PROBLEM-BASED LEARNING IN ENGINEERING EDUCATION

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Abstract - *The repass of well defined actions, when correctly applied and at the appropriated order, leads us to the solution of the problems. That is part of the engineering education. The learning process depends on the teacher's expertise and knowledge upon the techniques to deal with problem solutions. In this sense, the disciplines of the engineering courses are structured to transmit a complex whole of techniques. Many exercises are solved in classroom, being all of them well- structured problems. It means that each problem accepts a numerical solution, that is generally associated with the application of one algorithm. It's of great importance to teach solution techniques, but it has to be teached along with the methodology that drives the problem identification, formulation and analysis. Otherwise, students would solve the problem without understanding what was being expected, what was really being asked, and they would end up not exploring the non conventional alternatives and not having the consciouness of the logical process that is being used. Students, in this case, are not able to transpose the theory adapting it to practical situations. So, the term "problem solving" ends up having a narrow meaning and a limited aplication as an instructional strategy. When we deal with real situations, the problem solving tends to have a wider comprehension. One problem is first detected when it is realized that something is not working as well as it should or is not being accepted as it is. The problem solving involves the transformation of the actual state into a desirable or acceptable one. The engineering education despite being mainly structured upon knowledge transference based on problem solving techniques, does not explore neither discuss the use of available methodologies. With this in mind, the objective of this paper is to review the main methodologies related to problem solving, and to evaluate the introdution of Problem-Based Learning as an instructional strategy in Engineering Education.*

Teaching under a Problem Solving View

To teach very defined actions, that if applied correctly and in the appropriate order leads to problem solving is part of engineering teaching. The "cookbook" way to introduce the subject is still actual. The domain of the solution technique strongly influences the problem's formulation; it is the teaching dependence upon the teacher's expertise.

Find the solution of the problem it is important, but if unaccompanied by the methodology that guides the process of the problem's definition, its analysis, the rising of alternatives and choice of the alternative's solution conduce the student to:

- do not have the conscience of the mental process used to solve the problem, so he doesn't get the ability to describe it;
- do not use a method to solve problems;
- get involved with the problem without understanding what is asked; and
- do not explore the alternatives that are not conventional.

The engineering courses are structured around set of objectives. Each course has a set of solution techniques to be taught at the theoretical and practical levels. Each solution technique is presented, and then applied to a selected example problem in class, followed by assignment of a few preformatted exercise problem as homework. At the exam time, students are supposed to show their ability in applying a technique to solve a new problem [3].

The engineering teaching mostly leans on the transmission of knowledge in the solution of problems, without the necessary involvement with the systematization of the decision process. The vital information is usually omitted, the symptoms are not observed or they are told incorrectly, and the expected result is not always known or understood. In this category are the ill-structured problems.

At the moment that more information are collected (precise and significant information), the problems begin to take form, to have a better structure for analysis. These are called well-structured problems, and they are solved starting from a sequence of very defined steps which have a correct, answer.

The term "problem solving" has a narrow meaning in engineering education, due to the "classroom problems", *i.e.*, the exercises and assignment proposed, whose solution is summarized to the choice of the technique to solve it and the derivation of the appropriate answer, usually numeric. The approaching of solving the "class problems" can be, by itself, a problem for the newly graduated engineers that will be placed in the market.

Organizations use a more general concept for problem solving. The problem is initially detected by noticing something doesn't work well and it is not accepted in its form or current state. The problem's solution looks forward to modify the current situation into a wanted or acceptable state.

A Theoretical Approach to Problem Solving

There are many relative contributions to the meaning and strategies involving the problem solving and they have such a diversity of aspects that would not be possible to summarize them here. Therefore it was opted for selecting some contributions regarding this theme, especially, the aspects directly related with teaching-learning process.

