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A "CONCEPTS-ON" PROJECT ON UNDERGRADUATE CONTROL EDUCATION*

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Abstract: The relevance of the conceptual learning in control education is analyzed in this paper. It indicates a *concepts-on view* of control education. This approach, that already is the tacit model of classroom education, tries to complement recent control educational trends. In this context, it presents a recent project called "Virtual Control School" in development at the Federal University of Santa Catarina. This project tries to integrate pedagogical, computational and epistemological aspects in order to assist the control teaching and learning processes. *Copyright © 2002 IFAC*

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1. INTRODUCTION

Influenced by the information technology and because of the central role that control has in a automation based society, many works have focused on control education in the last decade. Many of them, such as Kheir et. al. (1996) and Heck (1999), are related to the undergraduate level.

Undergraduate control education is usually linked to traditional undergraduate programs, such as electrical and mechanical engineering. However, there is a tendency to the creation of specific control undergraduate programs. Bissell (1999), Dorato (1999) and Rodrigues (2000) approach this scenery in Great Britain, United States and Brazil, respectively. In traditional programs, a better formation in control would require a post-graduate course in the area. In control programs, however, four or five graduation years should be sufficient.

Originated in the Engineering, control has a technological nature. But the area differs from traditional areas because it is not connected to specific corners of the Science. In fact, it involves processes applied to science and technology in general. In addition to its technological characteristics, control education also has particular important attributes, such as, for instance, the higher level of abstraction of its concepts. For this reason, the dichotomy between theory and practice is specially relevant in this field. Kheir et. al. (1996, p. 150) describes it as two distinct thinking streams: one mathematical, focused on the definition and organization of the abstract concepts of control systems; and another physical and problem-based (control must be always controlling something). Bernstein (1999) presents several suggestions to reduce the gap between theory and practice in the undergraduate control education.

Heck (1999, p. 36) identifies three main trends related to the undergraduate control education: increase in the participation of modern control techniques in the curriculum; integration of computational technologies; and greater importance of control practical aspects. In all of them it is clear the influence of Information Science. Such influence has being decisive, for instance, on the development of modern control techniques and on the implementation of new educational methodologies.

The development and use of modern control techniques is an effect of the acceptance of such knowledge by the control community. On the other hand, however, the pedagogical and epistemological

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aspects of the other trends require a more consistent analysis.

It is important to contrast the traditional process engineer, like electrical, mechanical and chemical ones, and the control engineer itself. For the former, it is acceptable a general comprehension of the basic control concepts, while for the latter it is essential a deep and rational comprehension of the classical control theory and of the main modern control techniques. Unfortunately, in general, control engineering pedagogy is based on improvements over the control pedagogy applied to traditional programs.

It is also important to contrast the nature of the control knowledge and the traditional technological knowledge. While for the latter the knowledge is originally scientific, the control knowledge is metaphysical (Rodrigues, 2002). Therefore, if experimental work allows a straight and precise perception of scientific laws and its functional relations, the same does not apply to the control systems concepts, that are general and abstract. Physical aspects are the core of the scientific areas, but for a general area as control, they merely attach the key concepts, that are essentially mathematical and logical, to the reality. The metaphysical nature of control can be ordinary to the specialist, but it is not to the beginner, whose cognitive structure must be properly activated in order to well assimilate the control essence.

Information Science has been used in many ways to implement educational strategies in control education. Copinga et. al. (2000) shows an example of a planning tool that uses the computer aid on the management of teaching activities. Poindexter & Heck (1999) describes how to handle Internet to construct educational applications.

The practical tendency in control education itself is an effect of the capabilities of information technologies. It is possible, for instance, to develop local and remote simulation environments with direct manipulation where the behaviour of controlled systems and controllers are represented. Several works, such as Johansson et. al. (1998), Wittenmark et. al. (1998) and Bequette et. al. (1999), have described these kind of environments. In traditional courses, the intuitive notion of control can be obtained through such environments, but in order to obtain a solid undergraduate formation on control, they would only be used as a supplement of an effective conceptual learning.

Conceptual learning is particularly important on control because of its high degree of abstraction, but it has been few aided by Information Science. Additionally, an excessively practical curriculum in control would tend to decrease the students efforts assigned to the conceptual learning.

