# Learner-centered Activities for Engineering Students using a Dynamic Teaching Methodology

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*Abstract*— **This work proposes a series of activities to promote the motivation and curiosity of engineering students. The activities are designed and coordinated to progressively involve the student in the subject through the use of a dynamic methodology. The proposal includes monitored problem-solving, small application problems, cooperative activities and challenging problems. This methodology is tested in two student groups: second year students (Electric Circuits) and third-year students (Electrical Machines).**

***Keywords- learner-centered; dynamic; methodology.***

## I. Introduction

This paper describes a work in progress at the University of Málaga in Spain, so it is focused on the Spanish and European case. Spain is currently carrying out a process of change in universities to conform to the guidelines of the European Higher Education Area, which in the case of Spanish universities involves significant changes in different aspects of the education process, in particular regarding the teaching methodology [1]. In close relation with these changes, national programs have been developed to ensure the quality of the teaching activity at universities [2], and to verify the official studies (grade and master) [3] following the recommendations from the European Association for Quality Assurance in Higher Education (ENQA) [4]. All these efforts, along with the special issues from Bologna Process [5], call for a new way of teaching that involves students more directly in the learning process.

The traditional method in most Spanish universities, broadly speaking, consists of master classes with little or no student participation, and evaluation by a final examination. What is proposed here is a strategy for engineering courses in order to achieve a set of learning outcomes and, at the same time, to promote an entertaining and intellectually exciting experience. That is, to consider explicitly the affective dimension of the course. Although many methodological proposals have been made (e.g. Problem-Based Learning, (PBL) [6-8]), this work does not describe a single procedure or activity but a set of combined activities that improve the learner involvement, motivation and technical performance. Master classes with scarce participation of students can promote a passive attitude and hence a lack of motivation, which is widely regarded as a key aspect of the learning process, [9]. On the other hand, full Problem-Based Learning (PBL) is difficult to implement in lower courses with high number of students.

In relation to the adaptation to the new teaching requirements, many works have been developed focused on different aspects, like lab practice [10][11], learning outcomes [12], self-assessment tools [13], [14], using conceptual maps [15], or opening learning objects [16].

The main contribution of this paper is the definition of a strategy which objective is to obtain the best of the previous pedagogical methodologies using a mix that blends a wide range of activities. This procedure has been partially implemented in two courses at the University of Málaga, electrical circuits and electrical machines.

The paper is organized as follows. In Section II the general strategy is described, showing how the activities are integrated over one course. Section III contains a detailed description of the proposed activities, in Section IV the work in progress in relation to the practical implementation is summarized. Finally, Section V provides the conclusions for the paper.

## II. Proposed Methodology

The main objective is to guide the students to develop a work dynamic, both in class and outside the class, to maximize their learning outcomes, and to ensure that the process is an intellectually exciting experience. Learning outcomes are used to define what is required to successfully complete a module, according to quality standards [12], [17].

Many works regarding learning models, course materials, and other related issues have been presented. Most of the previous works are focused on particular aspects of the learning process, as self-assessment tools [13], [14], lab experiences [10], using conceptual maps [18], [15], or using open learning objects [16]. The main contribution of this paper is to propose a strategy that considers simultaneously the most of the issues involved in the learning process, for certain particular engineering courses, and combines a wide range of activities based on the main students' motivations, that is, considering the affective domain.

Maybe, this is more a strategy than a methodology. The implementation of the strategy consists of a sequence of activities that progressively involves the student in the subject, in a similar way as you are trapped by a good story when you start reading it.

The strategy lays stress on the affective domain as a medium to facilitate the achievement of the objectives. There are different sets of objectives and constraints to consider, for this reason a multi-objective optimization like approach has been followed. The objectives include:

- Facilitating the achievement of course milestones and learning outcomes.
- Making the process enjoyable and intellectually attractive, meaningful learning.
- Involving the students in their learning process, and making them aware of their responsibility about it.
- Giving a stimulating context, encouraging the students to go further in the subject by their own, with some guidance.

And the main constraints considered are:

- The available time, both for students and teachers.
- The socioeconomic context.
- Inclusion in the continuous improvement loop, and flexible adaptation to the changing conditions, (e.g. different students and different available technologies).
- Results must be measurable.

The implementation of this process involves (1) a work dynamic based on (2) students' motivation to achieve the objectives previously described. In what follows these aspects and the relation among them are described.

