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Concept Maps and Learning Objects – Part 1

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***Abstract*— This work presents the first results of a part of a project under way that has a wide scope. This part of the project addresses the development of Learning Objects in Linear Time-Invariant Systems. This work communicates the use Concept Maps to identify topics in the area where Learning Objects must be developed. The final objective is that the products, the Learning Object, can be shared and reused among many disciplines in the undergraduate engineering courses of the university.**

***Keywords*— Concept Maps; Learning Objects; Linear Time-Invariant Systems; Signals & Systems; Electric Circuits; Electrical Engineering**

I. Introduction

The curricula of some courses (degrees) in the area of science and technology at PUC-Rio – Pontifícia Universidade Católica do Rio de Janeiro share many disciplines. Other courses have other disciplines that show large overlappings with the ones that are shared. This happens mostly due to historical reasons – disciplines were related to the departments that offered the courses and there was less interdisciplinarity

The case to be examined in a larger universe is a set of three disciplines offered by the faculty of the Course of Electrical Enginering. The first is Signals & Systems (S&S), the second is Electric & Electronic Circuits (E&EC) and the third is Controls & Servomechanisms (C&S). The first is a prerequisite to the other two. Table 1 shows the curricula that have one, two or three of them as mandatory. The courses are Control & Automation Engineering (ECA), Computer Engineering (EC), Electrical Engineering (EE), Nanotechnology Engineering (EN) and Computer Science (CC). At the same time, students of two other courses – Industrial and Mechanical Engineering often choose to take S&S as a way of learning more Math that is applied in Engineering. This happens mainly when students plan to go abroad in the international exchange program.

TABLE I
Courses and Disciplines

	ECA	EC	EE	EN	CC
Signals & Systems	Y	Y	Y	Y	Y
Electric & Electronic Circuits	Y	Y	Y		
Controls & Servomechanisms	Y		Y		

Electric & Eletronic Circuits is a prerequisite to other disciplines in the area of Electronics that are mandatory for EC, ECA and EE. These disciplines deal with nonlinear circuits – Analog Electronics, Digital Electronics and Power Electronics. This is an important remark, as it will be shown later on in this article.

Mechanical Engineering shares mandatory disciplines with Control & Automation that have redundancies in the area of linear systems. This happens because some disciplines are mandatory to the latter but not to the former. This situation emphasizes the importance of the topic addressed here. This will be commented later on in this work.

II. A Problem

At the end of the school year 2011, a problem was identified – the high percentage of students who did not pass Signals & Systems and Electric & Electronic Circuits – they either failed or dropped out. Figure 1 shows a time-series of the percentages of students who did not pass the disciplines in 6 semesters (2009-2011). In S&S the percentage was above 30% in 4 out of 6 semesters and in E&EC this happened in 5 in the same time frame. When trendlines are added to the lines of the figure, they have positive derivatives.

Faculty who teach these two disciplines examined data and decided that an action plan had to be implementd to change the trend – due to the importance of these two disciplines and to the prerequisites chain, failing one or both delays graduation. It is important to remember that the disciplines in the area of Electronics require E&EC as a prerequisite, as mentioned in section I.

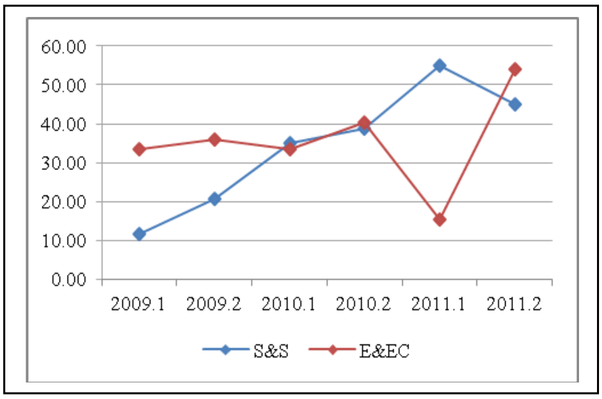

Figure 1. Percentages of students who did not pass S&S and E&EC in 6 semesters 2009-2011

To address this problem, a first and fast action was undertaken – additional homework was assigned to students on a weekly basis. Small projects, besides laboratory work, were added to E&EC. LMS supported discussion forums to address topics related to applications of DSP – Digital Signal Processing and to the history and results of Signals & Systems were included in the activities. Projects and discussion forums aim at motivating students. In order to make to easier for students to access digital contents, a new function was added to the Maxwell System – Elétrica On-line. It is an interface that integrates all EE related digital contents on the system – courseware, senior projects, theses & dissertations, articles, interactive books, etc.

