CREATIVITY AS A REFLEXIVE TRANSDISCIPLINARY LANGUAGE IN THE MECHATRONICAL KNOWLEDGE

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Abstract

Starting from the transdisciplinary approach of knowledge is proposed a new transdisciplinary creative reflexive language in a way that can lead to knowledge, enabling the teaching of science and technology to disciples (students, apprentices, pupils, adults) from a large variety of backgrounds, motivating them for research, planning, design and creation of technological projects. Creative thinking is working within and through the design process of projects, changing the teaching methods and creating a rich and flexible learning environment, adopting new assessment methods, combining practical and theoretical knowledge, synthesizing vertical and lateral thinking. Students are preparing themselves the design process, structuring the programs to control the projects, learning environment that emphasizes planning, building activities and team projects, creating challenges, curiosity, imagination, and success in studying technological subjects, to become good mechatronicians.
Key words: *transdisciplinarity, creativity, problem-based learning, design-process, mechatronician*.

Introduction

To achieve knowledge in the transdisciplinary context, it is necessary to reconfigure the framework of the way the four pillars of knowledge: *learning to know, learning to do, and learning to be and learning to live with others* (Delors, 1996) are working. There is a well known relation between them: "how to learn to make (to do) while learning to know" and "how to learn to be while learning to live together with others", learning and understanding being the complementary most important issues of the transdisciplinary integrative process of knowledge. In the new transdisciplinary framework proposed (Nicolescu, 1996; 2002; Pop & Maties, 2008), the achieving information and knowledge is expressed as "learning to learn to know by doing", an objective, rational, active extrinsic process, and as "learning to understand to be by living with others", a subjective, relational, reactive intrinsic process, both these syntagms generating the knowledge search window multiple paradigms of knowledge achievement. So, transdisciplinary knowledge can explain the way the creativity, with a flexible adaptative innovation with a synergistic signification, works as an intentional action through ideas, design, modeling, prototyping, simulation, incorporating informaction (information in action) in mattergy (energy incorporated in matter) to produce smart products, sustainable technologies and specific methods to give solution to the emerging problems (Hmelo et al 1995; Gitt, 2006; Pop & Maties, 2008). "Learning to learn to know by doing" represents synergistic knowledge search windows entering apprenticeship in creativity, discovering what is new, lightening the creative potentialities at the top possible level, as an extrinsic active knowledge syntagmatic chain, represents the key in acquiring a profession, in a challenging world, with excessive specialization risks, reconciling the exigency of competition with equal chance and opportunity for all. "Learning to understand to be by living with others" is another chain of synergistic knowledge search windows, working as an intrinsic reactive syntagmatic approach of the transdisciplinary knowledge and involves the spiritual dimensions of the knowledge relational process; otherwise the knowledge couldn't be understandable. So, are generated the conditions for modeling the authenticity of the person, by its integrity of the character and competence, through participation in communion as apprentice. "Learning to be" and "learning to know" are working together complementarily in an apprenticeship way as a cooperative permanent teaching/learning process, where teachers and disciples are informing one another about the problem they have to solve together, in a necessary context to create an equilibrium between the outside (with its extrinsic active knowledge aspect) of the person and his inside (with its intrinsic reactive knowledge aspect), the only possibility being the transdisciplinarity (Pop & Maties, 2008).

Creative Thinking as Transdisciplinary Approach of Knowledge

Considered as an exploration of the conceptual structures, creativity is simply defined in a descriptive way with rules for admissible states and for moving process from one to another state, exploring and possibly adapting through reconfiguration such a "conceptual space", of the most importance being "the identification, stimulation and evaluation of creativity" (Langley et al, 1987; Boden, 1994). Tradition and innovation are not opposed one to another, but complementarily, because creativity is exploration of the conceptual structures in different degrees of creativity and grading of creative achievements. Considering the counter for creativity the fact that there is no purpose to educate disciples (students, pupils, adults, apprentices) to design according some generalized imposed procedure, external to them (De Vries, 1996; Doppelt & Schunn, 2008), to put in practice their ideas, solutions, and products, teaching them to nourish their thinking properly and thereby enabling them to reflect on their creations and how they developed them it is important to reconsider the necessity to introduce a new transdisciplinary approach to achieve knowledge. So, with their free innovative minds, disciples are expected to internalize their adaptation of the design process, using it in their own way, applying it to new emerging situations, and to demonstrate general patterns of lateral and vertical thinking in the technological projects they started (Waks, 1997; De Bono, 2003).

