TEACHING MECHANICS FOR REAL.
A DIFFERENT APPROACH FOR CIVIL ENGINEERS

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ABSTRACT

In most traditional engineering schools in Chile, Mechanics is a fundamental course taught by physics professors, using a theoretical approach which often disregards what civil engineers do. This usually creates a gap in a student's learning process, who must later apply these theoretical fundamentals in structural courses, which are usually taught by civil engineers. Therefore, students must be re-taught to think about mechanics in an appropriate context, and, by doing so, these fundamentals finally make sense to them.

This paper describes the experience of a mechanics course for Civil Engineering students at UCSC under a CDIO approach. This initiative considers several CDIO standards, but mainly active learning (CDIO Standard 8), context of civil engineering (CDIO Standard 1), hands-on activities for building systems and structures (CDIO Standard 6), among others. This course employs several active learning strategies, of which PBL (problem based learning) is the center piece. But what differentiates the most this initiative from others that also use PBL is the type of problems employed. We use more complex-real cases, which are a way of taking CDIO Standard 1 to a different level. By the end of the course, students are highly motivated, use critical thinking and show higher proficiency levels on standard and higher learning outcomes as well as other skills.

KEYWORDS

Active learning, Problem Based Learning, Project Based Learning, experiential learning, engineering education, Problem Solving Workshops (PSW), engineering context.

INTRODUCTION

I have been teaching the Mechanics course at UCSC over the last 14 years and this is the first time that this work is presented publicly. Therefore, this is not a pilot study or a new experience, but the result of 14 years of a trial-and-error process full of successes, mistakes, research, innovations, discoveries, hard work and, most importantly, a change in the hearts and minds of those involved in this process. Due to the lengthiness of this experience, different strategies and methodologies were tried out through the years, getting therefore a pretty good idea of what works and what doesn't. It's important to point out that, as engineers, our approach is completely opposite to that of someone from the education field. At the beginning, I had no theoretical background regarding education and the first efforts came from common sense, experience, and a very down-to-earth and practical vision of how things work. This challenge was approached in a way any engineer would approach a challenge: seeing it as a process and therefore trying to continuously improve it. This clearly differentiates engineering professors from colleagues of the Education Department; and without even knowing it, I was applying a CDIO approach to the Mechanics course. Through the years, terms like skills, active learning, student centered, etc., started to resonate through engineering schools worldwide, and I was able to attach the proper labels to many of the things that I was already doing, and learned more theories and techniques that facilitated my work even more. Therefore, I went from a practical to a theoretical approach versus the opposite, most common route.

The Mechanics course described in this paper is the core course for the structural engineering discipline within this program. Note that what is presented here only regards the Statics part of the course which in this case represents 80% of the course.

How are we teaching Mechanics to Civil Engineers?

In many traditional engineering schools, mechanics is a fundamental course taught mostly by professors from the physics department. As with most science courses in Chilean universities, it has direct hour activities (lectures, assistantships and labs) and indirect hours (self study), whereas lectures represent 60-80% of the direct hours. As seen in Figure 1, students have an active role mostly during the indirect hours, leaving them in a passive role during the rest.

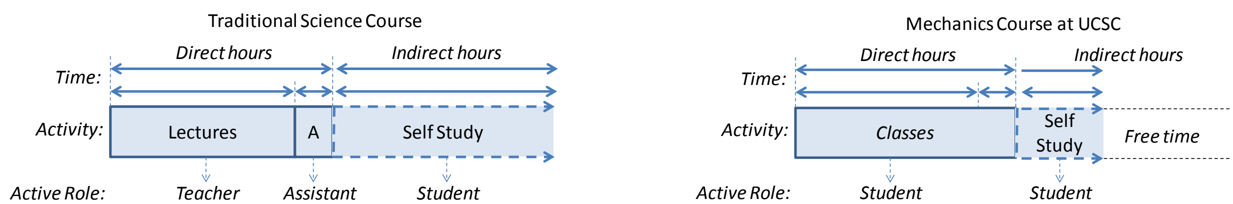


Figure 1: Structure of a traditional science course v/s UCSC Mechanics course

Exercise Solving:

The long lists of exercises that students must solve outside of the classroom do not necessarily lead to significant learning either. Instead, it ends up mechanizing the student in the art of exercise solving but not necessarily understanding what or why they are doing it [2]. At some point students stop questioning the fundamentals and go on an *exercise solving loop*, which can become quite an addiction. They stop questioning, they stop reflecting, they stop thinking; they just solve, solve and solve. We like to call this *automatic pilot mode* [2]. Therefore, in our experience, students apparently master the art of solving certain problems, but once you start to scratch a little under the surface by asking them questions about their work or changing a specific part of the problem, most students are not able to follow through. This is a very big issue for civil engineers, as their job is precisely solving new and complex problems. We believe this may be due to some or all of the following:

- These lists are mostly textbook problems that are not applied to civil engineering situations, disregarding engineering learning outcomes.
- These problems are not designed to lead to reflection or analysis.
- Most of the times the problems are not solved in the presence of the teacher or assistant, so as to ask them questions. In fact, in these cases students rarely get the chance to solve a problem in the presence of the teacher. Normally, the teacher or assistant solves a few problems for them and then they expect students to do the same on their own at home. Therefore, when they're on their own, there's no one to ask questions to, and even with today's information technologies, it's hard to get the answer right away.

Our main concern is that this exercise frenzy is a common practice, but people don't seem to take into account the true consequences of this practice, resulting in a false sense of security in terms of results of the students' learning process.

Context of what Civil Engineers do:

The traditional approach is strongly theoretical, with little context regarding what civil engineers do. Normally, these courses rely on traditional lectures, but even if they have an active learning approach, there is still a gap in the learning process. Students must later apply these theoretical fundamentals in a new and unknown context once they reach the higher-level structural courses that are taught by civil engineers. Are they able to cross that gap on their own and understand the application of all these fundamentals in the field of civil engineering? Experience has proven that only a very small number of these students are able to do so on their own; therefore, teachers have to re-teach students to think about mechanics in an appropriate context, and by doing so those fundamentals end up making sense to them. It's important to point out that I'm not saying that these courses can't be taught by a physics professor. So it's not about how good or bad the physics professor is, but whether he knows what civil engineers do and the practical usefulness of the topics seen in this course, as the context of mechanics for a physicist is completely different from that of an engineer. But how much context is enough? And what do we understand by context? This is a crucial question and one of the innovations of this experience that is address further on in this paper.

Why Change?

Decades ago people used to think that getting good grades meant that they were learning everything that they needed to know. Nobody questioned the educational system. It was the only system we all knew and it seemed to work. Even today, and in spite of all the evidence, there are still people saying things like: *"I went through the traditional system, and I didn't turn out so bad!"*. Well, you could respond back: "You're right, it could've been worse". This response may seem a little drastic to some, but when you take into account that every person invests at least 12 years of his/her life in education, you expect to get your money's worth, but we know that's not the general case. Instead of really learning, we were momentarily memorizing [4], otherwise we would remember everything that was taught to us. According to Zull [4], we should expect our students to say: "I not only know the answer but I also understand it" [4].

Additionally, in the School of Engineering at UCSC we have to deal with serious deficiencies in our freshmen students [2] & [5], since we're not receiving the best high school graduates. But it is in our mission and belief to form competitive world-class civil engineers, so the gap that needs to be covered is even greater, therefore the need to change.

THE LEARNING PROCESS

In order to design and teach a course you first need to understand the learning process. The mechanics course's design takes this into account and below some of the main theories and models that have been considered and incorporated are summarized.

David Paul Ausubel first talked about ***meaningful or significant learning*** back in the Sixties [6] and his theories are still valid today. Research has led us to believe that students have different **learning styles** that depend on personal characteristics, the environment and/or on how the student approaches the learning process. Ronald Schmeck [7] defines 3 types of processing or learning styles that develop different types of skills, as shown in table 1.

Table 1: Schmeck's Learning Styles [7]

Learning Style	Type of Skill Learned
Superficial	Basic skills: Copy, repeat, name, memorize, execute…
Elaborative	Elaborative skills: Compare, deduce, contrast, classify, infer, sort…
Deep	Complex skills: Discover, analyze, create, synthesize ...

Traditional teaching styles focus on Schmeck´s first level of learning. There is little significant learning and students end up forgetting an important part of what they have learned in following semesters. In other words, students might remember or memorize but not necessarily understand, which is consistent with Zull's saying [4]. Schmeck [8] also states that by developing a deep-elaborative style, students also improve their capacity to memorize things in an effortlessly way and spend more of their study time thinking and less time repeating. *"They classify, compare, contrast, analyze and synthesize information from different sources. They elaborate by thinking of personal experiences, visually imagining personal illustrations and restating information in their own words."* In order for students to reach deep-elaborative levels of learning, teachers must use different ***learning strategies***, like active learning [8].