To address this reality, this work introduces a new educational approach called *concepts-on education*. It defends the creation of a conceptual kernel through an integrative process performed by control specialists (professors in most cases). This kernel constitutes a nucleus from where additional educational components can be joined. Concepts-on education is directly related to the metaphysical nature of control and to the conceptual learning. The implementation of such approach is specially feasible through the application of recent information technologies, that can promote collaborative activities.

The paper is organized as follows. In the next section, a general view of concepts-on education is presented. The study starts with an epistemological analysis which discusses the relation of this approach to the control knowledge. After that, the systematization of a local control community is analyzed, and some pedagogical aspects are considered, including specific points about laboratory education. Finally, elements about interpersonal capacity are lightly examined. Section 3 presents an example of concepts-on application called "Virtual Control School" (VCS). It presents its implementation context and outlines the joining of additional layers of educational aids. The paper ends with the conclusions.

2. CONCEPTS-ON EDUCATION

Concepts-on Education is based on a collective cognitive system where control concepts are cooperatively managed by the local control specialists community in a dynamic and continuous development. This conceptual structure, called Control Academy (CA), represents a kernel from where may be achieved additional layers to support the control learning and teaching processes. Control knowledge is abstracted and systematized through specific structures called "Knowledge" Items (KI). The logical linkage of such items through dependency or reciprocity relations constitutes the CA conceptual net.

Information Technology has a fundamental role to implement concepts-on education because of the level of integration required, where the knowledge information is the result of a collective construction and must be fully accessible by all the local control community, mainly the students. Some points related to this implementation are discussed in section 3.

2.1 Epistemological Aspects

Since individual constructions of knowledge are directly influenced by the way the objective knowledge is perceived, the epistemological analysis of an educational proposal is essential. One of the main blames pointed to the "traditional educational paradigm" is the perception of a static and finished knowledge that tends to be assimilated as a kind of rational dogma.

Dynamic side of knowledge, that is usually denied in traditional models, is recovered in the CA through a public and collective construction of its KI's. Students can watch or even participate on a process of constructing and validating local control knowledge. On the other hand, even a collective knowledge construction does not cover some relevant epistemological aspects. Thus, KI's also include related information other than the knowledge itself in order to improve its comprehension.

The knowledge inserted in the CA is already established in the control community. Thus, each KI should indicates the historical process of its knowledge, including a reference to first papers.

When presented to the knowledge, students in general miss a clear notion of its scientific, technological and social importance. This notion is usually thrown to the future. To cope with this reality, each KI should indicates the significance of its knowledge.

Other important epistemological aspects are the *exemplars* (Kuhn, 1971), that can be defined as standard cases that tend to reinforce a given paradigm. In control, the current paradigm is the classical control theory plus some extensions to modern control techniques. Bissel (1999, p. 46) presents some control exemplars: inverted pendulum, helicopter model, levitating ball, ball and bean, and coupled flywheels. Exemplars related to the KI's must be added in the CA in order to support the paradigm assimilation by the individual cognitive structures.

To stimulate an additional intuitive comprehension of control knowledge, the KI's may include on-line and off-line simulation cases. This closeness between simulation and its theoretical foundations enhances learning conditions because it allows students to analyse the intuitive and rational aspects of the knowledge in a integrated way.

Learning involves accommodating new knowledge in a cognitive structure that ever presents previous conceptions, as it is discussed in Silveira & Carmo (1999). These conceptions are usually biased in comparison to the knowledge itself. Their roots are the common sense, but they also can be stimulated by an education without epistemological concerns. In order to cope with this situation, each IK includes a specific area to handle such preconceptions before approaching the knowledge itself.

As mentioned previously, the CA substance results from a continuous development. Thus, the KI's will not be finished when created, but will be cooperatively refined by their control specialists. For instance, a specialist can introduce a new KI about the Laplace transform, while another includes its historical aspects, another indicates its applicability, and so on, in a improvement process without end.

At steady state, the CA is regulated by the synthesis of the individual knowledge and notations of the control specialists. It tends to mirror the local control community scenery in terms of knowledge. The CA also represents, thus, an alternative view of the traditional Cartesian perspective of a knowledge based on isolated courses.

2.2 Social Aspects

By structuring a conceptual medium to the local control community, the CA creates several possibilities to the practice of a formal scientific community. Therefore students can exercise their scientific nature alone or under the stimulus of the professors.