*1)* Regarding the work dynamic, the main points considered are:

- It must become self-supporting in a few weeks after the beginning.
- Measurable results (reference based on historical data from previous years):
  - More participation: participation rate in class, voluntary works, workshops, and in general, in the subject development.
  - Better achievements in terms of learning outcomes.

*2)* Students motivations. In order to asses the students motivations, several surveys have been used. One survey takes place at the beginning of the course; its objective is to collect information about their preconceptions and their expectations regarding the course. At the end of the course another survey is conducted to evaluate the level of achievement of the initial expectations and to collect suggestions to improve the implemented activities. The surveys results are summarized in the following list:

- Applicability of the learning outcomes. Students want to know the explicit links between the learning outcomes and the real world and how they could be useful in their lives.
- Curiosity. The students' main complaint is that they want to know how to apply the learning outcomes to understand the technologies that they find in the current market and the new technologies that are coming, and usually it is very hard, because there is a big gap between the two.
- Implicit competitiveness. Grades of some exercises are published, in such a way that each student knows his own grade and also the distribution of the rest of the grades of his classmates. The key point is that every student has the information about his position relative to the whole class; usually students are concerned when they are under the average of the class, providing additional motivation.

With all these objectives and constraints, the proposed solution for generating the objective work dynamic, is the following time sequence of activities, which relates learning outcomes and motivations on different time scales:

*1)* Getting involved. This part includes activities to be done at the beginning of each unit (or only once at the beginning of the course). The main objectives of this activities is to define the learning outcomes and to show explicitly its applicability to real life problems. The activities are called "motivation exercises", and work on real problems using a guide to analyze the problem. The objective is to generate interesting questions in the students' mind, like "how does it work?", "what are the physical phenomena involved?", "what do I know in relation with this?", "what do I need to know to find a solution?".

*2)* Generating the intellectual excitement. This part includes activities related with a particular block of contents, it should be done periodically, maybe once a month depending on the subject. The objectives of these activities are to put into practice the learning outcomes with real problems (problems related with real technology from every day life), stressing the link between them, and, at the same time, allowing the students to obtain information about their achievements and how to improve their learning outcomes. Also, the teachers get information about the main problems that students found, and which are the most interesting kind of problems for them, thus feeding the continuous improvement loop. Most of the problems in this stage have an unique solution. Activities in this range are: tutored problems sessions, implicit competitiveness exercises, small challenges (short problems), small projects (students have to search for additional information), assessment tests, cross scoring, and surveys for evaluating the process and collecting suggestions for improvement.

*3)* Keeping the intellectual excitement. The proposal here is to make two course projects, both of them very close to professional practice, the kind of work that a consulting engineer would do; of course, students will have additional guidance and support from the teachers. The first project must be finished by the middle of the course, and the other one before the end of the course. The objective of the first project is to gain experience, and to learn from errors. On their second project, it is important that the students realize that, the experience they already have makes the work easier and the results better. In general, the projects will have more than one possible solution, and students will need to search in technical journals and other bibliographic resources, and also, they will need to use their inventiveness. The projects will be prepared in groups, following the well-known methodologies of project-based learning and collaborative-work. In the upper courses, selected students (volunteers with great interest), could try to prepare a conference paper and attend the conference.

*4)* Encouraging to go further. This is the last stage in the course and, at this point, the students must have reached the objectives in terms of learning outcomes and to be able of continuing progressing in the subject by their own means. The proposed activity is to inform about other possibilities to continue working on the topic, or related topics, as for instance, to attend to other subjects (more advanced), collaborations with the corresponding department, conferences, workshops or other similar events.

This approach pretends to be flexible enough to adapt to new contexts, new students, and new social requirements, incorporating the suggestions of the implied agents, almost in real time.

A possible time sequence that combines the previous four stages is depicted in Fig.1, that shows the initial step (block I) to get the students involved, that is an activity in the short term (in terms of course time), activities for generating intellectual excitement every two or three weeks (block G), that are activities in the medium term, the block G is repeated three times before the first course project, block K, that contains activities in the long term, and after that, again some activities in block G are repeated every two or three weeks. At the end, the final course project, block K, and some activities to encourage to go further, block F. Block F could include activities from the short term to the long term depending on the course planning.