A neo-behaviorist approaching is given by GAGNÉ [6], for whom the solution of problems is "a learning type that habitually requests internal elements called thoughts. Two or more principles previously acquired are combined in a way to produce a new capacity that can indicate the dependency of a principle of superior order"

According to the author, this learning type has two basic characteristics in problem solving:

1) it is a learning type that involves the combination of principles previously learned into a new principle of superior order, that solves the problem and extends it to an entire new class of situations that has problems of the same type;

2) it demands to discover the principles of a superior order without any specific verbal aid, what doesn't mean, however, that no orientation should be given to the student. On the contrary, specific level of instruction should be supplied to reduce the time of the searching and choosing, what, however, won't decrease the significance of the obtained result.

GAGNÉ [6] also alerted that if the teacher presents the principle of superior order to the student, that concept will be learned as a simple verbal chain and not as a discovery. In that case, the learning won't be significant and it won't be shown resistant to the forgetfulness.

Traditional researches concerning problem solving were mainly based on three models: 1) the one that Dewey proposed as a regular sequence of temporary stages of the reflexive thought; 2) the gestalts, oriented to the required condition for occurring the problem's solution (they emphasize person's previous experience and the ideas reorganization, interacting with the problems' aspects); and 3) the one based on stimulus-response, behaviorists and operating centered in the trial and error conception, habits and reinforcement contingencies [7].

There are several variations of Dewey model elaborated by other researchers [4], where problem solving is stated as a specific type of learning. This proposal, a lot similar to the one proposed by Dewey, supplies a structure from where heuristics are elaborated, understood as operational rules for the solution of the problem and directed to the teachers. The proposal's stages are:

1. **identifying the problem**: several situations come with many potential problems, students should be guided to notice the problem when it comes upon;
2. **formulating the problem**: noticed the problem, the students should be able to describe its complexion, structure and values;
3. **looking for solutions**: by gathering data and by their own ideas students should formulate possible solutions to the problems;
4. **selecting an approach**: if there are several solutions for the problem, the student should be guided to select the more adapted one to the situation;
5. **implementing and evaluating**: the chosen solution is put on practice and its applicability, toward the aim objective, is analyzed. If the current solution is not accepted, new solutions are tried.

A cognitive focus on problem solving is supplied by AUSUBEL [1], when he affirm that: "the solution of any problem supposes the reorganization of the last experience reminders, and adapted to the concrete requirements of the current situation." To this statement other aspects are included:

- the existent cognitive structure is an important key to the problem solving, once the concepts, principles and standards previously learned constitute the aim to problems' solution;
- if the problems' previous knowledge are clear, stable and discriminated, its resolution will be facilitate;
- without that previous knowledge any solution are possible, independent of the skill that the student has to solve it ;
- without such knowledge, the student cannot even understand the nature of the problem that is to be solved.

According to the nature of the problem two main classes: solution by trial and error and solution by discernment. The focus on the trial and error consists of the variation, approaching and correction of answers, done at random or in a systematic way, until the correct answer is obtained [1]. The discernment already supposes the "willingness" for the discovery of a significant relationship between means and ends, that is made through hypotheses formulation and confirmation.

Many other studies and projects research have been published about the procedures involving engineering's problems resolution. Some authors relate their efforts to teach the students more effective techniques to solve problems and others emphasize the stages or strategy to be adopted.

Problem Solving Strategies

CORL [3] attests that several models have been proposed, with different stages or phases that allow the identification of the problem and its solution [8, 9].

WOODS et. al. [12], define problem solving as "the activity whereby a 'best' value is determined for an unknown, subject to a specific set of conditions", they identified this activity as a group of stages that combine analytic and creative thought, denominating it Problems' Solutions Strategy. Drifted rationally, the strategy demanded that the students should concentrated on a stage at the time and, simultaneously, they should discuss each idea with the others.

An interesting result discussed by those authors was that, although they presented countless suggestions of how to solve problems and varied examples, students didn't capitalize on those suggestions or examples. And they concluded that, probably, they failed because its contributions in class were made orally and not on the blackboard. They also concluded that engineering's teachers although are capable to specify the process that is used to solve problems, they have difficulties to transmit it to the students. Possibly because theirs actions are oriented by the practice and experience that they possess.