The way disciples start, progress, and complete their project demonstrates that this new creative thinking in technology, as a combination of vertical thinking as learning to know by doing in a rational bottom-up contextual approach and lateral thinking, as understanding to be by living with others, in a relational top-down contextual approach, is able to create, design, implement, control, and document authentic, real-life projects instead of solving well-defined problems prescribed by the teacher (Pop & Maties, 2008; Barak & Doppelt, 2000). So, the disciples prove that through their projects are capable to deal with the "large definition of design" – that the "design activity does, in fact, encompass the entire process of planning, designing, constructing, and managing the development of a product" (De Vries, 1996). Starting from the multiple transdisciplinary knowledge paradigms introduced in a previous paper (Pop & Maties, 2008) it is obviously that in the included middle logics (Nicolescu, 2002), there is a possibility to extend the definition given before about the creativity and its relation with design, considering creativity as a new transdisciplinary reflexive language. As any language, the creative-innovative language is working with a specific code, where design, simulation, modeling, prototyping are considered as specific synergistic instruments in a process organized in a creative thinking way, where synergy ($1+1>2$) and signification ($1-1\neq0$) are the main important channels, as search knowledge windows, through that the creativity (adaptability and innovation) is put in action (competition and performance), generating the authenticity (integrity and excellence) through participation (communion and apprenticeship), presented shortly in a previous paper (Pop & Maties, 2008). In this way, "learning to know" becomes a ring of the extrinsic active knowledge chain, with its "know what" as experiential selection,"know how" as synergistic communication, and "know why" as functional contextual legitimacy (Grimheden, 2001; Pop, 2008). To work efficiently in the synergistic contextual model (Pop, 2008), with a new reflexive language of creativity, it is necessary to establish bridges between the different disciplines, between the meanings of these disciplines and the capabilities of the inside transdisciplinary potentialities as an indispensable complement to the disciplinary approach creating an active learning framework (Nicolescu, 1996; 2002). This new language introduced works transdisciplinarly to adapt the disciplines to the necessary and continuously changing of professional exigencies, with a permanent flexibility oriented towards the actualization of their inside, and to open windows towards the knowledge field in the integrative knowledge based society. In this way, the bottom-up and top-down levels of the transdisciplinary search window allows us to know and to understand the possibilities the knowledge can be achieved, being creative in the design process which requires complicated mental efforts to get through combinatorial exploration the physical alternative solutions. The building of the creative language is more difficult than for a simple innovative design, because the creative design should generate different novel functional resolutions for the same design task. The new creative system with the new reflexive language must be able to detect the original ideas defined by constraints, recognizing them to perform an efficient exploration requiring an intelligent search strategy as are presented in some papers (Barret, 2005; Savary, 2006).

On the other side the more creative individuals are considered those who explore a conceptual structure going beyond them, overpassing barriers, as real giants, known as the determined individuals who manage to discern and articulate new structures which transgress the existing ones. There are several intuitive touchstones for creative achievement, such as the complexity of the questions answered, its centrality or importance for the field explored. To learn the trade is to learn these structures, and to be creative is to produce new applications at the individual P-creativity level, or at the scientific community H-creativity level (Boden, 1994), considered as representations of the authenticity, as individual level, through participation, as communitarian level (Pop & Maties, 2008) . Disciples are tasked to create new mental outlooks, internalized, the teacher providing an initial problem set, disciples being free to suggest them, working alone or together to find solutions, analyzing several ways in which information technology could play a catalytic role in enriching the teaching/learning experience in a significant synergistic way: (1) in an active engagement of the disciples rather than passive reception of information; (2) with a lot of opportunities to apply the new achieved knowledge to real-life situations; (3) getting the ability to represent concepts and knowledge in multiple ways, rather than using the text; (4) using computer technology to achieve mastery of skills rather than superficial acquaintance; (5) learning as a collaborative activity rather than an individual act; (6) an emphasis on learning processes rather than memorization of information (Lamancusa, Jorgensen & Zayas-Castro, 1997).