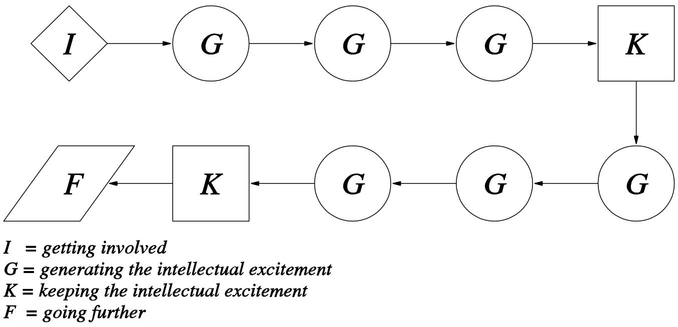


Fig. 1 Example of sequence for the proposed work dynamic

## III. PROPOSED ACTIVITIES

In this section the proposed activities are described in detail, even though, some of them have already been described in the previous section.

*a)* Motivation exercises: the objective is to generate interesting questions in the students' mind, like "how does it work?", "what are the physical phenomena involved?", "what do I know in relation with this?", "what do I need to know to find a solution?". These activities work on real problems using a guide to analyze the problem.

*b)* Tutored problems sessions: the students work on real problems (or part of real problems) on a particular topic. The main objectives are to promote participation, training and evaluation of the achievement in terms of learning outcomes. The students work in groups of 4-5, to complete the problem within the class time.

*c)* Implicit competitiveness exercises: it is a variant usually applied to the tutored problems, in which, the solution for each group of students is assessed at different stages, in real time, writing the score on the blackboard. In this way each group knows its own mark and the mark of the rest of groups, but they do not know exactly to which group corresponds each mark. The observed result is that, usually, the groups make efforts to achieve the highest mark, or at least, not to have the lowest mark.

*d)* Small challenging problems: they are very short problems in which students have to use, not only their knowledge about the topic but also their inventiveness.

*e)* Small projects: they are commonly a set of case based questions (maybe only one question). Students have to combine their skills in different topics, and search for additional information to answer the questions. They have to use their capacity of synthesis. This activity is based on the study case method, and it is a homework that can be done in 2-3 hours.

*f)* Course projects: they are the longest kind of activity in the course, in terms of time, and an average student could need up to 10 hours of work at home to complete it. Students work in groups of two or three, following the principles of project-based learning and collaborative work. The contents of these projects come from real problems solved in consulting engineering offices (maybe a small part of a real problem), that match with the topics in the subject. The principle is that it is necessary to use most of the learning outcomes in the course to complete the project.

*g)* Assessment tests: two types of assessment are considered, the first type are assessment tests that only try to obtain feedback for the continuous improvement loop, and information about the achievements in terms of learning outcomes. The second type of assessment tests are employed for the calculation of the final course mark.

*h)* Cross scoring: the problems solved within the class are scored in three stages. Firstly each student scores its own solution with the help of books, software or any other course material. Secondly the problem solutions are crossed so that each student scores the solution of another student. Finally the teacher scores the solutions of all students. The three scores are shown to the student aiming to promote self-learning capabilities and critical thinking.

*i)* Surveys: they are very useful to collect information about how the course is progressing and suggestions for further improvement. Three surveys are programmed along the course, one at the beginning for collecting the expectations, and other two, one in the middle and one at the end, both with the objective of getting information about the fulfillment of the expectations, the progress of the course, problems detected, and suggestions for solving the problems detected and general improvement.

*j)* Literature review: this activity is a part of both small projects and course projects. Students get a guide on the main bibliographic sources on the subject, how they are classified and rated, how to manage the information, the references, how to make filter search, and so on. The objective of this activity is to learn where to find the interesting information for solving problems, and for satisfying the curiosity about the current state of any particular type of technology.

*k)* Conferences, congresses, workshops: our experience tells us that, attending to, or preparing a work for some scientific meeting is a very encouraging activity for students, and that they become very satisfied with their work. In addition, students are interested in getting to know the authors of the articles and books they have read and studied during the course. This activity is reserved for students in the later courses of the degree.

The relation between the proposed activities and the learning outcomes, according with Bloom's Taxonomy, [19], are listed in Table I.

