A MODEL TO PEDAGOGICALLY SUPPORT TEACHING & LEARNING SCENARIOS FOR ENGINEERING INNOVATION FROM A COMPLEX SYSTEMS PERSPECTIVE

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Abstract

Education for innovation requires innovation in education. To innovate in education implies new pedagogical models. It is not enough to just apply teaching/learning methods or strategies in a mechanical or procedural approach. It requires the conception of new pedagogical models based on theories that allow for processing of different interpretations of diverse complexity educational phenomena, i.e. other ways of producing and implementing pedagogical knowledge. Education in the different engineering programs has been carried out through analytical and linear processes; however, the reality of education through a Complex Systems lens is characterized by uncertainty, chaos, breaks, nonlinearity and self-organization. To optimize curriculum processes that foster innovation skills in students requires strategies and teaching-learning scenarios that stimulate nonlinear processes and generate a change in the mindset of the professor and the student. It is important to understand and approach the reality of educating engineers in new ways. Making methodological adjustments without the understanding of the epistemological orientation that take into account complex dynamic processes will only generate pseudo-changes, which limits creativity and innovation processes. Currently, there are several global initiatives for the development of teaching-learning scenarios that facilitate innovation processes in engineering education and education for innovation. This paper is a proposal by the Complex Systems & Education Network (SCED-ISTEC) and the College of Engineering at the University of South Florida (USF), of a model developed to pedagogically support innovation scenarios in educating engineers for innovation using the principles of Complex Systems. The suggested scenarios are framed in a dynamic curriculum structure. They are characterized by hard and soft state-of-the-art technologies; interdisciplinary, flexible, pedagogical research processes; methodologies for cognitive restructuring, solving complex problems, and modeling, simulation; interactions with university/industry programs; and the facilitating of applications according to context and societal needs.

Keywords: Innovation, Complex Systems, Education, Engineering.

1. Introduction

The processes of education planning, academic coordination and curricular design are based on a pedagogical model which is aligned with the mission, vision and strategic goals of the institution.

The pedagogical model is theoretical representation of multiple elements that interact in educational processes based on one or more theories, which justify and give meaning to the educational practice at the various levels and programs. That is, it guides the institutional education project and is implemented in the curriculum.

The College of Engineering, University of South Florida, in collaboration with the Systems Complex & Education Network (SCED-ISTEC) has been developing a transdisciplinary educational research project to restructure the engineering curriculum under a new pedagogical model based on complexity theory, with a view to implementing innovative pedagogical dynamics that enable the training of an engineering with the ability to meet the need and challenges of the contemporary society characterized by globalization, multiculturalism, multidisciplinarity, the rapid progress of technology and the complexity of cultural, social and scientific phenomena.

The mentioned curricular project includes an interdisciplinary learning laboratory for innovation in engineering. Below we present its pedagogical foundation from the point of view of the complexity theory.

2. InterDisciplinary Learning Lab (IDLL) Pedagogical Model

The InterDisciplinary Learning Lab (IDLL) is a common learning scenario at the University of South Florida to train innovators in science and technology. It promotes academic collaboration among undergraduate and post-graduate students, professors, researchers and external students who can do internships and networking. It integrates engineering programs at different learning levels and promotes the participation of students from other programs.

Figure 1 InterDisciplinary Learning Lab (IDLL) @ USF

Based on the analysis of the social, cultural, political and economic context that surrounds the university, the model answers questions related to the type of training required, the skills to be developed, the theory that builds the foundation for the pedagogical processes, the structure of the model, the role of the professor/facilitator, the teaching/learning scenarios, and the evaluation methodologies and processes.

2.1 Training Purposes and Skills

The aim of the laboratory is to train science and technology innovators with a global vision and the ability to solve high impact challenges in multicultural, inter and transdisciplinary contexts. To achieve this goal, specific skills must be developed in the following areas: Knowledge –disciplinary, social, cultural, technological, scientific knowledge and knowledge on innovation models; Being –social sensitivity, ethical and human sense; and Know-how –ability to identify, formulate and solve problems, from the most basic to the most complex, to work in a team with a multicultural, interdisciplinary and transdisciplinary approach, to effectively communicate in speech and writing, to engage in active listening, to read local, regional and global trends in the labor, social, cultural and economic contexts, to manage the relationship among universities, industries and the society, to identify the needs and demands, to manage complexity, to handle linear and non-linear computer tools, to manage innovation software and to apply innovation models in different contexts. According to the level of training there are competencies defined in each of these three key areas.