At the end of 2012, results of the two new semesters will computed to assess if the trends changed to lower levels., i.e., if the new graphs have trend lines with negative derivatives.

A second action is under way – the development of additional courseware in digital formats – Learning Objects (LOs). A significant quantity of digital courseware has been available for many years [1], but simulators, vídeos and other types of animated objects had never been used. This is the focus of the second action whose preliminary results are presented in this work.

III. LEARNING OBJECTS

LOs can be an enhancement to traditional education as well as be used in distance learning. They can vary in contents and in types – from hypermedia topics to online simulators. There is a characteristic that good learning objects share – their development is both time and money consuming. This means that developing LOs deserves good planning both in terms of contents and technology.

Pavani & Luckowiecki [2] examined the use of digital libraries as a way of sharing courseware (they can manage learning objects by themselves, not only as parts of a discipline or a course) and Cardoso & Pavani [3] studied the case of the actual sharing of courseware on the Maxwell System (http://www.maxwell.lambda.ele.puc-rio.br/). Both works are more than 10 years old, but they reflect the concern of the Maxwell team of PUC-Rio with developing and managing course contents in a way that they can be shared.

At the same time, Wiley [4] presented a doctoral dissertation where the terms reusable chuncks of instructional media, reusable instructional components, reusable digital resources, reusable learning object (LO) were used.

The size of a “chunck” or of the “chuncks” in a colletion is known as the granularity of the LOs. This size, also referred to as granularity, is of paramount importance when chuncks are put together to create lessons, modules, disciplines, etc. This means when they are aggregated to yield bigger “chuncks”.

The definitions related to LOs and their structures are quite varied; some differ in the way they are viewed – from the size in bytes to time necessary to study them. A good overview of LOs is presented by Balatsoukas, Morris and O’Brien [5]. This work also addreses different content models, i.e., the levels of aggregation of raw materials, data, digital objetcs and even LOs to create other LOs. It is quite obvious that smaller “grains” allow more flexibility to aggregate them. A final stage of aggregation may be a certification course (degree) . But there are many levels between an image and a certification course, and it is convenient to establish a way to define the “chuncks”.

Since in [5] it is shown that there are many ways of defining and classifying LOs, a decision must be made concerning the granularity to be used. This is quite important because it impacts on the flexibility to aggregate and, therefore, share and reuse.

IV. CONCEPT MAPS – A BRIEF OVERVIEW

Concept Maps (CMaps) were created in the 1970s by Joseph D. Novak and his team at Cornell University (http://www.cornell.edu/).

A current work that presents CMaps in detail and also indicates examples of use [6] was taken as a reference to this part of the larger project mentioned before. In [6] there are two points worth mentioning.

The first, for those not familiar with CMaps, is their definition. They are ways of organizing and representing knowledge using graphical tools. They are composed of boxes or circles that contain concepts. Concepts are linked to one another by lines associated with words – linking phrases or linking words – that express the relationships between two concepts. CMaps are hierarchical with the most inclusive (more general) concepts on the top and the most specific (less general) ones in the lower parts of the graph. There can also exist cross-links, i..e, links connecting concepts in different domains (segments) of a CMap. A CMap can have large branches – the domains or segments.

The second point is that the authors suggest that before a CMap is created, it must clearly be defined the objective of the organization of knwoledge. They call it the focus question to be answered; it yields the context of the knowledge in the map.

V. STATEMENT OF THE SCOPE OF THIS WORK

This work deals with the development of learning objects to enhance the learning process of two engineering disciplines in which there has been a high failure rate among students. There is no doubt that the third discipline shown in table 1 will also benefit from the LOs since it addresses linear time-invariant systems too.

The two disciplines are in the set of three in the *Livros Interativos de Engenharia Elétrica (*Interactive Books on Electrical Engineering*)* [1]. In the books, there are almost 300 exercises in S&S and E&EC, plus almost 240 in C&S.

The characteristic of the books is that exercises are tied to a discipline and to a chapter. So, they are developed using the usual “boundaries” to fit them in. Besides this fact, they only contain exercises – there is neither contextual explanation nor a theoretical introduction to each.

The current project introduces two significant differences. The first is that LOs will be defined according to topics regardless of the discipline(s) they may belong to; they will not be fitted with discipline or chapter “boundaries”. The second is that each LO will be usable by itself besides having the potential of being aggregated to a higher level. If table 3 [5] is used, they will be classified in level 3 of the IEEE LTSC classification. This is an important characteristics due to the redundancies there exist among topics in different disciplines as mentioned in section 1.