The specialists, that belong to the control community, are supposed to know the dynamic process of a scientific community. So they are able to manage the collective development of a local conceptual net, what involves objectivity, accuracy, mutual respect and other typical attributes of a scientific society. These specialists can perform the additional role of editors and reviewers of the CA. Indeed, the local community can be stimulated to directly participate on the academy development through asynchronous feedback or by theoretical articles. The epistemological aspects help to promote this perspective.

Another relevant social aspect is related to the feeling of an authentic participation. It arises from the close and transparent relations among the actors and the knowledge information. Everyone can be an active member of the community. Local specialists in turn are distinguished due to their manifest responsibility in the management of the CA. On the other hand, the relation to the global control community should be also strengthen. In this direction, the CA complements the conceptual net with information about the main control scientific societies, their main publications and meetings.

2.3 Pedagogical Aspects

One of the improper tacit beliefs instigated by the information technology development is the possibility of a computer-based education, recalling the teaching machines pursued by the behaviourism. In fact, teaching/learning is a cognitive relationship that comprehends an active dialogue between the cognitive structures of professors and students. The weakening of any side of such dialogue would eventually weaken the learning relationship. Therefore, a more active participation of the students should not mean a more passive attitude from the professors.

It is a mistake to depreciate the individual teaching experiences and/or to impose methodologies that just superficially will address the pedagogical problem. Teaching and learning depend essentially on the individual attitudes of their subjects, what emerges from their motivations and from the environment. Thus, Information Science must aid the traditional education, giving foundations to a better educational treatment of the knowledge, that really is the object of the educational process. Teachers must have the conditions and the autonomy to project the didactical activities considering their individual experiences and the pedagogical goals. Students must have a general comprehension of the education process in order to manage adequately their learning activities. The pedagogical relationship must be well defined and with clear responsibilities to their participants.

In the case of the professors, it is also important to mention that they are researchers too and many times have to perform bureaucratic activities in their departments and laboratories. Their teaching activities also include the maintenance of the pedagogical material of their courses. A little room remains to develop and manage additional didactical activities to extend the classroom teaching. However, classroom teaching, in its essence, already is a concepts-on education.

The foundations supplied by the CA allow the classroom concepts-on education to be extended in a consistent way. This is done by the direct linkage among the course curriculum and the KI's. Teachers can evaluate their courses comparing their curriculum to the curriculum of adjacent courses, decreasing curricular overlaps, very usual in undergraduate control programs. Students can have a plain view of the control conceptual net and be able to freely review preceding concepts or even to move forward on uncovered concepts. The undergraduate program can have a global view of its conceptual substance, what facilitates the definition of strategies to implement curricular improvements.

Information Technology still can complement the classroom direct communication through the electronic interaction among the actors. However, it is fundamental not to overload the activities, what would saturate the pedagogical process. The professor, in agreement with her/his classes, has the responsibility of defining the way such computational capabilities will be used. They can be applied, for instance, on the treatment of specific needs of the class or on the management of complementary works.

2.3.1 Laboratory Education

A particular question on the control pedagogical context is the laboratory education, with emphasis to the analysis in Kheir et. al. (1996, pp. 155-157) and Rodrigues (2000, p. 1471). While the classroom goals are the teaching of control concepts, laboratory goals are the comprehension of how to apply these concepts in the reality. It is natural, hence, that the relation among classroom and laboratory be polarised in the dichotomy between control theory and practice, what is partially incorrect.

Control application actually is a responsibility of automation. It is necessary, therefore, to distinguish two classes of laboratories: the control laboratory and the automation laboratory. The former is concerned with the consolidation of the control logical and mathematical concepts, using, for instance, mathematical tools like Matlab^{TM}. The latter is concerned with physical and practical aspects of the application of control in automatic systems. This distinction is also pertinent at the conceptual field. A control curriculum excessively “practical” tends to be in fact an automation curriculum.

A real laboratory could be at the same time a control and an automation laboratory. Considering these two realities, CA is a straight base to the control laboratory with experiments and simulations linked to the KI's, while it is just a conceptual reference to the automation laboratory. To completely address this second case, it is suggested the additional use of a hands-on methodology (see Silveira & Carmo, 1999). With a learning based on practical automation projects, hands-on implementation would be attached to a concepts-on implementation, complementing it on the automation pedagogical aspects.