2.2 Theory of the Pedagogical Model

The model is pedagogically based on the theory of Complex Systems. It is understood educational reality as a complex adaptive system characterized by multiple interactions between faculty, students, context, information etc. that generate collective patterns not attributable to its isolated components. These patterns are given in different levels or subsystems with non-linear dynamics and heterogeneous behavior characterised by ruptures, forks and uncertain emerging processes, change the order from the disorder and from the disorder is feedback and autoorganize.

Due to this dynamics, education processes –from planning to training at the lab– are not always as expected. The team is responsible for identifying the point at which a situation or a phenomenon stops being linear and changes its behavior, or when it leaves a chaotic status to enter an organized statutes, and for managing the resulting patters using dynamic and evolving pedagogical strategies that promote the development of creative and innovative processes.

Using the same strategies for different phenomena without understanding the various dynamics and the emerging processes that occur at a given moment does not generate positive results. This approach applies to curricular, didactic, cognitive, evaluation strategies, etc. The understanding of complex phenomena requires new approaches and cognitive processes with logics that go beyond the classic and linear methods (deductive or inductive) which aim to understanding the behaviors of the academic landscape.

2.3 Model Structure

The structure of the laboratory is proposed as a system of complex systems that enables interaction of researchers, professors, information, design tools, projects, etc. The laboratory is a sub-system of the curricular structure at the College of Engineering (Cruz, Moreno 2012) which comprises five academic training units, a student support team, a curricular committee and a college academic research and development area.

The academic units have three disciplinary units –basic disciplinary knowledge, deep disciplinary knowledge and a knowledge application and transference unit– and two general training units: general training and comprehensive skills.

The laboratory processes (IDLL) articulate and streamline the College curricular system elements, and are characterized by its interactivity, non-linearity, change, flexibility, feedback, adaptability, trans/inter/disciplinarity and self-organization.

The laboratory receives students from all levels and from the different training units. Each training level requires the student to have enough useful knowledge to be problematized in different reality contexts. The aim is for the students to have a clear, organized and systematic conceptualization in their cognitive structure that enables the teacher/researcher to design pedagogical strategies that optimize the construction and integration of new cognitive processes that generate innovation.

In order to optimize the process, an induction mechanism is implemented, which shows the structure of the laboratory and its relation with the College's curriculum. The theoretical, pedagogical and epistemic grounds of the training process at the lab are explained, along with the goals, functions of the equipment, coordination mechanisms, learning models, the curriculum for the relevant level, learning levels and the evaluation and follow-up mechanisms.

2.4 Approach

Academic training at all levels is achieved through an inter-structuring relationship between the professors and the students within a context of empathy, engagement, reflection, analysis and discussion.

Although starting with a preliminary diagnosis and the specification of the skills to be developed, the teaching/learning dynamics at the laboratory are changing and allow for multiple possibilities depending on the interactions and patterns that emerge at a given point. Therefore, didactic approaches are not rigidly determined. They vary according to the group, the student and the situation. Autonomous, collaborative and guided learning is comprehensively approached.

The learning and innovation process is developed in different stages: a) Cognitive structuring, b) Problematization and c) Resolution and Innovation.

a) Cognitive structuring stage: Achieved through the stages of diagnosis, teaching transference, deepening, student transference and evaluation.

The diagnosis stage aims to assess the previous learning and conceptualization level of the student through pre-tests, concept maps, mind maps, presentations, essays, etc.

At the transference stage, depending on the student's knowledge of the concept structure and according to this latter, the teacher/researcher transfers the required and relevant concept and propositional networks, clearly and from the broader and more inclusive concepts to the more specific ones, to allow for an easy construction of relevant learning (Ausubel, et al.,1978) through short participative sessions.

At the deepening stage, the student researches using different approaches and reflects on the concepts. At the transference stage, the student is able to communicate the new concepts in his or her own words, supported by different didactic strategies, and then presents them for group reflection and discussion. Finally, in order to verify the degree of content assimilation, concept representations are used (including concept maps, graphs, mind maps, algorithms or written papers).

b) Problematization stage: Once the student has shown concept clarity and deep understanding of the topic, this knowledge is problematized through problemic teaching methods (Bravo, N1998), question making and problemic situations which lead to a cognitive integration of knowledge to identify need in specific socio-cultural contexts and propose innovations. Besides mind maps, other resources are used, including Socratic dialogues, heuristic research model games (UVE) and networks.