A very interesting approach of the creativity as a reflexive language in achieving process of knowledge is project-based learning in engineering education. Originated from education in medicine since the early 1960's, Problem-Based Learning (PBL) method is the overlapping with other active learning models such as *group work*, *guided design*, *work-based learning*, *learning by doing* and *case studies, learning by discovery,* being distinguished from these by solving a complex and realistic problem (Barret, 2005; Boud & Feletti, 1991; Fink, 2002; Grinko, 2008; Savary, 2006). The work is organized in projects, small groups of disciples and guides (instructor, teacher, mentor, facilitator) meeting together to discuss about a case, get solutions in a creative-innovative framework, where the project aims working towards to solve a particular problem in a learning environment characterized by a large responsibility of the disciples and teachers, as well, having a cognitive coaching role instead of a lecturing one, the disciples receiving from the guide an initial guiding plan-work (as a scenario), then they question the guide to get any additional information to solve the problem (Boud & Feletti, 1991; Barret, 2005; Savary, 2006). Consequently, the disciples are reflecting, at several points on the case, about the data they have collected so far, to generate questions about these data, and to hypothesize about underlying the mechanisms or solutions for the problems in discussion. They must also identify issues that they do not understand and need to learn more about them and, with their own naive knowledge, the disciples proceed to research independently the learning issues they have identified, sharing what they learned, reconsidering their hypotheses and/or generating new hypotheses in the light of their new learning skills achieved. There is also an evaluation sequence when the disciples reflect

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on what they have learned and assessed their own contributions and that of the other members of the group. As disciples (students, apprentices, adults and pupils) articulate and reflect upon their knowledge in PBL, they develop more coherent understanding of the problem space and potential solutions (Arora, 2004; Fink, 2002). The acquisition and indexing of examples that occurs during PBL should allow later problems to be solved by case-based reasoning, promoting the self-directed learning strategies and attitudes needed for lifelong learning (Brussels, 2007). On the other side, the guide (class instructor, mentor, facilitator, teacher) has the role to open "knowledge windows" (Pop & Maties, 2008), facilitating discussions around issues of technology, environment, economics, and ethics (the dimensions of sustainable development and spiritual dimension of knowledge, as well) and to encourage the use of fundamental principles and tools to address these issues. Specific events, processes and issues at the global, national, or industrial level are objectives for the recovery and reuse the products, raw materials, and/or energy, making engineering more „green", from a sustainable approach determined by examination the impact of a process/product, which can be evaluated in terms of waste generation, toxicity, environmental impact, safety issues, actual product use (need, demand) and finally economically (Reason, 1998). Topics addressed include the technical feasibility and economic tradeoffs of alternative processes and products, preservation and efficient use of matter, energy, and space and uncertainty in data in material properties, global, regional and local inventories, environmental health and human health risk information, a common theme in these cases being involving the production and the environment (Giurgiutiu et al 2002). To assess the understanding of the nature of the issues in a sustainable development is to develop them and present cases that can be used in the future. The cases are examined for evidence that the disciples collected information regarding the themes that were pervasive throughout technology, ethics, economics, and ecology issues, as an opportunity for disciples to make visible their thinking, which provides a meaning of assessment of this intentional action that is also a learning opportunity for them as they display and communicate the achieved knowledge and problem-solving to a larger community. A key part of the PBL approach is collaborative learning, the group problem-solving allow to disciples to tackle more complex problems than they could on their own, using the computers as a way to support collaboration, especially not in the classroom, the major tool used for this being an interactive, distributed, collaboration environment that scaffolds learning, reflection, access to materials, and problem-solving tools, in which disciples enter ideas, questions, and responses to the ideas of other colleagues. It is necessary to attach documents and graphics of various forms to the disciples' notes and to create links to resources on the World Wide Web. The disciples have to use this environment as a tool at times when they need to collaborate to complete a project and when it is integral to an assignment, being encouraged to use it in their collaborative efforts to post their questions and to engage in dialogue around these questions and their collective problem-solving efforts in order to be able to transfer what they learned to a novel case, within the creative language, showing a significant improvement to identify the sustainable development technology issues. In the case of mechatronics the subsystem-based approach usually lead to a distributed team environment, as engineers working with different subsystems located at an apparent physical distance from each other. As a member of such distributed team it is possible to imply complicated work conditions, besides complicated communicational patterns, distributed teams could have problems to determine and to maintain a strong team identity.