Kolb's Experiential Learning Cycle [3], leads to deep-elaborate or significant learning. The traditional teaching approach only considers two of these stages. It starts with the abstract conceptualization (theory) and then moves on to the next stage, but in the mechanics course we follow all 4 stages, as can be seen in figure 2.

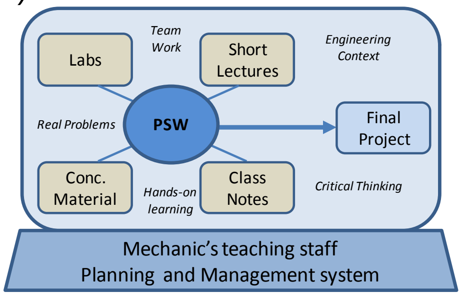
Therefore, teaching strategies must consider a wide and diverse range of active learning activities in order to consider and/or change students' learning styles, leading them towards deep-elaborative and significant learning.

MECHANICS COURSE

The Mechanics course at UCSC was first redesigned in the year 2000. Since then, it's constantly being improved, but the main methodological approach still prevails. I will refer to the course as it is today, and will make no attempt to describe its evolution, unless it's strictly necessary.

As explained earlier, the current format of this course is the result of 14 years of a trial-and-error process. Although all the major changes were implemented before being familiarized with CDIO and the authors' theories, they are very coherent.

In a nutshell, the mechanics course is far from being a traditional course. It considers 7 of the CDIO standards [1] and has learning outcomes that take into account the context of civil engineering. It does not have a traditional structure: Problem-Based Learning (PBL) is the backbone of the syllabus (as opposed to a set of programmed lectures), along with hands-on activities that use concrete materials for building systems and structures. There are no lectures or assistantships in direct hours, simply classes, where in 90% of them students are engaged in solving problems in small groups (Problem Solving Workshops: PSW), with the guidance of the teaching staff. There are still a few lectures, but always in the context of the problem that students are working on at that moment. The set of problems that structure the course are designed to introduce all the *fundamental tools and skills* only when they are needed (*just in time*).



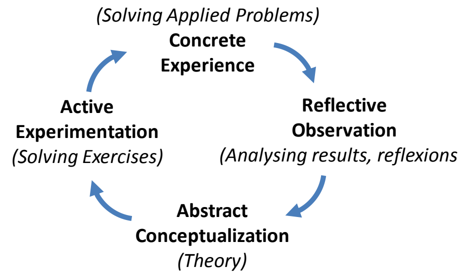


Figure 2: Mechanics Course Model and Kolb's Learning Cycle Model (Adaptation) [3]

Learning Outcomes and Civil Engineering Context

How do you put a 2nd year science course in the context of civil engineering? That has been a constant concern for us and we have come a long way since our first attempts back in 2000 (there was no CDIO back then). One of our first convictions was that going through Civil Engineering at UCSC should be a little like going to a boot camp. Our students have all kinds of deficiencies, not only cognitive [5] & [9]. As many other youngsters in our country, they have serious problems writing and reading comprehensively and on top of that they have other upbringing deficiencies due to the fact that many of them come from low-income families. In Chile there is a direct relation between the person's family income and their education status. Therefore, you can't expect them to reach the professional learning outcomes (2, 3 and 4 of the CDIO Syllabus [1]), in a few or final courses, they must "work them" from the very start.

The main engineering, interpersonal and personal learning outcomes considered in the mechanics course are presented below and are consistent with the CDIO Learning Outcomes:

- Students must read technical information comprehensively and be able to follow written and verbal instructions (this is very important because civil engineers use codes, which are being updated all the time).
- Students must be able to work with others as a team when solving engineering problems.
- Students must be able to identify, formulate, solve and then analyze engineering problems. This requires not just a systematic approach and cognitive skills, but also the capacity to think in a critical and systematic way.

Aside from the standard cognitive learning outcomes of a mechanics course for engineering students, this course considers a few more that have to do with the context of civil engineering. These are presented below, in no particular order:

- Students must understand the basis of how structures work, in terms of external forces, role of joints and supports and how structures transmit those forces, in order to put the mechanics course in the context of what civil engineers do.
- Students must be able to visualize and understand complex 3-dimensional structures and calculate its geometrical variables.
- Students must be able to identify and understand the effect of forces over structures (in 2 and 3 dimensions) in terms of possible movements (translation and/or rotation)
- Students must be able to formulate and model (simplify and formulate assumptions, build the free body diagram, etc.), complex 3 dimensional hyperstatic structures.
- Students must be able to formulate, simplify if necessary and model real structures and analyze the effects of forces and moments.