TABLE I. ACTIVITIES AND LEARNING OUTCOMES

| Activity | Cognitive Dimension | Affective Dimension |
|---|---|---|
| Motivation exercises | Analysis | Valuing |
| Tutored problems sessions | Application | Responding |
| Implicit competitiveness exercises | Application | Characterization |
| Small challenging problems | Synthesis | Characterization |
| Small projects | Synthesis | Characterization |
| Course Projects | Evaluation | Characterization |
| Assessment tests | Application | Characterization |
| Cross scoring | Evaluation | Characterization |
| Surveys | Evaluation | Valuing |
| Literature review | Evaluation | Characterization |
| Conferences, congress, workshops | Evaluation | Characterization |

## IV. PRACTICAL IMPLEMENTATION

In the following sections we describe how we intend to apply the concepts previously presented in two courses that some of the authors teach at the University of Málaga, Spain. The first of these courses is a basic course on Electrical Circuits that is a compulsory subject for all engineering students. The course is ambitious and needs to set the basis for a number of different courses that the students find later in their studies. The second course is also a basic course on Electrical Machines for students that select the electrical engineering specialization. Using the Electrical Circuits background, the students learn about the principle of operation, mathematical model and final application of electrical machines both in motoring and generating modes.

The methodology described in Section II and some of the activities described in Section III have been implemented in theses courses. In what follows the experience on the implemented activities is summarized and the ideas to continue the work are outlined.

### *A. Application to Electrical Circuits*

Electrical Circuits is a basic course that the students take on their second year at the School of Engineering. This course sets the bases for all advanced courses on the topics of electricity, electronics, power systems and many others. The course is usually full, with up to 100 students per class. The high number of students present in the course implies that any measure taken with them has to be very well prepared in advance. On the first year of implementation of the new methodology presented in this paper the authors consider that only a limited amount of innovation can be tested for practical reasons. In the following paragraphs we describe the different tasks that we have planned:

*1)* To start the course, a test was prepared for the students and distributed to them during the first class of the year, with questions concerning their interests and the ideas they had regarding the subject, this task corresponds to activity i in Section III. At the end of the academic year a very similar test will be presented to the students in order to be able to assess the students evolution during the length of the course. This task forces the students to ask themselves questions regarding their motivations with respect to the course they are taking.

*2)* One task that will be proposed in class will be tutored problems (activity b in Section III); this task will be very important in terms of final grades. Once every two or three weeks one hour of class will be devoted to this task. At the beginning of the class, the teacher will propose and explain in detail one problem from the topic that the students are currently learning in the theoretical classes and will form groups of 4-5 students. Each group of students will try to solve the problem and write the solution they find in a document that will be presented to the teacher at the end of the class; the teacher will remain in class helping the students clarify the problem and occasionally giving some hints regarding the adequate solution procedure. At the beginning of the following class, the teacher will announce the correct results for the problem and will hand the corrected problems back to the students. The specific problem used for this activity has to be very carefully chosen in order to select a problem that is neither too easy nor too difficult for the students considering their knowledge at that point of the academic year and their experience with the subject.

*3)* A variation from the previous task will also be implemented at least once during the year: tutored problems with cross scoring (activities b, c, and h in Section III). The first part of the task will be identical to the task described in paragraph 2) above, but a twist will be added on the next day of class, when the teacher will ask each group of students to correct the work done by some other group; the students will have a detailed solution available and will be asked to correct the work of their classmates. The teacher will at the end asses how the correction was made and will grade the correcting group of students accordingly. This task is very useful for several reasons, among them: i) it makes the students aware about their communicating skills and allows them to learn how to improve in that area; ii) the task also allows the students to critically analyze the work of their classmates.

*4)* Also, two or three times during the academic year, students will be presented with the possibility of providing their own examples to illustrate some concepts that are traditionally harder to grasp for them: Thevenin's Theorem, reactive power, phasors, etc, (activity e in Section III). For example, during the class that covers the topic of reactive power, the teacher will provide one of the more common analogies of the concept and will propose to the students that they also provide their own original analogies; one additional grade point will be rewarded to the most original and useful analogy presented by the students. This task forces the students to think outside of the class environment and to use their imagination and wit to solve a type of open problem that their rarely see during the regular classes.

### *B. Application to Electrical Machines*

The proposed methodology is applied to the Electrical Machines (EM) course aiming to promote motivation and curiosity. For this purpose, a top-down approach is adopted by starting with the industrial applications of the electrical machines and ending with the details of the mathematical modeling. This procedure helps the student to understand the final application of the taught content and this sense of purpose helps to maintain motivation throughout the course. The sequence of activities in the EM course can be summarized as:

*1)* The student is introduced to traditional and new industrial applications of electrical machines, including renewable energies (e.g. wind energy systems) or traction applications (e.g. plug-in electrical vehicles) to name a few. This task corresponds to activity a in Section III.