This section presents the steps being followed in this development.

A. First Step – the Choice of Linear Time-Invariant Systems

Linear Time-Invariant Systems are important models to many engineering problems. They are very present in Electrical Engineering and also in other engineering courses that share disciplines such as Signals & Systems, Linear Circuits, Control Systems, Communication Systems, Digital Signal Processing, etc. Linear Time-Invariant Systems are also present in disciplines of the Mechanical Engineering course, so LOs can be also used in them. This reason helped strengthen the choice.

In the case under consideration, table I showed 3 disciplines that are almost 100% based on Linear Time-Invariant Systems – the exception is the part of Electric & Electronic Circuits that deals with analog electronics.

Due to the importance of Linear Time-Invariant Systems in different disciplines and courses, and to the fact that they permeate the syllabi of the 3 disciplines, the option was to develop LOs on this subject.

B. Second Step – the Identification of the Problem: Granularity to Allow Reusability

The number of topics that are contained in the broad name Linear Time-Invariant Systems is very large. At the same time, many of them are present in more than one discipline, if not as the main focus, at least as a prerequisite or a reference.

If other engineering courses are considered, as for example Mechanical Engineering, the same topics are studied in their own disciplines..

Considering the various disciplines of different courses, it seemed important to be able to define LOs whose granularity would allow them to be shared and reused. This could be done quite intuitively by faculty experienced in the area. At the same time, personal views and previous experiences could bias the decisions jeopardzing the share and reuse of LOs, specially if different courses were involved. It would be quite natural for faculty in EE to choose RLC circuits to study transient responses of 2nd order systems, while in ME the choice would be systems with a mass, a spring and a damper.

Besides this bias risk that intuition could bring, it would also lack theoretical bases. For this reason, Concept Maps were chosen as a tool to identify the sizes of LOs.

C. Third Step – the Use of Concept Maps to Identify "Grains"

Since topics in the subject Linear Time-Invariant Systems are spread in many disciplines, LOs have to be defined such that they can be combined (aggregated) in different ways in order to support the learning processes of the different syllabi; they can even belong to different engineering curricula.

The decision to use CMaps was made to allow the definition of the LOs to be less intuitive, though experience can challenge or validate results.

Following the suggestion in [6], a focus question was formulated. It is:

How to identify topics to yield shareable and reusable LOs in the subject area Linear Time-Invariant Systems.

This means that they can be combined in different ways to support the learning processes in different disciplines. The first 3 disciplines to be considered are Signals & Systems, Electric & Electronic Circuits and Controls & Servomechanisms. This was the easiest choice since they are under the responsibility of the faculty of the Electrical Engineering Course. After a proof of concept, faculty members of other courses can be contacted to examine and, eventually, use the LOs.

D. Wrap up of the Section

This section presented the decisions and actions related to the development of LOs to enhance the learning process of Linear Time-Invariant Systems. This problem came to focus in the analysis of failure rates among students in S&S and E&EC.

VI. The Implementation of a Concept Map for Linear Time-Invariant Systems

The use of CMaps presents two challenges. The first and most difficult is to be able organize concepts/knowledge – the first attempts are quite frustating! The second is the drawing of the CMap – if one decides to use paper, pencil and eraser it will be frustating too, because when a new concept, link or cross-link is identified, the drawing maybe ready to be discarded.

Novak and Cañas [6] are with the Florida Institute for Human and Machine Cognition (http://www.ihmc.us/). This institution developed and made available a software product called Cmap Tools (http://cmap.ihmc.us/) that makes it very easy to draw and redraw and redraw … a CMap. It is free and allows the results to be customized in terms of color, styles, etc.

The use of Cmap Tools removes the second difficulty. The first challenge is left and it is a big one.

A. The Actual Creation of a CMap for LinearTime-Invariant Systems – Assumptions

Once the focus question had been identified and the Cmap Tools had been installed, it was time to start "organizing and representing" knowledge.

The following assumptions were made to start defining concepts, links and cross-links.

1) Linearity and time-invariance was the strongest concept – therefore the concept at the highest level of the CMap: For this reason, the decision was to include all concepts and links that are under this huge umbrella. A clear definition based on the Superposition Principle (Additivity and Homogeneity) would be the starting point.

2) Signals: Systems are excited by signals and react to them; for example, filters process them and yield a new filtered signal in the output, while a motor receives a voltage signal in the input and modifies angular velocity and/or position in the output. For this reason, signals had to be included as a concept.

3) Signals can be continuous or discrete time: Systems can vary in nature – they can be continous or discrete time and there can be A/D and D/A conversions. This characteristic had to be included.