Course's Structure

The course is structured as a set of problems designed to introduce all the learning outcomes that a student should become proficient in throughout the course, at the precise moment that they're needed, as seen in figure 3. Therefore, when planning out the classes, we don't program lectures; we program Problem Solving Workshops (PSW).

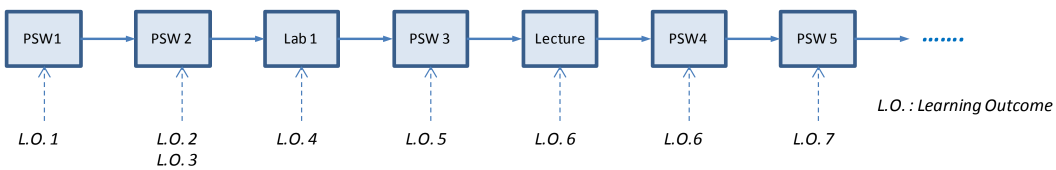


Figure 3: Problem Based structure

These PSW are the backbone of the Mechanics course and their design is very important in order to meet the criteria that was set up. This is further addressed down below.

Due to the PBL approach, this course does not have the classical lectures and assistantships. Instead they just have classes, in which they can carry out different activities. These activities (active learning activities) can be PSW with or without the use of concrete material to build models or structures, short interactive lectures or classroom labs. PSW take up nearly 90% of the time.

PBL and PSW

The PSW have to be designed in order to meet certain standards. The learning outcomes are mapped along the whole set of workshops. First, we divide the course in the main cognitive themes (for example, statics of a particle in 2 dimensions, static of a rigid body in 2 dimensions, etc.). A set of PSW are designed for each theme, and they must be structured as shown in Figure 4.

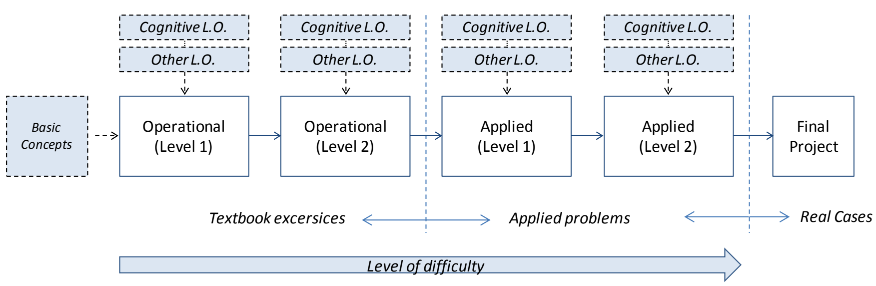


Figure 4: How PSW are structured

For each theme, we design 4 different levels of PSW. The ones on the left side we call operational exercises. They have 2 difficulty levels and their objective is for the student to master the operational aspect of solving this kind of problem. These textbook-type exercises don't take much into consideration the engineering context. The ones on the right are applied problems, also with 2 levels of difficulty. The first level deals with applied problems of less difficulty that can be solved using Newton's laws. The second level considers more complex structures (hyperstatic), that cannot be solved using Newton's Laws, but the objective is for the student to learn to formulate these more complex real life cases and to analyze the effect of forces and moments over the structure. The concepts or cognitive learning outcomes are introduced within the workshop throughout the semester, as are the other learning outcomes. In order to determine when to introduce a specific concept or tool, the following criteria must be followed: “If you’re not going to use, it, then it’s not time to introduce it yet.” When designing these problems, we’re very careful not to put everything in at once, it’s a process, and they can’t deal with everything from the beginning, it’s overwhelming. This is precisely what happens with traditional long lectures, it’s just too much information to process. Our students deal with real facts and structures (bridges, buildings after the earthquake, warehouses, etc.), and must read most of the information. In the end, students must prepare their own project, for a real situation.

Introductory Lecture

At the beginning of the semester the course’s learning outcomes and methodologies are explained to the students, as well as the reason why the course has been designed in this way. This is done though an introductory lecture on learning process and learning styles. These students have some self esteem issues, due to their social background; therefore we give them a little pep talk and challenge them: Where do you want to be in Schmeck’s learning level? We also always procure to keep a healthy work environment in the classroom. Therefore, it’s very important that they know what is behind these methodologies in order for them to be more open and less resistant.