A careful analysis of that literature suggests, basically, the following points:

- it is indispensable to develop the ability to identify (to define) the problem or what is being to be solved. Therefore, the student needs to be trained to identify the unknown variable of a problem and to recognize the important details supplied in its formulation;
- planning the problems' solution is also very important, mainly on those that are considered most difficult and complex. Experiences with the development of a general strategy benefit the problems' solution no matter which group they belong to;
- doesn't matter how good the strategy is, it doesn't release previously consolidated knowledge and the expertise;
- different types of problems request different competencies, varying from simple problems to more complexes and abstract ones;
- the practice is indispensable so the student could develop its own style in problem solving. There are not procedure, method or technique that can be considered good enough to solve every problem. From varied experiences, students acquire confidence and skills in order to develop a work method.

Based on the contributions here described, it can be inferred that problem solving is a complex process, constituted of several abilities and, one of them could be causing difficulties for the student. In that case, the teachers' task is to discover what is causing the difficulty to the students, so they can help them to overcome it. In this way, forward it is described an instructional strategy based on the problem solving, aiming to evaluate the potential of its use in engineering education.

Problem-Based Learning

Engineers deal with systems that result from generic subsystems as well as customized ones. Few literature has been published about what would be a normal or expected performance. Frequently, engineers come across unique systems that were created to full fill specific or even eventually needs. As consequence, the engineers should integrate their knowledge and experience on each new system that comes across on their professional life, attempting to identify, to prioritize and to correct problems.

Problem-Based Learning (PBL) may be described as an instructional method characterized by the use of real world problems, as a context for students to develop critical thinking and problem solving skills, and acquire knowledge of the essential concepts related to the course. Using PBL students acquire life-long skills, which include the ability to use the appropriate learning resources.

This method, used to engage the students on the learning process, is based on two basic points of cognitive theory. First of all the students works on the problems graded as significant or important, and second they try to obtain more information when facing a situation that they don't understand it at first.

The process begins with the teacher presenting the problem to the students, that in groups research, discuss, get explanations or even recommendations on how to solve the problem by their own. It is a interactive process, composed by the following steps [5]:

1. **Present the problem statement**– introduce on ill-structured problem scenario to students, that should not have enough prior knowledge to solve it. This means that they should obtain the necessary information on the problem, learning new concepts or skill, as soon as they engaged in the problem solving.
2. **List what is known** - student groups list what they know about the presented situation. This information is kept under the heading: *"What do we know?"*. This may include data from the problem as well as information based on prior knowledge.
3. **Develop a problem statement** - the problem statement should come from the students' analysis of what they know. The problems' delimitation will probably be refined as new information is discovered. Typical problem definitions are usually based on incongruities, discrepant events, anomalies or stated needs of a client.
4. **List what is necessary** - presented with a problem, students will need to find the necessary information to understand and to solve the problem. A second list should be prepared under the heading: *"What do we need to know?"*. These inquiries will guide the searches that may take place on-line, in the library and in any other place, out-of-class.
5. **List possible alternatives action or hypothesis** – at this time and under the heading: "*What should we do?*", students list actions to be taken (for example, consulting an expert) and formulate and test tentative hypotheses.
6. **Present and defend the solution** - as part of closure, teachers may require students to

communicate, orally and/or in writing, their findings and recommendations. The product should include the problem statement, questions, data gathered, and support for solutions or recommendations based on data analysis.

Students should be encouraged to share their findings on-line with others, making use of available technologies. Students must be encouraged to divide the work through a delegation of tasks. Some students may be working on the computer, while others are finding written references, interviewing experts or using other audiovisual aids.

