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Ethical Education in Engineering: A Pedagogical Proposal Based on Cognitive Neurosciences and Adaptative Complex Systems

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ABSTRACT

The contemporary society characterized by inter/multi/trans-disciplinary, globalization, multiculturalism, connectivity, continuous change, complexity, and the rapid advance of science and technology, generate new challenges in the ethical formation of future engineers. Although the education of engineering students has made advances in curricular, pedagogical and didactical areas with the support of new technologies, ethical training has not significantly advance at the educational level. It requires a new pedagogical framework that facilitates engineering faculty to innovate in the teaching and learning processes of ethics training that will enable new generations of engineers to adapt to the socio-cultural, technological demands and dynamics of the 21st century. This paper highlights innovative processes in the ethics formation of engineers from the inter/multi/trans-disciplinary perspective based on new fundamentals that integrate Research & Development and Education (R+D+E). In addition, this paper shows the pedagogical foundations of the processes of teaching and learning for the formation of engineering students in ethics and its relationship with the Integral Formation of the Engineer based on fundamentals of cognitive neuroscience and adaptive complex systems.

The proposed framework for ethics training, allows for a contextualized and meaningful learning model for new engineers favoring the inter/multi/trans-disciplinary with the development of social and cross-cultural skills, emotional intelligence, social and ethical responsibility, adaptive leadership, creativity & innovation, critical thinking & resolution of complex problems, communication & collaboration skills, team work, global awareness, environmental cognizance, flexibility & adaptability, resourcefulness, citizenship competencies, among others.

Key words:

Ethics, engineering ethics, ethics training and complex systems, cognitive neuroscience, inter/multi/trans-disciplinary and ethics.

I. INTRODUCTION

The engineering colleges of the 21st century are challenged to train professionals capable of adapting integrally to the globalized world. This implies not only adapting to the rapid advances in science and technology by facing ethical dilemmas related to robotics, artificial intelligence, artificial life and genetic engineering, among others, but also working inter-disciplinarily in multicultural, multi-ethnic and changing contexts that are required to establish ethical codes of professional conduct.

The Code of Ethics for Engineers of the National Society of Professional Engineers (NSPE) states: "Engineering is an important and erudite profession. As members of this profession, engineers are expected to uphold the highest standards of honesty and integrity. Engineering has a direct and vital impact on the quality of life of all people. Consequently, the services provided by engineers require honesty, impartiality and fairness, and must be dedicated to the protection of public health, safety and welfare. Engineers must perform in accordance with a standard of professional conduct that requires adherence to the highest principles of ethical conduct" [1].

Ethical practice is crucial to ensuring public confidence in engineers and engineering, especially as engineers increasingly address international and social issues that combine technical and ethical challenges. ABET, the organization that accredits engineering programs in the U.S. and the National Science Foundation (NSF) have recognized the importance of preparing engineers for ethical practice by requiring accredited and funded programs to develop the competence of undergraduate and graduate students in this area. However, there is not much information on the range of relevant activities and programs available, nor has there been an effort to review how ethics requirements for ABET accreditation and NSF grants are met in engineering and engineering technology programs [2].

Although ethical codes define the standards and norms of behavior that professionals must have in order to perform optimally in society, clearly establishing what should or should not be done, during the exercise as engineers; the training of students to achieve such behaviors corresponds to the engineering faculties and their curricular processes.

In order to achieve the ethical formation of the students, theoretical courses of ethics have been implemented in engineering syllabi based on the consideration of ethical and moral values, although most of the time these courses are perceived by the students as foreign to their formation as engineers.

However, there are significant advances such as those presented in reports by the Center for Engineering Ethics and Society (CEES), the National Academy of Engineering (NAE), the National Academy of Sciences funded by the National Science Foundation (NSF) where research and experiences carried out in twenty-five universities in the United States have shown that the best practices for ethical education are those that are closer to the real world. Practices include incorporating multidisciplinary, team-based projects into curricula to help students develop skills in decision-making, leadership, oral and written communication, organization/time management, cultural awareness, and problem solving [3]. However, in spite of the advances achieved, ethical training in engineering continues to be a challenge for engineering programs and requires new research approaches.

This article presents a pedagogical proposal for the ethical formation of engineering students theoretically based on the cognitive neurosciences and the theory of complex adaptive systems. The hypothesis of this proposal is that ethical training requires the construction of neural pathways or networks within the student's brain through effective pedagogical mediations and if a change in the student's neurobiological structure is not achieved, ethical behaviors are not modified.

This proposal is the result of a research initiative that is being carried out in the Electrical Engineering Department of the University of South Florida in conjunction with the Complex Systems & Education Network of the Ibero-American Science and Technology Education Consortium SCED-ISTEC for several years under the research areas of Neuro-cognition, Teaching & Learning and Complex Systems [4-5].