Lectures

There are very few formal lectures and students must read in advance the teacher’s notes on the subject which are available on the Moodle platform. Mostly, there are short interactive lectures that are given in the context of a specific problem. Most new concepts are introduced to the student through the problems that they have to solve. They are not previously warned about a new concept, they just run into it. Students normally try to solve the problem anyway, and when they can’t continue, they start asking questions. That’s the moment when the teacher stops the workshop and gives a short lecture on the specific topic. These short lectures are planned ahead, since by designing the PSW, we know exactly when students won’t be able to make progress anymore.

The key is to give the short lecture once the students get stuck and not before. This is much more effective because students are hungry for this explanation. They know exactly what they don’t know in order to move forward, so the teacher’s explanation falls right into place. This is what we call just-in-time lectures and is highly effective.

It’s important to point out that all lectures are interactive. The teacher always carries concrete material to the classroom that is used to help student visualize better what the teacher is explaining, and the teacher must relate to the students in an interactive way. You can’t just explain, you have to engage the student by using lecturing active learning techniques, such as questions.

Course Planning and Management

This is a very important part of the job, it’s the control center. The course’s teaching staff is the team behind the course. It’s integrated by the teacher and a group of advanced and well-trained student assistants. We work as a team and plan and assess the course together, holding weekly meetings to evaluate the work done during the previous week and to plan ahead the next week.

Team Work

Problem solving is done in teams of 2-3 students. Students are not accustomed to working in teams. They normally gather up in groups where each student works on their own problem and at the end they compare results or ask questions. In this course, students are guided in their team work by a few basic rules, with the teacher/assistant playing a specific role. First of all, students are told to read and analyze the problem handed out to them. Then, they have to discuss the problem with their group and come up with a strategy or systematic procedure to approach the problem. Students are not allowed to work on their own until the group discussion session has ended. After this, they can carry on working individually on their problems. Another rule is that when they have a question they first have to ask the members of their own team. This work does not evolve around solving exercises, but on analyzing and reflecting on each problem. Peer assistance is of great help. Only in the case that they can't come to an answer, they can call on the teacher or assistant. The teacher or assistant never answers the question directly, but instead she or he asks the students more questions in order to guide them into getting the answer on their own. Student assistants are trained to do this. It is expected that these groups improve their performance throughout the semester. It's very important that the students' learning processes occur within the classroom under the presence of the instructor.

Hands on Learning and the use of Concrete Materials:

Computers can do wonders with their graphics and high resolution, but in our opinion, in mechanics nothing beats the use of concrete materials. Physical models and structures let you use all of your senses when analyzing it. You can look at it from all directions and you can actually touch the third dimension, something that can't be done with a computer.

Over the years, we have observed over and over again how these models help students understand much more not only the spatial dimension of structures, but also make sense out of such an abstract concept as moment, simply by rotating these structures.

Although teachers have better-quality scale physical models of the problems being solved, students are also able to build simple and functional models during the class, by using sticks, plasticine and string.

Classroom Labs:

Labs are a more experiential approach [4], designed by the course's teaching staff. Basically, it's a hands-on experience that allows students to understand certain concepts or theories better by manipulating certain concrete materials. These activities are structured and systematic and are carried out inside the classroom or outdoors.

Assessment

For the Mechanics course several sources allow us to assess the learning outcomes: traditional tests, portfolios, lab reports, final project (presentation and written report), feedback from peers that receive these students in the following course and our direct observation. All these tools are useful, but one of the most powerful assessing tools is direct observation on an almost daily basis. The teaching staff gets to know all the students, their strengths and weaknesses and by the end of the semester, you really know who knows and who doesn't.

RESULTS AND FINAL CONCLUSIONS

The results presented in this paper are mainly qualitative, and they don't cease to amaze us. Students show a higher proficiency level on standard learning outcomes for a mechanics course, but tackling problems of a much greater difficulty level. In this course they start developing critical and systematic thinking skills. But most importantly, we get highly motivated students that understand the bigger picture putting their learning in the context of what civil engineers do. They're more reflexive and question everything, as opposed to just accepting what the teacher says. They're more eager to think and analyse new problems on their own (more autonomous).