The students develop the ability to design Solutions to real and relevant problems in inter/transdisciplinary teams through problem-based knowledge (Schwartz,P, et al.,2001) and problem immersion, problem posing, design of alternative solutions and innovative solution models. These problems imply the interaction with social, cultural, political, economic and technological elements.

Pedagogical strategies are also used, including Teaching for Understanding (TFU) (Stone, 1998), which combines communication methods, contents, purposes and channels that enable understanding of social contexts and needs through the exploration of topics, directed research and construction of innovative synthesis projects.

c) Resolution and innovation stage: outlines possible innovative solutions to complex problems by means of non-linear neurocognitive methodologies developed through transdisciplinary research (medicine, neurosciences, computer science, teaching and engineering), as carried out and promoted by SCED/ISTEC/USF (e.g., Neurobiological Computation), in order to identify, formulate and solve complex problems. They facilitate creativity and disruptive innovations.

Teaching modeling and simulation is carried out in transdisciplinary work teams in order to generate innovation supported by non-linear computer programs such as cell automation, agent-based simulation, genetic algorithms, fractal geometry, and more, which are applied to problems that come from real needs (Cruz, 2011b).

Software programs are used for ideas management innovation, technological surveillance and knowledge management.

In the training process in the laboratory, there are unexpected situations that arise of a personal, motivational, group, social, cognitive and learning nature, characterized by the uncertainty and chaos. This requires that students are supported during the whole training process by the coordination team of the laboratory, who are experts in pedagogy and complex systems. The teaching staff, together with the student, identifies problems, explore possibilities to allow him to make adjustments or undertake new interactions.

2.5 Integration of disciplinary knowledge units with the laboratory

From the first semester, students of the *basic disciplinary knowledge unit* attend the laboratory to develop skills in the application of knowledge and problem solving in a first level.

Those students in the *deeper disciplinary knowledge unit* apply their knowledge, solve problems (both linear and complex) and carry out interdisciplinary simulation processes in a second level, in order to generate innovation.

Students in the *knowledge application and transference unit* apply their knowledge to particular contexts according to their line of research. They carry out modeling and simulation processes, and work with interdisciplinary and transdisciplinary networks and research projects. They develop specific skills for the application of knowledge and problem solving (both linear and complex) in a third level. They generate disruptive innovations. It is at this level where the more elaborate neurocognitive learning processes are applied to complex problem solving.

2.6 Integration of general training units with the laboratory

Besides the disciplinary component, the laboratory integrates in a practical way those skills developed by students in the *general knowledge unit* to innovation processes according to their academic level. This knowledge comprises social, life and human sciences, articulated with political, historical, economical and socio-cultural variables, of local, regional and global varieties. These concepts are applied by means of cases of situations in which there is a need of solving a problem which has a social impact.

Taking into consideration the fact that innovation processes require cognitive, emotional, social, artistic and sports skills, they are articulated in a practical way in the *comprehensive skill unit* for collective innovation projects. Among the cognitive skills carried out we can find operations of linear mental summarizing, argumentation, categorization, conceptualization, critical reasoning, symbolic analysis and mathematical reasoning. They also undertake non-linear mental operations facilitated by non-linear or complex reasoning didactics aimed at creating new neurocognitive networks that allow for identification and solving of complex problems. This is articulated with structuring and optimization processes in the written and verbal communication.

Emotional and social intelligence skills comprise the development of skills in an intrapersonal, interpersonal and social level by means of learning strategies which optimize effective communication processes, assertiveness, empathy and teamwork. Second and third language and sports and artistic skills complement the comprehensive training and foster the development of creativity and innovation.

2.7 Internship and exchange programs

Those university students who aim for exchanges with other universities, industries or other institutions must attain a certain skill level in the five training units, according to the project they will be developing. Conversely, those students coming to the laboratory for internships and academic visits are leveled according to internal standards. According to their level of knowledge and skill, they are placed in a particular work group under a defined project and work plan.

2.8 Interactive academic processes

There is a permanent interaction between the laboratory and the curriculum committee, the student support team and the educational research and development department.

Given that the curriculum committee is in charge of design, implementation, follow-up and permanent adjustment of the curricular structure, a mutual feedback process is carried out by means of identification of graphs or individual and collective behavior patterns that result from the pedagogical dynamic between the training units and the laboratory.

The support team works jointly with the laboratory in order to provide a permanent assistance to those students who experience specific personal (adaptation, motivation, stress) or academic (autonomous learning, study techniques, basic skill reinforcement) difficulties.