There are two well known problem solving strategies, namely bottom-up and top-down approaches in design literature. As the bottom-up strategy produces solutions at physical, practical level, top-down design strategy looks for original ideas at functional level before investigating physical solution alternatives. To be able to face effectively the challenges of economic development within a global marketplace, it is of a biggest importance to educate the new generation of engineering professionals in a new framework, as a continuum educational program, to develop and strengthen the integrative skills in analysis, synthesis, and contextual understanding of problems and also, to expose them to the latest technologies in different engineering fields and the implications for sustainability of their use. So, the problem-based learning (PBL) approach, open-ended design problem solving by a multi-disciplinary team of disciples in a transdisciplinary context, simulation, modeling, prototyping, are integrated altogether with the four dimensions of the sustainability: technology, economics, ecology and ethics (Reason, 1997), considering them as parts of a synergistic approach of knowledge (Grinko, 2008; Pop, 2008).

Very often PBL method is associated with Team Teaching (TT) method, where a group of teachers work together, plan, conduct and evaluate the learning activities for the same group of disciples in traditional team teaching, collaborative teaching and complementary team teaching, parallel instruction, monitoring teacher, depending on the different roles that team teachers perform (Goetz, 2000; Macedo, 2002). This method open the minds to be creative in more than one opinion, developing a team work increasing the level of understanding within a large variety of teaching styles, methods, achieving different skills during the activities, the teams being supervised and counseled by monitors with different backgrounds, the creative-innovative language being the synergistic significant only way to communicate through design, simulation, modeling, prototyping in order to make a project for smart products.

The Problem-Based Learning method has different specific features, at three levels, disciples as receiver (students, apprentices, pupils, adults), instructors as senders (teacher, facilitator, guide, mentor) and methods used to achieve knowledge (experiential selection - know what, interactive synergic communication-know how, functional contextual legitimacy-know why, working together as is presented in the semiophysical contextual message model) (Grimheden, 2001; Pop, 2008). Rather than what the teacher propose, in PBL the focus is on what disciples learn, more important being the way the knowledge could be applied. PBL project work represents a method used to maintain a balance between theory and practice, creating open-ended problems taking time where the creativity support of teaching assistants is essential. In the assessment stage, the learning team (disciples) is evaluated by the teaching team (instructors), resulting a better coverage of specific problems, the results and experience of the research activity carried out by the teachers can be incorporated in the educational and training programs for disciples. Both, PBL and TT methods lead to more self-motivated and independent disciple, these learning methods preparing better the disciples (students, apprentices, pupils, adults, as well) to apply their learning to real-world situations, using the creative reflexive transdisciplinary language to achieve mechatronical knowledge at every level presented before, disciples, instructors and methods.