To deal with an ill-structured problem stimulate students' perception that they need more information than is initially presented to them. Missing information will help them understand what is occurring and help them to decide what actions, if any, are required to solve the problem. In that kind of problem there is no right way or fixed formula for conducting the investigation.

Each problem is unique, and problem changes as new information is found. The processes to get information are varied, and lead students to look for new processes, when the current one is no longer desired or when the interaction with other students shows its necessity. Students make decisions and provide solutions to real world problems, working on a process defined by all the students. This means there may be no single right answer.

Students familiar with the traditional 'talk and chalk' classroom are likely to be uncomfortable with the PBL format for some time. It will be up to the teacher to convince students that they are researchers looking for information, and solutions to the problems. Students usually want to know what they really have to do in order to get their grade. They will expect the teacher to describe what should be done. Students used to the "cookbook", may feel uncomfortable with the new profile looked for on the new proposal.

Teachers that are not familiarized with the Problem-Based Learning (PBL) are in for some surprises. Moving into a non-conventional instructional mode may appear risky, scary, and uncertain at the beginning. At the first time using this method, teachers may be tempted to give students too much information key-words or to simplify excessively the problem. Complexity of scenarios have been shown to increase students' motivation and engagement.

When using the PBL method in classroom teachers should act as metacognitive consultants, thinking about the solution along with the students and stimulating the conduct that is expected from them. Students should get used to questions like: What is going on here? What do we need to know more about? What did we do in an effective way?

Several reference books can be consulted on the subject, offering a lot of complimentary references [2, 10].

Final Remarks

According to VASILCA [11], there are three fundamental objectives that the modern engineering education should contemplate. Firstly, it should provide students with knowledge that has enough breadth and depth. Secondly, it must ensure that engineering education meets the demands of tomorrow's corporation. And thirdly, it should provide engineers with a better foundation, with the ability to upgrade knowledge and skills over life-time period.

Some experts recommend that continued education should valorize the postures, values and habits that promote the personal growth. Engineering students should acquire reasoning capacity, be engaged in decision making process, improve the ability to solve problems and to interpret computational results correctly.

The engineering education process must change to respond adequately to the current needs, to identify the threats and the opportunities, and internalize actions that adjust to the changing process or to the educational engineering process.

To determinate what is wanted and then establish what will be the necessary resources to reach the goal is a compatible attitude toward quality demanded and productivity on engineering teaching. Abandoning the illusory idea of efficiency in favor of the effectiveness means to recognize that more important than to use the resources properly to get it well done, is to get it well done the correct activity by itself.

In spite of those ideas not been recent discovered, neither unknown, the cognitive aspects enchased on them are not discussed. The cognitive aspects of learning can't be visualized and are hard to evaluate. The teacher indeed doesn't really know what the student learned, if they learned what was taught or what the student wanted to learn. Therefore, it can be possible that values and negative faiths has been incorporated, what would lead to an incorrect knowledge and mistaken actions.

It is necessary that the engineers develop the ability to adapt to the new reality, creating new work opportunities and not just exploring the existent ones, but getting prepared to deal with creativity and flexibility, and not just to reproduce well-known solutions.

The main questions placed here are: How to adjust and prepare the new type of engineer? How to structure the Engineering Education to face the challenges of the 21th Century?

It is vital that the students should not only know the techniques, but mainly know why and when to apply them. It also should be reminded that the obsolescence can come to be a problem, once the engineering education process stays supported basically on a stable and cultivate structure of technical knowledge for the past years. The technological cycle of life is getting shorter, when compared to the educational cycle of life in engineering, what demands an additional care with what is taught in schools.

A new teacher's and student's posture is longed for at the new scenery. More emphasis will be given to the learning process. Therefore , the technology and the methods of problems' solution should be strongly add to the teaching-learning process.

The future, certainly, will be different from the past and from the present, and this is why we can not continue teaching what was taught, and on the same way. Team work, initiative impulse, multiple intelligence and creativity, shortly will be a part of the professionals' day life jargon, at companies and at teaching institutions.

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