Finally, there's a degree of articulation with the educational research and development department of the college, in order to research challenging situations which arise from the pedagogical, curricular and didactic processes detected in the laboratory, with the aim of creating research projects that feed its own academic process.

2.9 Learning scenario

The laboratory is characterized by its broad scope, openness and flexibility. It allows for the adaptation of diverse teaching/learning scenarios. It promotes the interaction and participation of students of different levels. It allows for independent, collaborative and supervised work. It features state-of-the-art technology, and it is run by a multidisciplinary team that brings together engineering, health and education.

2.10 Role of the Research Professor

The Professor/facilitator in the model needs to have an open mind, designs teaching/learning environments which optimize the construction and discovery of knowledge, facilitates active learning and transfers conceptual networks to students, as needed.

They identify the emergence of individual and collective patterns and forks that arise from the interaction of different elements in the teaching/learning process (professors, students, contents, projects, disciplines, cultures, context, etc), and adopt the required pedagogical measures to be able to manage instability and uncertainty through the implementation of strategies to face each new problem (Cruz 2011a).

They provide diverse tools and didactic resources to optimize learning according to the situation, to bring students to a state of cognitive efficiency that facilitates integration, transformation and application of knowledge into creative processes and innovative solutions (Cruz 2011a).

They possess effective and assertive communication skills, and exercise an adequate emotional and social intelligence providing empathy and motivation to the student.

They are strategists and managers of unstable and changing pedagogical scenarios, with training in complex systems. They possess knowledge and expertise in the discipline, and a solid training in teaching and didactics.

They know the models for innovation and the skill level to develop in each of his student groups.

Therefore, the research professor is a mediator for the teaching/learning processes who facilitates the student the realization of his potential. However, even as a dynamic enabler of innovation, they can also become a barrier, when lacking the required training and skills.

2.11 Evaluation

Finally, the IDLL program has two evaluation stages: process evaluation and outcomes evaluation. In relation to the first, a dynamic and permanent assessment of the process is made, according to the level of training and the skills from the different units, integrated in a practical and active manner to the pedagogical dynamics of the laboratory. The development of the different phases and stages of the process is taken into account. The assessment is supplemented by constant feedback and support to the students, not only by the laboratory work team, but also by the external support units.

In relation to the second, results are evaluated according to the type of innovation generated, depending on whether it is an open or closed innovation, or whether it is an evolutionary innovation, or a novel or disruptive one.

2.12 Conclusions

Innovation training centers require permanent training innovation processes.

The laboratory specialized in innovation in engineering requires a strategic, tactic and operational structure based in a pedagogical model which orients every process and is understood and adopted by the academic community as a whole.

An innovation training laboratory is a Complex System, therefore it must be have an epistemological and pedagogical basis in the theory of Complex Systems.

The pedagogical basis of the innovation center on the theory of Complex Systems includes dynamic non-linear processes. However, it does not exclude linear processes, it incorporates them.

An innovation laboratory must be dynamically articulated with the curricular system of the department. It must be strategically and operationally oriented under the same pedagogical model.

Innovation training centers require an interdisciplinary and transdisciplinary management.

2.13 References

Ausubel, D., Novak, J., & Hanesian, H. (1978). Educational Psychology: A Cognitive View (2nd Ed.). New York: Holt, Rinehart & Winston.

Bravo, N (1997). Pedagogía problémica. Acerca de los nuevos paradigmas en educación.Tercer Mundo-Convenio Andrés Bello

Cruz, L.F. (2011a). Complex Systems as a Basis for Education and Pedagogy in the 21st Century. En XVIII Ibero- American Science and Technology Education Consortium General Assembly ISTEC. E-Books. SeDiCI.Universidad Nacional de La Plata. Argentina. (2011a). pp. 25-34

Cruz, L.F. (2011b). Modelamiento y Simulación Educativa como Base del Desarrollo Sostenible. IV Simposio Bienal Internacional Complejidad 2011 - Por un Desarrollo Sostenible Educación, Complejidad, Interdisciplinariedad, Transdisciplinariedad Universidad de Camaguey, Cuba

Cruz, Luis. Moreno, Wilfrido (2012). Curricular Development for Engineering Education to meet the challenges of the XXI Century from a Complexity Perspective. World Education Engineering Forum (WEEF) Argentina.

Schwartz,P, Webb,G Mennin,S (2001). Problem-Based Learning: Case Studies, Experience and Practice, Ed:Routledge

Stone, M (1998). Teaching for understanding: linking research with practice Jossey-Bass Publishers