2.3.2 Other Graduation Aspects

Kheir et. al. (1996, p. 153) states that “although general industry surveys indicate that new graduates often lack practical, hands-on experience, this is not necessarily the case with control system engineers”. According to the author, industrial needs includes a better formation in automation by the control engineers. However, it is unfeasible, for a control undergraduate program, to address in a deeply way all the automation aspects so that future control engineers would be able to cope immediately with any kind of automation problem.

Although, the most important needs indicated by industrials are the interpersonal skills, with emphasis to the team work aspects. This need is specially significant to the control engineer, because of the multiplicity of relations implicit in the engineer career, and the multidisciplinary nature of the control area.

Interpersonal skills are individual attributes, but can be strengthen by an integrative educational perspective enabling a better responsibility assignment to their actors. Social and pedagogical aspects of concepts-on education produce this integrative perspective and promote the application of cooperative pedagogical methodologies such as hands-on education based on team projects.

3. APPLICATION – VIRTUAL CONTROL SCHOOL

The neat ideas of concepts-on education are being exploited through the project called “Virtual Control

School" (VCS). Control School due to the focus on control education, and Virtual because of being attached to a real school, that is the Control and Industrial Automation Engineering at the Federal University of Santa Catarina (UFSC).

VCS has been developed in the hiperNet environment (Melgarejo et. al., 1991; Ramos, 1996). HiperNet is an HTML application managed by the UFSC Educational Software Laboratory (EDUGRAF – http://www.hipernet.ufsc.br). This cooperative environment is designed to decentralize the educational process and to improve conditions of individual and team education. All VCS participants are registered at hiperNet environment through their e-mail accounts, that can be used to perform, for instance, specific discussion groups. VCS has an improved interface, so that specialists are able to edit VCS components without further understanding on HTML.

In its implantation process, VCS in being introduced in the classical control courses (Linear Systems and Signals, Feedback Systems, Multivariable Systems and Non Linear Systems). Thus, initially it tries to address classical control needs in order to latterly introduce modern control concepts. For the first time it is being applied in the current school semester. In this first school semester, it is being applied to four Linear Systems and Signal classes in a total of approximately forty students with classroom and control laboratory activities. In this first stage, three professors (control specialists) of the Automation and Systems Department are cooperating. In the next school semester it must be extended to all classical control courses of the Control and Industrial Automation Engineering at the UFSC. Until now, the CA includes about a hundred KI's, such as Feedback, Automatic Control, Frequency Response, Systems Linearization, Sampled Signals, etc. Besides the analysed epistemological aspects, each KI still has bibliographical and electronic references and theoretical quizzes. Simulations on Java, Matlab™, or in any other electronic way can be directly included (VCS already includes several simulation cases).

To support the courses, VCS offers an initial structure that comprehends the following ingredients:

i. The curriculum, that directs to the CA related KI's.
ii. Pedagogical regulations concerning professor/students relations.
iii. A general reference bibliography.
iv. Classes planning.
v. Student information about performance and appearance.

The professors can freely extend this structure depending on their particular needs. Additionally, specific areas can be assigned to the students in order to, for instance, maintain their individual files. Each professor already have a specific area to keep its classes materials.

VCS complements pedagogical and educational areas with three additional ones: professional, institutional and social. The professional area indicates the regulatory entities and regulations of the control engineer profession, and also trainee and job opportunities. The institutional area indicates university and program regulations. These two former areas still contain several related information. The social area, in turn, is freely edited by all VCS participants, already presenting a comprehensive set of information about miscellaneous topics.

This is just a general view of what VCS is at this time. It is a project based on concepts-on education that tries to improve the application of information technology to the education on control engineers, a complex task in a society where the excess and misuse of information is a reality.

4. CONCLUSIONS

Information society creates several possibilities to apply information in all areas, including education. It is necessary, however, to use this potential in a rational and consistent manner. Taking in consideration the particular characteristics of control, this paper has presented a general view of concepts-on education and an outline of this implementation in the VCS.

This work arises from a need for the cooperative integration of different technological/educational aspects over the control conceptual kernel. Instead of trying to shift blindly the "traditional educational paradigm" in a "revolutionary" step, it tries to construct firm foundations to evolve the current educational context.

A complete and deep analysis of the substance of this paper will be covered by a thesis on control engineering education being performed in UFSC.

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