4) Signals can be represented in the time and/or in the frequency domains: According to the application under consideration, systems, and therefore their signals, must be represented in either domain. This concept was included to yield a part of the CMap devoted to transforms (Z, Laplace and Fourier).

5) Systems have characteristics that classify them and determine their models: Systems can be mono or multivariable and continuous or discrete time, even hybrid. The first assumption is that linear time-invariant systems are under consideration, so these two characteristics must also be presented – linearity and time-invariance. The characteristics imply in the types of models they must have.

6) Continuous and discrete time systems: Due to the decision in 1), the CMap would include both continuous and discrete time signals, something very important when A/D and D/A conversions and sampling are addressed.

7) Input-output and state variable models: The study of control systems implies in classic and modern methods. The first set is based on input-output models (both in the time and the frequency domains) and the second on internal variables (state variables) models. The correspondence between the two natures of models is addressed in the C&S discipline.

8) Time and frequency domain models: The use of input-output models can be both in the time and the frequency domains, and transfer functions play a key role in circuits, filtering, classic control, etc. Therfore, both time and frequency domain models were included.

9) Mono and multivariable systems: Many control applications require modelling with multiple inputs and/or outputs. For this reason, mono and multivariable systems were included.

10) Properties: Systems have properties that determine their behavior – stability, controlability and observability are the most common in the syllabi of undergraduate disciplines. Engineers must learn to analyze models in order to verify properties. Properties had to be included and closely related to models.

11) Modifying system behavior: Systems may require that their behavior be modified in order to satisfy design specifications for specific applications / functions. Thus the methods of interfering with system behavior (output and state feedback, controllers, etc) were included.

These assumptions were the key concepts to be used to build the CMap. They led to the exercise presented in the next subsection.

B. The Actual Creation of a CMap for LinearTime-Invariant Systems – First Attempt

Once the software was installed and running, and the assumptions were made, the first attempt to create a CMap could start.

After the first attempt, it became clear that the CMap would have two segments (domains): (1) signals; and (2) models.

It was also possible to visualize that the first was much simpler that the second. At the same time, cross-links appeared naturally. This version with the two segments did not get to a complete end; it was interrupted so that the results from the signals segment could be used.

An important conclusion of the first attempt was that the CMap would be large and complex, but this was a consequence of the highest level concept – Linear Time-Invariant Systems that is very broad. So it was not a surprise.

When the first draft was almost finished, there were more than 40 concepts. The authors [6] mention that, in general, 15 to 25 will suffice. For this reason, a decision was made that led to the current CMap.

C. The Actual Creation of a CMap for LinearTime-Invariant Systems – Current CMap

In order to start analyzing the results, a v1 of the CMap was created. In v1, the first segment was maintained and only the highest levels of the second segment remained. This happened because the lower levels of the second domain have weaker relations with the first.

Figure 2, at the end of the article, shows v1 of the CMap.

There is not doubt though that A/D and D/A Conversion will be linked to hybrid models as well as Transforms (Laplace, Z, Fourier, etc) will be related to model transformation (frequency domain $\Leftrightarrow$ time domain). The Transforms will also be related to the definition of transfer function and the relations with difference and differential equations in the input-output models in the time domain..

D. Preliminary Conclusions from the CMap for LinearTime-Invariant Systems

The CMap of figure 2 allows the identification of key topics for the development of LOs. They follow:

1) Superposition Principle: This is a key concept that allows the understanding of all topics that follow.

2) Classification of Signals: This topic is to introduce the concepts of continuous and discrete time signals and their representations (analytical, graphical and numerical). It is useful to set the foundation to analog and digital systems.

3) Sampling and A/D & A/C Converters: This topic is important in S&S, filtering, telecommunications and control systems.

4) Series and Transforms: This topic will yield many LOs since it contains: (a) Fourier Series for both continuous and discrete time signals; (b) Fourier Transforms for both continuous and discrete time signals; (c) Z Transform; (d) Laplace Transform; (d) Discrete Fourier Transform (DFT); and (e) Fast Fourier Transform. It will be a key topic for Digital Signal Processing (DSP) and Communication Principles.

This set of topics offers many possibilities of the development of LOs. The statregy for the development is addressed in the next section.