Active learning is, without any doubt, much more effective than traditional passive teaching techniques. In the case of the Mechanics course, students learn much more during their classes, since they're doing all the work, and they can clarify all their doubts right away. Therefore, in my experience, it reduces the amount of indirect hours that students must dedicate to this course. Therefore, they learn more, better and in less time. The differences with respect to traditional approach were already shown in Figure 1.

Since 90% of the time students are working under guidance, the teaching staff get to know all of the students early on in the semester and also get immediate feedback from the students in the classroom. Therefore, by the end of the week, the staff has a pretty good idea about the students' learning process, which is useful in the weekly planning meeting, having the chance to adjust the activities and programming according to the students needs. Quantitative and formal assessing tools are of great importance. However, working directly with students gives a direct feedback that you can't get through formal evaluations. This working style also creates stronger bonds with the teaching staff, which has a positive impact on the students.

Although students tend to embrace this new approach, at first it's not that easy for them. They're used to their passive role in the classroom leaving all their work for later, once they get home, so making them work in the classroom takes them out of their comfort zone. At the beginning of the semester the staff observes that most students are not autonomous, they're not used to working in the classroom and they are not used to taking responsibility for their learning process. Also, they have difficulties working as a team when solving problems in the workshops. Normally students just "group up", and solve problems by themselves and then compare results. Therefore, this is a big struggle for them at first, and the role of the teacher/assistant is crucial, but by the end of the semester students are more autonomous and responsible.

PBL approach is very effective in this type of course. At first it seems impossible to go without the lectures, but it can be done. Teachers are so used to explaining things that they have a hard time realizing that some things explain themselves and that our students are smart and can get there on their own to. Teachers have to prepare the environment and guide their students' learning process.

This initiative is like a small island in the middle of the ocean. What being done with this course is a lot of work for the staff and the students, so it's almost a pity that once they finish they have go on to the next course that is traditional. In some cases students have no problem going back to their old ways (bad habits die hard), but in other cases students start to resist traditional teaching. In the last couple of years, faculty from the structural discipline have started an informal teaching community. Up to now we discuss students' strengths and weaknesses when they take the following course and they're performance in general and we also share experiences and methods. We came to a point where we had the need to formalize and systematize this, so we're now part of the recent teaching community at our school and we're on our way to formalize a smaller teaching community of just structural engineering. We have been granted university funds for this, and our first mission will be to once again revise the structural course sequence in terms of learning outcomes and methodologies, and transfer the mechanics course experience to the other structural courses.

Having a good teaching staff is of great importance. None of this would have been possible if I hadn't counted with this team. But maintaining such a high quality team is hard work. Student assistants must be carefully picked out and systematically trained and after a few years they must leave, so this is a continuous process that has been carried through the years.

REFERENCES

[1] Crawley, E., et al., "Rethinking Engineering Education: The CDIO Approach". Springer Sciences + Business Media LLC, New York, 2007.

[2] Meza J., Carrasco C., Loyer S., Morales J., García F., "Information Technologies as a support of the Teaching Learning Process: A Practical Experience.", REXE: Revista de estudios y experiencias en educación, Volumen 2 (N° 3), 2003, 135-147.

[3] Kolb D.A., "Experiential Learning". Prentice-Hall, Englewood Cliffs, NJ, 1984.

[4] Zull J.E., "The art of changing the brain: Enriching teaching by exploring the biology of learning". Stylus Publishing, LLC., Sterling Va, 2002.

[5] Loyer S., et al., "A CDIO approach to curriculum design of five engineering programs at UCSC", Proceedings of the 7th International CDIO Conference, Technical University of Denmark, Copenhagen, June 20-23, 2011.

[6] Rodríguez L., "The Theory of Significant Learning", Proceedings of the First Int. Conference on Concept Mapping, Pamplona, 2004, 535-544.

[7] Tufello I., "Strategies of private learning: a theory and its field application", Pensamiento Educativo. Revista de Investigación Educacional Latinoamericana, Volumen 16 (N° 1), 115-119, 1995.

[8] Schmeck K. R., "Improving Learning by Improving Thinking", Educational Leadership, Volume 38 (N° 5), 1981, 384-385.

[9] Muñoz M., et al., "Active Learning in first-year engineering courses at Universidad Católica de la Santísima Concepción, Chile", Proceedings of the 8th International CDIO Conference, Queensland University of Technology, Brisbane, July 1-4, 2012.

BIOGRAPHICAL INFORMATION

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