufficiently prepared, they must have developed their common sense and enough abilities for distinguishing between bad and good evidences [21], and they must be able to extract logic conclusions from those evidences. Among other things, they must consider:

1) Many issues that put to the test common sense appear like scenarios for making decisions. Although the situation can be strange for the engineer and the questions could seem to be complicated, the response is found when remembering how to divide the problem in its part and how to think logically about this situation. Common sense is an important feature that must be developed by these professionals, and frequently common sense is represented like an instinct before a situation to which it responds taking the first offered by the reasoning. But consciously it produces a process that remembers it what is right and what is wrong, for this reason is convenient that he learns to listen also to this part.
2) Often, deductive logic tests evaluate the skills for inductive reasoning, for this reason they are useful for evaluating if a strong evidence of a deductive argument is believable and reasonable.
3) Contexts faced by engineers put to the test their reasoning skills and in some cases they will need drawing conclusions from evidences. A necessary skill for answering to this is ensuring a correct response through elimination processes. Therefore, considering the evidences given by the contexts, engineers must be able to eliminate automatically some of the possible answers.

IV. Logic Reasoning in Engineering

Generally, decision making involves the sensorial engine, perception, cognition and the expression of results in the brain [20], and very frequently feelings, perceiving, thinking, remembering and reasoning are performed in an adaptive manner, consciously and unconsciously. When engineers face problems or situations in daily life where they must make a decision, they need to apply logic and logical reasoning to reach the expected results, therefore is important that their educational processes would be influences by processes tending to develop both abilities.

In general, logic is based on deduction, an exact inference method which studies the right reasoning constituted by language and reasoning [21]. Logical reasoning implies deciding what to do for achieving success based on emitting one intention. These decisions are structured through a set of viable actions, a set of restriction and a set of possible ways to take, and the decision consist in finding the better sequence of events, admissible and acceptable, and actions which permit passing from *intentions to actions*, and for achieving the best results each step between thinking and action must be given using logic and logical reasoning. Often common sense is applied for decision making processes, indicating what to do, regardless of one's thinking, and it is a key factor for engineers' performance, because although the basis of their decisions always will be the logic is possible that common sense could help them for facing the complexity of real world and give them a direct and fast access for making critical decisions.

Another important issue appears when these engineers have to face moral matters, because many times they must act based on instincts and must wait for reasoning about what to do, in order that their actions would be more coherent with their thinking. Before difficult circumstances or these being very important, engineers normally have three options for decision making: 1) if the circumstances of the situation can be compared to other they have faced before, 2) if the problem is different than those faced before and 3) if some features of the situation have been already faced with success. In any of the options listed above the engineer must combine the previous success in order to reach the expected results and in order to solve the current situation. Engineers need applying logical reasoning for acting because is not possible being an expert in any situation [19]. Other important aspects for logical reasoning are:

- *Philosophical logic.* Because of its influence on the life of persons and its contributions for the general solution of problems. Among other things it helps for analyzing concepts, definitions, discussions and problems themselves, and it contributes to the ability for organizing ideas and issues related to each situation.
- *Communication skills.* Because the way how a person express his ideas greatly determines the understanding of the other people about the solution he has proposed. The ideas must be presented by means of well structured, systematic and reasoned arguments.
- *Persuasive skills.* For this is necessary learning to construct and defend one's points of view and appreciate the positions of rivals, indicating firmly why one must be chosen as the better option.
- *Writing skills.* Which is achieved through logic and reasoning while doing interpretative and argumentative writing, depicting details of specific examples.

zIn the same sense, George Boole wrote his work thinking on investigating the fundamental laws of mind operations, by which reasoning is performed, and he gave them one expression in the symbolic language of calculus, and he believed that human reasoning was guided by formal logic [22]. This view of logic goes back to Aristotle, who create syllogism-based and modal logic, Aristotle added the values "necessary" and "possible" for the premises [23]. Until recent times the understanding of an effective system for decision making was based on formal logic and statistics, but Braverman [21] was of the opinion that a real situation, regardless of its complexity, could be decomposed through a reduction process in its constitutive parts until any detailed level, and that adding the solutions of individual components would give as result the general solution, which is reached by means of a continuous application of logical reasoning.