The Mechatronician, the New Synergistic Job Profile

As a consequence of the existence of a synergistic communication in achieving knowledge process through the new creative-innovative language proposed before to create new kind of products in a socio-interactive context, it is very important to take account of the changes in the economic system, which leads to the transformations of the labor relations observed in all economies. The changing nature of economical relations, the evolution of organizational forms and the use of laboratory work leads to the need for structural changes in priorities and the content of the training: themes, methods, teachers, disciples, as well. The people as scientists, teachers and employers are identifying new promising areas for the development of education to meet the strategic queries of growing and changing economy and the interests of modern dynamic society, in the context of changing and disappearing of the professional boundaries. There are an increasing number of workplaces just temporarily, being necessary an adaptation to the new conditions as quickly it is possible. So, web-based virtual laboratories, remote laboratory experiences and access to digital libraries are some examples of the new learning enhancing opportunities to increase connectivity. In this context, tertiary institutions with virtual libraries can join together to established, inter-library loans of digitized documents on the Internet to form virtual communities of learning helping each other to apply and enrich available open education resources with significant challenges (Salmi, 2005). In this way could be created a more active and interactive learning environment, called “instructional integration” with a clear vision to develop and create the new adequate technologies and the most effective way to integrate them in the design programs

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and delivery (Bridwell et al, 2006). Combining online and regular classroom courses gives to disciples more opportunities for human interaction, and developing the social aspects of learning through direct communication, debate, discussion in a synergistic communicational context (Pop, 2008). These requirements are applied also to the design and delivery of distance education programs which need to match learning objectives with appropriate technology support. The new types of distance education institutions and the new forms of e-learning and blended programs meet acceptable academic and professional standards, but a poor connectivity is a serious constraint in the use of the informational control technology related opportunities, with their limitations. The use of simulation tools has a number of benefits in education, because the disciples is not strictly related with real world, and at the same time is able to explore a range of possible solutions, easily and quickly, with tools available in industry, with significantly less costs than the real world components and allows more participation and interaction than a limited demonstration. But, it is very clear that real experience can not be replaced by learning with simulations, being necessary to use complementarily, the virtual tools as design, modeling, simulation and the real world representations as prototyping, building smart mechatronical products (Bridwell et al, 2006; Giurgiutiu et al, 2002). Only computer simulations cannot replace all forms of applied training, but in many branches of the science and technology-oriented programs hands-on activities in laboratories and workshops remain an indispensable constituent of effective learning. Flexibility and adaptability as strong conditions for creativity in action should be characteristics most important to determine tertiary education ability of the institutions to contribute effectively to the capacity building needs of developing knowledge achievement skills and to react swiftly by establishing new programs, reconfiguring existing ones (Pop, Maties, 2008 May). It is very important to eliminate outdated courses without any administrative obstacles, in the context of systematic efforts to develop and implement a vision through strategic planning, by identifying favorable and harmful trends as well, in their immediate environment and linking them to a rigorous assessment of their internal strengths and weaknesses, so the institutions can better define their mission, market niche and medium-term development objectives and formulate concrete plans to achieve these objectives. As is presented in a lot of papers (Salmi, 2005) an efficient educational technology at every school level allows to improve the efficiency of learning/teaching material by disciples and to give more attention for the individual and personal growth of them, using both ways of teaching, the passive (reading, hearing words, looking at pictures, watching a movie, looking at on exhibit, watching a demonstration, seeing it done on location) and the active way (participation at the discussions, having a talk, doing a presentation, simulating the real experience, making real things). The very important goal of the education is to promote educators (instructors, facilitators, teachers, mentors) to incorporate engineering concepts into the learning environment and to investigate how experiences of the disciples have shaped their perceptions of the field of mechatronics at all levels; to enhance the understanding of the relationship between spontaneous activity of the disciples and to achieve adequate concepts, such as to determine the effects of participation in pre-engineering activities on elementary perceptions of the disciples in the field of intelligent systems and to understand the interest in studying science and engineering as well. Therefore, learning and teaching in the AVE (authority, values, efficiency) synergistic communicational model (Pop, 2008) are considered as activities carried out by professionals (educators and disciples as well), who change the mentalities of the people providing them with new knowledge, skills, values, education being delivered, from pre-school through university, continuing after, according to recognized syllabi and institutional requirements, in a well-organized structural-functional system (Grinko, 2008). While in the disciplinary educational system there is obviously a lack of flexibility and low level of adaptation to the changing conditions of the environment, there is a need to build new synergistic entrepreneurial skills, where with flexibility and adaptability educators (instructors, facilitators, teachers, mentors) and disciples (students, apprentices, pupils, adults) actively respond to the rapid change of economical conditions and increasingly combine practice and theory, to determine the direction of these changes and to offer a tool that will work for promising competences, bridging formal and informal learning, as well.