VII. LO DEVELOPMENT – NEXT STEPS

Currently, there has been activity in the development of LOs at the Electrical Engineering Department of PUC-Rio. A set of seven LOs is available from the Maxwell System, in the Series, under the title *Objetos Educacionais em Engenharia Elétrica* (Learning Objects in Electrical Engineering). The LOs are: (1) Half-wave Rectifier – a Nonlinear System; (2) Thévènin Equivalent Circuit; (3) Norton Equivalent Circuit; (4) Full-wave Rectifier – a Nonlinear System; (5) Linearity; (6) Mass-Spring-Damper System; and (7) RLC Series Circuit.

Six in this set of 7 LOs were chosen by suggestion of two faculty members – the ones involved with the action plan to enhance the performance of students in the disciplines mentioned in the beginning of this work. There was no methodology for the choice, except the fact that these are important topics and both are experienced in the area.

After CMap v1 was finished, the decision was to follow the topics presented in section VI while the second segment of the CMap is fully completed and analyzed. For this reason, a 7^{th} LO was designed and implemented – Linearity. The are some options for the immediate future that share almost the same level of importance / priority; decisions will be made taking into consideration avalability of content writers.

VIII. FINAL COMMENTS

This is a first set of results in the use of Concept Maps in defining LOs and an strategy to implement them. This work will continue in order to complete Linear Time-Invariant Systems. Development of LOs will go on according to the results of the use of CMaps.

A close examination of the disciplines in Mechanical Engineering is necessary so that topics that are key to this area are not ignored.

In parallel, the two faculty members involved in this project are examining the use of Concept Maps to analyze syllabi and eliminate redundancies that occur, specially with disciplines in Mechanical Engineering.

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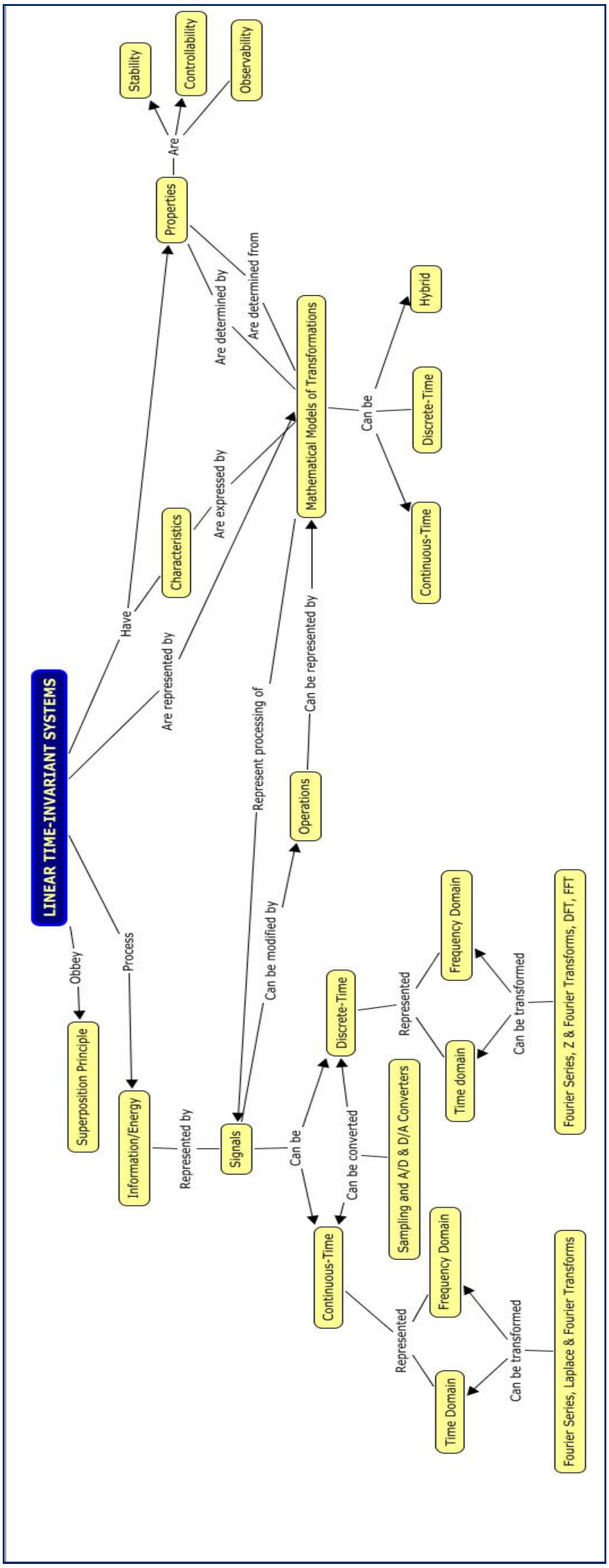

Fig. 1 CMap (v1) for Linear Time-Invariant Systems