*2)* Standard theoretical lectures are developed next to provide the student with the basic knowledge about EMs. This part of the course is however shortened compared to previous years and more test questions are included within the theoretical explanations.

*3)* Problems in which electrical machines are used are synchronously solved by the students during the class in cooperative groups (activities b and c in Section III). Each group selects a speaker to discuss with the teacher the solution of the problem. The group needs to internally discuss the solution of the problem but only the speaker provides the solution. The problem is then scored and the different groups compete with each other while the teacher acts as a supervisor. Examples of this type of problems include the copper mining industry where a 2 MW synchronous motor is used to smash the raw material in a mill or the wind energy industry where a 4 MW permanent magnet synchronous generator is used within a full-power topology with back-to-back converters. The applications becomes the context and the questions are exclusively related to the operation of the electrical machine (e.g. reactive power capability). This part of the course serves to promote cross competences related to leadership and team-work abilities.

*4)* In addition to the problems solved during the class, extra problems are proposed to the students to let them solve the problems in advance. The solution is provided later on by the teacher in standard blackboard methodology.

*5)* After the students have the theoretical background and have been trained in group and individual problem solving activities, a project related to electrical vehicles is proposed (activities f, and k in Section III). The solution of the project can be individual or in groups and it implies a 10% of the subject final score. This project goes beyond the complexity of the problems previously described in 3) and involves some additional aspects which are not directly related to EMs but to the electrical vehicle application (e.g. electronic converter, control, drive topology). A DC motor is considered for the propulsion system of the vehicle. This type of machine is selected for the sake of completeness since previous tutored problems where related to the synchronous machine both in motoring and generating mode of operation. Although some of the content of the project is not directly related to electrical machines (e.g. batteries), it shows the students related topics and final application of the course content. The score of the project is explicitly shown and the best project is converted into a conference manuscript and submitted for evaluation as a reward for the students.

In addition to the previous undergoing activities, the following ideas have been proposed for future implementation:

*1)* Cross scoring: the problems solved within the class are scored in three stages (activity h in Section III). Firstly each student scores its own solution with the help of books, software or any other course material. Secondly the problem solutions are crossed so that each student scores the solution of another student. Finally the teacher scores the solutions of all students. The three scores are shown to the student aiming to promote self-learning capabilities and critical thinking.

*2)* Class challenging problems: although the teacher constantly aims to challenge the student, special short problems with a non simple solution can be used during the course to challenge the student (activity d in Section III). For example, the lecturer may raise the question 'Why one should avoid operating a synchronous machine with a load angle of 90 degrees?' or propose a demonstration 'demonstrate the expression of the reactive power in salient-pole synchronous motors'. These problems would be presented during the class but should be solved afterwards. The problems can be tagged as challenging problems to promote competitiveness among students and a reward in terms of public acknowledgement would be advisable.

*3)* Assessment tests: A series of short test questions can be used to review the main concepts of the subject (activity g in Section III). Students can be asked "If a synchronous motor is operating in overexcited mode, the power factor is:", and then provide as solutions "a) inductive", "b) capacitive" or "c) one". These test questions can be uploaded a web-based platform so that the students can verify their subject skills and knowledge at any stage of the subject. The platform used at the Universidad de Málaga offers self-scoring after any test try and explanation of the reason why the questions have been failed. This tool is basically an opportunity for the student to self-evaluate and have an idea of his main weaknesses in relation to the subject content.

## V. CONCLUSION

A learner-centered approach to teaching introductory electrical engineering concepts has been proposed as an effective tool to improve student motivation and satisfaction results. Most of the ideas presented in this work were geared toward applications to electrical circuit and electrical machines. The research has shown to be very effective for student learning in different contexts.

As a first observation of the work in progress, we conclude that we must develop more realistic case studies and examples as well as pedagogical patterns for evaluating the learners evolution and performance. We also must find ways to facilitate customization of the curriculum to different contexts.

## ACKNOWLEDGMENT

The authors would like to thank University of Malaga for supporting this work through the Project of Innovative Teaching PIE10-024.