II. NEUROCOGNITIVE FUNDAMENTALS

Ethical education has a neurobiological basis. It requires pedagogical interventions that allow the creation of neural networks or pathways in the brain so that ethical behaviors are consolidated, established and they persist in the professional practice throughout life. If there is no structural change in the neurobiological system, the behaviors are not modified.

The brain is a complex system characterized by the interaction of multiple genetic, chemical, electrical, and neurohormonal factors that interact with each other and with environmental and sociocultural factors. From this dynamic interaction, biological processes emerge that condition thoughts, emotions and behaviors through a multiplicity of channels that tend to self-organize spontaneously and in ways that are difficult to predict [6-7].

The process of neurocognitive construction and transformation is not linear. Each element of the neural networks influences and is influenced by many others. The duplication of a stimulus does not necessarily mean the duplication of the response. That is why small modifications in one location can generate great changes in the system. In the interactions, the information is modulated along the way and can be amplified, reduced, modified or eliminated in different ways [7].

Although the possibilities of interaction of the central nervous system are practically infinite (100,000 million neurons in constant interconnection), the system organizes itself in patterns that allow coherent manifestations of thought, feeling and action. However, internal or external disturbances to the system can potentially generate abrupt changes and breaks in patterns [6, 8].

Under annotated dynamics, the brain integrates basic and higher cognitive functions. Some are more advanced than others, as is the case of the cerebral cortex. Cognitive functions generally involve three large groups. A first group of intellectual functions that make up functions such as attention, perception, memory, judgment, analysis, synthesis, abstraction reasoning, language, metacognition and creativity, among others; a second group of emotional functions that are related to feelings, affectivity and motivation; and a third group of psychomotor functions [9-11]. The three groups are biochemically modulated by more than sixty chemical substances created by the body called neurotransmitters, which transmit information [12-13].

These biochemical substances, such as serotonin, adrenaline, noradrenaline, acetylcholine, glutamate, dopamine, oxytocin, endorphins and gamma-aminobutyric acid, among others, are responsible for all cognitive processes such as memory, attention, reasoning, learning, managing emotions, planning and creating strategies, performing movements, and using language [10-12-13].

The action of neurotransmitters in the organism does not always function in the same way. Sometimes, some neurotransmitters are more activated than others. They change and interact according to the circumstances and conditions of the organism. The dynamic and changing activation of the great variety of neurotransmitters allows for the nervous system to have a wide range of behaviors necessary to adapt to an environment that is constantly changing. However, a deficiency or excess of a particular neurotransmitter can produce disorders at the cognitive level (thoughts, emotions and behaviors). Brain functions do not act separately. They constantly interact and self-integrate to perform specific actions such as problem solving, decision-making and in general any behavior of the person in their daily lives [9, 12, 13].

The brain network functions as a highly complex system of systems that interacts permanently and in a changing way with the rest of the systems of the organism, and with the external environment generating, reinforcing and creating new neuronal pathways thanks to a brain plasticity process that allows for modifying neurocognitive structures [6-11].

The annotated neurobiological dynamics allow us to understand why ethical behaviors are not predictable, and are the result of multiple factors. On the one hand, there are the individual cognitive factors that integrate intellectual, emotional and motor elements. Their interaction can generate different and changing behaviors at different times. It is modulated, among many others, by the type of thoughts, affective changes, situations of stress, physical tension or health conditions of the different systems of the organism. On the other hand, there is the interaction of the individual with other people. Depending on the type, characteristics and number of people, unpredictable behaviors will emerge; finally, there is a third factor that has to do with context. Individual and collective interaction in diverse contexts and learning environments generate different, unpredictable and changing ethical behaviors. In short, theoretical knowledge of ethics does not guarantee its application. This explains why a student can have a purpose or intentionality when being alone and a very different one when interacting with different people and situations. The simple fact of taking ethics classes does not guarantee ethical behavior in the engineer's professional setting.

In synthesis, the ethical formation is the result of a complex and adaptive neurocognitive system that goes beyond an isolated process of intellectual, emotional or motor skill functions. It is the expression of a whole, that is changing and open to multiple possibilities. The challenge of education is to carry out pedagogical strategies that really modulate the bio-psycho-social complexity of the student in order to facilitate his/her integral formation and adaptation to society.

III. PEDAGOGICAL PROPOSAL

Engineering has its own epistemological, conceptual and methodological status characterized by pragmatism and resoluteness. Therefore, the teachability of ethics must be adjusted to the characteristics of the discipline itself, otherwise there is a risk of not achieving meaningful learning. Engineering ethics must be a practical ethics, applied and oriented to the individual behavior, professional technical (micro-ethics) and to collective or social relations (macro-ethics) to preserve the common good and serve society [14-16].