As is presented in some papers (Bruns, 2005), the theoretical framework for this didactics requires more insight into how individual learning styles use individual learning methods, techniques and technologies, to outline paths to develop new meanings and concepts from basic experiences with natural and technical phenomena, being important to analyze the transitions between concrete and abstract models of production systems and to specify abstract solution for an automation problem by a concrete demonstration. To fulfill the demands for multi-skilled technicians and skilled workers vocational training schools together with industry are confronted with the need to develop theoretical integrated with practical learning sequences in a synergistic communicational networking system. To meet these requirements in education and training it has to elaborate concepts concerning pedagogical, technical and organizational aspects in a new significant synergistic way, that of the transdisciplinary educational paradigm (Pop, 2008). So, the vocational mechatronical training schools are teaching in an educational transdisciplinary paradigm, with *holistic-synergistic* problem solving or tasks distributed over time of training with increasing requirements to the learners, in a logic-creative framework. Through this new didactical tansdisciplinary concept is avoided the disciplinary distribution of learning contents into separate classes for different separated disciplines, whereas the learners had been left alone to find out the connections between these contents, fulfilling every one of the four didactical principles in the transdisciplinary field of mechatronical training paradigm (Grimheden, 2001).

Universities and vocational training schools with their links to industry are under an increasing pressure placed on them to expose disciples to real working environments in education and training of multi-skilled technicians leading to a new type of job profile which contains a mix of electrical, mechanical and IT knowledge, a mechatronical one. The mechatronician is a very new profession, so there are no sufficient elaborated didactical rules for mechatronical educators and disciples as well, only some first thoughts and empirical hints can be given. The new synergistic job profiles are created as a mix of mechanical, electrical and IT knowledge called mechatronical technicians and skilled workers which are to be trained for implementation and service using the education and training of engineers for design and manufacturing of mechatronical devices. Enterprises have come to realize that expertise is a vital and dynamic living treasure, their desire being meaningless unless an enterprise organization can develop it in ways that respond to its business needs. Many enterprises rely on formal learning (off-the-job training), but the informal learning (on-the-job training) can be more close to the problems to be solved (Jacobs & Jones, 1995), being organized in a synergistic way, crossing the borders between different professions that are involved in a project to fulfill the needs for customers. With a network structure, using well prepared training material usable at the workplace and facilitating advices from outside for synergistic learning makes informal learning a powerful tool, the experts working in projects as small groups of different professions to solve problems, learn how to learn and think critically, learn how to understand, identifying the skills needed to meet the requirements emerged (bottom-up learning-teaching) and developing a personal theory of management, leadership or empowerment (top-down teaching-learning) (Pop, Maties, 2008)

Conclusions

The transdisciplinarity knowledge achievement can explain the way the creativity, with a synergistic signification works, as an intentional action through ideas, design, modeling, prototyping, simulation. A very important conclusion is that real experience can not be replaced by learning with simulations, being necessary to use complementarily, the virtual tools as design, modeling, simulation and the real world representations as prototyping, building smart mechatronical products, as well. The vocational mechatronical training schools have to teach in an educational transdisciplinary paradigm, with *holistic-synergistic* problem solving or tasks distributed over time of training with increasing requirements to the learners, in a logic-creative framework with a new creative-innovative reflexive language to implement the very new profession, that of the the mechatronician, as the new synergistic job profile created by mixing mechanical, electrical and IT knowledge, in a context of a culture of expertise, for both, the enterprise (common place learning) and the individuals in it (personal process of learning-teaching) developing an active and interactive learning environment, called "instructional integration", in order to develop and create the new adequate technologies as the most effective way to integrate them in the design programs, as continuous learning activities. Expertise can be attained and promoted only through a synergistic learning and understanding process of achieving knowledge, in a creative background that should be integrated altogether with the technological, economical, ecological and ethical sustainability.

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