## REFERENCES

[1] J. Hernández Armenteros, J. A. Pérez García, and J. Hernández Chica. "La Universidad Española en Cifras. Información académica, productiva y financiera de las universidades españolas. Año 2008. Indicadores Universitarios." Technical report, Conferencia de Rectores de las Universidades Españolas (CRUE), 2010.

[2] Agencia Nacional de Evaluación de la Calidad y Acreditación (ANECA). "DOCENTIA. Programa de apoyo para la evaluación de la actividad docente del profesorado universitario." Technical report, ANECA, Spain, 2007.

[3] Agencia Nacional de Evaluación de la Calidad y Acreditación (ANECA). "VERIFICA. Protocolo de evaluación para la verificación de títulos universitarios oficiales (grado y máster)." Technical report, ANECA, Spain, 2011.

[4] European Association for Quality Assurance in Higher Education. ENQA report on Standards and Guilelines for Quality Assurance in the European Higher Education Area. ENQA, Helsinki, Finland, 3rd edition, 2009.

[5] Ministry of Education and Culture, Ministry of Science and Research, Austria. "Bologna process 1999-2010. Achievements, Challenges and Perspectives." Technical report, 2010.

[6] W. Daems, B. De Smedt, P. Vanassche, G. Gielen, W. Sansen, and H. De Man. "Peoplemover: an example of interdisciplinary project-based education in electrical engineering." Education, IEEE Transactions on, 46(1):157 – 167, feb 2003.

[7] F. Martinez, L.C. Herrero, and S. de Pablo. "Project-based learning and rubrics in the teaching of power supplies and photovoltaic electricity." Education, IEEE Transactions on, 54(1):87 –96, feb. 2011.

[8] D. Santos-Martin, J. Alonso-Martinez, J. Eloy-Garcia Carrasco, and S. Arnaltes. "Problem-based learning in wind energy using virtual and real setups." Education, IEEE Transactions on, PP(99):1, 2011.

[9] A.J. Saavedra Montes, H.A. Botero Castro, and J.A. Hernandez Riveros. "How to motivate students to work in the laboratory: A new approach for an electrical machines laboratory." Education, IEEE Transactions on, 53(3):490 –496, aug. 2010.

[10] X. Mu, D. Walter, H. Xu, P. Walter, and C. Berry. "Work in progress - video-based lab tutorials in an undergraduate electrical circuit course." In Frontiers in Education Conference, 2009. FIE '09. 39th IEEE, pages 1 –2, 2009.

[11] I. López-Paniagua, R. Nieto-Carlier, J. Rodríguez-Martín, C. González-Fernández, and A. Jiménez-Álvaro. "Clases prácticas: Una herramienta esencial en la enseñanza de las ingenierías en el marco del Espacio Europeo de Educación Superior." DYNA, November 2011.

[12] M. Dodridge. "Learning outcomes and their assessment in higher education." Engineering Science and Education Journal, 8(4):161 –168, August 1999.

[13] E. Guzman, R. Conejo, and J.-L. Perez-de-la Cruz. "Improving student performance using self-assessment tests." Intelligent Systems, IEEE, 22(4):46 –52, 2007.

[14] D.T. Rover and P.D. Fisher. "Student self-assessment in upper level engineering courses." In Frontiers in Education Conference, 1998. FIE '98. 28th Annual, volume 3, pages 980 –986 vol.3, November 1998.

[15] J. Turns, C.J. Atman, and R. Adams. "Concept maps for engineering education: a cognitively motivated tool supporting varied assessment functions." Education, IEEE Transactions on, 43(2):164 –173, May 2000.

[16] L. Li, H. Shi, Y. Shang, and S. Chen. "Open learning Objects for Data Strcture Course." Journal of Computing Sciences in Colleges, 8(4), April 2003.

[17] Declan Kennedy, Áine Hyland, and Norma Ryan. EUA Bologna Handbook - Making Bologna Work, chapter C 3.4-1. EUA, Berlin, 2006.

[18] J. D. Novak and A. J. Cañas. "Theory Underlying Concept Maps and How to Construct and Use Them." Technical Report CmapTools 2006-01 Rev 01-2008, Florida Institute for Human and Machine Cognition (IHMC), January 2008.

[19] B. S. Bloom. Taxonomy of Educational Objectives, Handbook 1: Cognitive Domain. Addison Wesley Publishing Company, 2nd edition, June 1956.