Subsequently, the concept of ethics being proposed in this work transcends the philosophical reflection of morality or the theoretical study of the importance of the values of general ethics. It focuses on ethics applied to engineering. That is to say, it deals with the study of students' behaviors and the decisions that they make in different contexts and situations in the university environment in order to undertake an integral commitment as professionals and as citizens. It includes the actions that must be taken to live in communities, the duties that must be fulfilled, the rights that must be respected and the consequences of behavior on others. Consequently, it is oriented to form in the student a balance between autonomy and respect for the other in disciplinary, multidisciplinary, interdisciplinary and transdisciplinary work environments. It involves, among others, formation actions in responsibility, communication, tolerance, transparency, honesty, sincerity, self-knowledge and self-management. However, the purpose is not to generate mechanical behaviors in the student for the fulfillment of norms in a rigid way. It is sought that in all actions, behaviors and decision making made by the students individually or collectively, in different contexts, that they develop ethical behaviors.

The pedagogical intentionality should be oriented to develop ethical behaviors in the student during the whole process of formation as an engineer and not to dictate isolated or elective courses of ethics to complement the engineering curriculum. The traditional teaching of theoretical courses in ethics characterized by the teaching of the history of ethics, conceptualizations, definitions, classifications and codes of ethics, although they give some knowledge, they do not go beyond short-term memoristic processes that do not transcend the classroom and therefore do not have an impact on professional performance.

Ethics and values are not taught. Ethics and values are only constructed, neurobiologically, through experience, daily interaction, experimentation, problem solving and decision making in diverse environments and contexts during the entire formation process. Therefore, it is very important that the student does not perceive ethics as something optional, isolated and associated to the social or human sciences, but that the student recognizes ethics as something inherent to his/her education as an engineer. At this point the professor plays a decisive role; on the one hand, he or she must be pedagogically trained to facilitate the formation process and on the other hand, as part of the system, he or she has the responsibility of modeling ethical behaviors in the different learning environments. Otherwise, they become a disturbing element of the system. If the student feels disrespected, in some way, by the instructor it will be difficult for him/her to consolidate an ethical conduct of respect, even if he/she receives a lot of theoretical concepts of respect.

The objective of the formation is for the students to develop ethical competences in engineering skills through active and collaborative pedagogical strategies. The pedagogical mediations include individual and team work, case study resolution, simulation practices, group discussions, analysis of problematic situations, innovation scenarios, development of real-world proposals, elaboration and discussion of projects, and interaction with industry networks. These mediations require the permanent observation and monitoring of ethical competencies by the faculty in order to be effective.

Ethical competencies should not be presented separately from the professional competencies sought by the program in training engineers. Ethical competencies should be included within all the competencies of the curriculum. This implies that they should be incorporated from the beginning to the end of the program in all learning and teaching scenarios such as classrooms, laboratories, projects, internships and field work.

The objective is for students to learn to develop ethical competencies in engineering through active and collaborative pedagogical strategies and not only transmit theoretical, historical concepts and codes of ethics. Pedagogical mediations include individual and team work, case study resolution, group discussions, analysis of problematic situations, innovation scenarios, development of practical proposals, elaboration and discussion of projects, and interaction with industrial networks. These mediations require the permanent observation and follow-up of the professor in order to be effective.

Ethical behaviors such as respect and tolerance must be manifested in all settings and with all people. In everyday practice behaviors change. They are expressed in one way in some scenarios and with one type of people, and in other environments and with other people, their expression is difficult or manifested in another way. The pedagogical use of all possible scenarios at different times, with different people, groups and contexts over several years of training is what can enable the creation of neurobiological structures or neural pathways.

Ethical behavior must be objective, observable and evaluable. They are expressed as specific elements of a general disciplinary competence. The elements must have indicators of achievement with evidence of compliance within them. The indicators are adapted to the needs. The design of the rubrics by competencies must be clear, unified and simple so that faculty and students can easily understand it. If they are very extensive and complicated, they overload the faculty and make the process difficult.

Keep in mind that the indicators are transversal to all courses.

The indicators of achievement seek the evidence that the student shows:

- Active listening
- Communicates assertively
- Communicates verbally and non-verbally in a friendly and respectful manner.
- Achieves empathy with team members.
- Achieves harmonious work in disciplinary teams
- Achieves harmonious work in interdisciplinary teams
- Respects the opposing views of peers and faculty
- Takes into account and applies the ideas of others
- Does not reacts impulsively and explosively to something that doesn't like.
- Attends on time the different activities proposed (classroom, laboratories, industry, committees, etc.).
- Fulfills responsibly with assignments left by the faculty.
- Fulfills responsibly the obligations agreed with the team members.
- Recognizes achievements and successes of peers.
- Doesn't take the credit of the work of his/her peers as his own.
- Does not falsify data
- Does not commit plagiarism
- Does not copied on exams
- Debate and argue with respect and courtesy
- Achieves consensus
- Reflects and discusses the pros and cons of ethical behavior in different scenarios of engineering training (laboratories, conferences, classroom, industry, committees, projects, etc.).
- Leads and settles discussions and debates.
- Accepts suggestions for behavior change given by peers and faculty.
- Identifies strengths and opportunities for behavioral improvement.
- Adapts to different learning and work scenarios.
- Proposes solutions (strategies and activities) to difficulties detected in his/her behavior.