The scientific hypothesis that states that persons have inherent logic as basis for rational thinking was strongly influenced by the works of Piaget and Inhelder [24]; however, later studies demonstrated that reality is different. Logic fallacies are common and catch permanently interest because human reasoning is prone to them [23], [25]. The findings of a set of logical reasoning experiments show that people make logical mistakes often and draw unnecessary conclusions, but laudable, based on their beliefs. Kahneman *et al*. [26] work support the opinion that logical reasoning systematically breaks the rules for statistical reasoning, ignoring, among others, the base rates, the sample size and the correlations. In his research they considered Bayesian probabilistic reasoning, as standardization criterion required for an agent to be perfectly rational, and they found that humans are systematically at the standards level, therefore they concluded that it seems that men are not a conservative Bayesian: *men are not Bayesian at all*.

Richardson [25] states that studies about formal decision-making must be replaced by the limited rationality because in this way complexity is eliminated from real world situations. An engineer having no education on logic has difficulties for developing logical reasoning, therefore he will face difficulties for isolating a specific reasoning task from its environment and will be mainly focused in the given premises. Evans [27] states that by default, the mode for logic reasoning is pragmatic and not deductive or analytical and that people tend to select credible alternatives, that is, they tend to choose something that would be justifiable in real world instead of following the rules logically reasoned.

Logic reasoning, like a cognitive central component, depends on the theories of understanding, memory, learning, visual perception, planning, problem solving and decision-making [28]. According to this research, brain has two complementary ways for decision making: 1) one for reasoning and 2) other for the immediate activation of previous emotional experiences in similar situations. The second one is a kind of reaction to a visceral sensation that activates an emotional signal for increasing the efficiency of the reasoning process and makes it faster. The difference in the way like engineers carry out these processes and how carry out the people coming from other professions is that most of the times engineers cannot act by instinct, because they cannot consider instinct like a substitute for real reasoning despite this take a longer way. When the situation requires a response the brain ask images related to the situation and options for the action, and in this form anticipates to the future results through abstract representations and by means of logical reasoning strategies will operate on this knowledge for making a decision.

TABLE I: TAXONOMY OF DEVELOPMENT OF LOGICAL REASONING

Skill	Capability	Context
Knowledge	Collecting, describing, identifying, listing, showing, counting, tabulating, defining, examining, tagging, naming, re-counting, citing, enumerating, dividing, reading, registering, reproducing, copying, selecting.	Dates, events, places, vocabulary, key ideas, diagram parts…
Comprehension	Associating, comparing, distinguishing, interpreting, predicting, differentiating, contrasting, describing, discussing, estimating, group, resuming, organizing, citing, converting, explaining, paraphrasing, reaffirming, tracking.	Find meanings, transfer and interpret facts, infer causes and consequences
Application	Applying, classifying, changing, illustrating, solving, demonstrating, calculating, completing, modifying, showing, experimenting, relating, discovering, actuating, managing, articulating, tracing, collecting, computing, constructing, determining, developing, establishing, preparing, producing, reporting, reporting, teaching, transferring, using.	Use information in new situations, problem solving…
Analysis	Analyzing, organizing, connecting, dividing, inferring, separating, classifying, comparing, contrasting, explaining, selecting, fragmenting, organizing, correlating, diagramming, discriminating, focusing, illustrating, profiling, prioritizing, subdividing, pointing.	Recognize and explain patterns and meanings, consult parts and wholes…
Synthesis	Combining, composing, generalizing, modifying, inventing, planning, substituting, creating, formulating, integrating, reorganizing, designing, speculating, re-writening, adapting, anticipating, collaborating, compiling, conceiving, expressing, facilitating, reinforcing, structuring, substituting, modifying, negotiating, re-organizing, validating.	Discuss *what would happen* before a situation, create new ideas, predict and give conclusions…
Evaluation	Evaluating, comparing, deciding, discriminating, measuring, classifying, testing, persuading, concluding, explaining, adjusting, judging, summarizing, supporting, evaluating, criticizing, defending, persuading, justifying, reformulating.	Make recommendations, evaluate principles and make decisions, criticizing ideas…
Affective sphere	Accepting, trying, challenging, defending, disputing, joining, contributing, eulogizing, asking, activating, supporting, and collaborating.	This sphere is reflected in the interpersonal relationships, the emotions, attitudes and values