- Modifies behaviors in different scenarios of engineering training (classroom, laboratories, industry, committees, projects, etc.).
- Complies with improvement plans.

The evaluation of the indicators of achievement should be quantitative and qualitative, recording in the observations elements that serve as the base for the improvement plans.

The indicators for each element of competence are determined in three levels of achievement: 1. high level, 2. medium level and 3. low level. Each level is assessed qualitatively and quantitatively. At the qualitative level, the factors that hinder the achievement of the competence are specified and at the quantitative level, the evaluation is carried out with the following score: 1. High level (A, 80-100), indicates that the competence is developed; 2. Medium level (B, 60-80), indicates that the competence is partially developed and 3. Low-level (C, under 60), which indicates that that the student has not properly developed the competence. In order to pass the course, the student must have developed a minimum intermediate level. In this case the student must establish the commitment to improve the deficiencies detected in an improvement plan. The idea is that, at least, from the fifty percent completion of the program's path, as defined in each curriculum and institution, the student achieves a high level and can maintain it for several semesters as a requirement for graduation [5].

The ethical dimensions or elements of each competency must include conceptual (knowing), attitudinal (being), and action (doing) aspects. Working all the aspects in the elements of the competences for adequate times and in a repetitive way facilitates the integration in the neural networks of the intellectual, emotional and aptitudinal functions allowing to consolidate an ethical conduct in the brain structure.

Although competences are defined previously, the system must be flexible and adaptable. Other competencies may arise to develop within the process which needs to be defined jointly.

The formation process requires a follow-up of the student's evolution. This implies that the team of faculty accompany and offer feedback permanently to the student and provide sufficient support to facilitate the process. In other words, the student identifies and actively participates in the process by proposing activities that will help to improve ethical competencies, and the faculty provides pedagogical tools and strategies to the student according to the needs and the level of development of the competencies.

Ethical formation implies a commitment from the academic community and industry that interacts with students through projects, internships, etc.. Feedback, accompanying, and improvement plans require active participation and joint empowerment. To optimize this process, the Electrical Engineering Department at the University of South Florida follows the TRUE T(Taking) R(Responsibility) U(to Understand) E(Engineering) philosophy. TRUE aims to change the way individuals, organizations and systems relate to each other and function. Its rationale is that responsibility and training is not unique to a particular individual. It is a shared and distributed responsibility. It involves the active empowerment of the academic community and industry to have an impact in the formation of the engineer.

The student must learn to create during his/her formation a metacognitive capacity. This ability allows to know their cognitive and emotional for the development of ethical behaviors. In addition, the student must learn to make a cognitive modifiability within himself to optimize his/her strengths and work on his/her difficulties. In this process, the work of the professor in the orientation, feedback and accompaniment is of vital importance.

IV. CONCLUSIONS

The formation of ethics in engineering must be based pedagogically on the knowledge of cognitive neurosciences.

Ethical formation is consolidated on a neuro-structural basis. It requires the creation of effective neural networks or pathways in the brain for ethical behaviors to consolidate, manifest and persist in the professional practice throughout life.

Ethical formation is a complex, difficult and time-consuming process to build. It requires pedagogical mediations throughout the entire engineer educational process from the beginning until the end of the career. It is not achieved with isolated courses. It must be integrated to the curriculum.

Ethical education required to develop competencies in various contexts and disciplinary, interdisciplinary, multidisciplinary and transdisciplinary teaching & learning scenarios.

Ethical formation must be observable, measurable and evaluable in order to be improved. It cannot remain subjective.

Pedagogical mediations designed for the construction of ethical behaviors must be consistent with the theoretical, epistemological and methodological status of engineering.

Ethical formation represents a great challenge for engineering faculties and a great responsibility to society.

The professor plays a relevant role in the ethical formation as a role model for the student and as a facilitator of the process, providing permanent feedback.

In the ethical education, the student should develop a metacognitive ability that allows the student to know his/her strengths and weaknesses and also learn to make a cognitive modifications in order to optimize his/her strengths and improve his/her weaknesses.

The ethical formation is a shared responsibility and requires the active empowerment of the entire academic community.

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