Of course, the difficulties in logical reasoning for problem solving depend on factors which are different to the reasoning mechanisms *per se*. If an engineer does not achieve to understand the pose of a problem, he will not understand

the task he is supposed must perform and he will not be able for structuring or formulating a proper solution, because his responses will not reflect a correct reasoning process. Different methodological difficulties can be observed in these processes, but it has been demonstrated that a proper education will permit him overcome this kind of isolation [29].

For people is difficult to carry out something which is not natural, like deductive reasoning, because people have to ignore the more current thinking and have to adopt a restricted case. Engineers, like other scientists, must be better prepared for thinking in restricted and artificial systems. Mortimer and Wertsch (2003) explains that scientific language has a different grammar, and that one of the problems because students do not achieve developing a proper logical reasoning is because they are averse to change, and they do not accept modifying their natural language for the theoretical discourse used by the teachers. Arguing skills depend largely on education in logic, because the educational systems seem focusing on different aspects of analysis capabilities, and they do not consider the issues related to modeling and abstraction [30].

Because of its nature, human brain has certain capability for logical reasoning, but first it needs giving potential, and in some cases, developing logical-interpretative and abstractive capabilities [31], especially in the professions which activity focus is problem solving like engineering. Table I presents one adaptation of Bloom taxonomy to the development of logical reasoning that must have engineers. Achieving the development of these skills and capabilities must be the objective of engineering program course plans.

V. Conclusions

The analysis performed in this work shows that engineering students, in spite of possessing formal training in mathematical logic, frequently apply a pragmatic reasoning for problem solving. The preference for this reasoning proposes certain concerns about its capability for making good decisions in work life. Because in the logic reasoning of this professionals are needed logic requirements, the contents of the university course plan must be structured with the objective of developing in them a differentiating logic, because in the decisions of engineering is necessary to respect a set of logic rules.

The need for logical reasoning in professional life of engineers lead us to conclude that through their educational processes logic and systematic thinking must be emphasized. Engineers must be able of properly selecting a logical reasoning for every situation, and they must be able of alternating between daily, formal and rigorous reasoning and the creative and heuristic solution of problems. For the above reasons is needed promoting for then a good capability for reflecting about the cognitive functions and the meta-cognitive skills. Therefore, the objective of developing the abstractive and logic-interpretative capabilities needs to be explicitly tackled in the course plans of university programs.

This analysis also indicates that language affects more than expected the formal logical reasoning capabilities of engineers. The result suggest that language as a mean for studying has a stronger effect on the learning of science and engineering that people commonly think. If this finding is confirmed by coming studies, we must pay more attention to the way how people is educated on reading and writing in general. However, more studies are needed to confirm and explain to what extent linguistic influences modify the development of logical reasoning.

Logic and logic reasoning are important items in the education and professional development of engineers. In no other field of knowledge is so necessary this kind of education, because through its proper development they will be able of widening the range of things they know and they understand, of promoting the self-knowledge, of understanding problems and presenting efficient and effective to daily problems. Therefore, educational systems must give the required importance to these fields and including them relationally in the course plans. In this way it will be possible that future engineers can properly solve the complex problems of 21st century society.

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