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STRUCTURAL DESIGN LEARNING BY BUILDING REDUCED MODELS

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ABSTRACT
Teaching engineering design through *project-oriented learning* and *learning-by-doing* methodology leads to the enhancement of engineering design skills, where the target is to cast the theoretical and technical knowledge through the solution of a specific design problem. The aim of this paper is to present a learning-by-doing experience by underlining its impact on the student's motivation as well as the faced difficulties. The multi-disciplinary aspect of this approach is seeing as the most important point in this experience. Beside the technical aspects, these projects have largely improved the perception that the students may have on structural design.

Keywords: Structural design, Learning-by-doing, Multi-disciplinary analysis

1 INTRODUCTION

Students learn in many ways [1], by seeing and hearing; reflecting and acting; reasoning logically and intuitively; memorizing and visualizing and drawing analogies and building mathematical models; steadily and in fits and starts. Teaching methods also vary. Some instructors lecture, others demonstrate or discuss; some focus on principles and others on applications; some emphasize memory and others understanding. Mismatches exist between common learning styles of engineering students and traditional teaching styles of engineering professors. In consequence, students become bored and inattentive in class, do poorly on tests, get discouraged about the courses, the curriculum, and themselves, and in some cases change to other curricula or drop out of school.

Traditionally, the education of strength of materials, theory of structures and structural design, is carried out through theoretical courses, illustrated by some simple exercises and experiments for student groups. With the increase use of analysis and design software, this learning has been enhanced by computer-based lessons. However, understanding the principles of structural behavior as well as design process still remains virtual in the student's mind. The confusion between basic ideas and principles is probably due to the large amount of information that the engineering student has to compile. It is always necessary to remind them that our final target is not compute, but to design, and accurate computation is just a tool and not a goal.

Moreover, there were an increasing trends to emphasize engineering science and theory. Recommendations to add more science and mathematics requirements to the engineering curriculum were directed at helping engineering students better understand the complex principles involved in modern technological developments. The courses that often were eliminated as a consequence were practical courses in shop,

manufacturing methods, and design. The shift toward more theory in the engineering curriculum has produced graduates with far less experience in the practice of engineering and design than those of years past. In many schools, senior-level project-oriented courses have been developed recently in an effort to bring the practical side of engineering design back into the engineering curriculum. Such courses provide an experiential learning activity in which the analytical knowledge gained from previous courses is joined with the practice of engineering in a final, hands-on project [2].
In the French Institute for Advanced Mechanics (IFMA), several courses are dedicated to structural analysis, design and optimization as well as material mechanics, characterization and appropriate choice. The whole curriculum is based on a large project-oriented strategy. However, it seems that the learning outcome of such a strategy depends on the project subjects and types (theoretical, numerical, practical), on the involved skills (knowledge levels and requirements, experience, project complexity) and on the supervision context (academic, industrial,…). The observation of this type of learning showed that some projects are very useful and some are only reduced to the application of already developed skills. During the whole curriculum, it has been tried to vary the subjects and types of projects for each group, in such a way that students can navigate between theoretical, numerical and experimental works; but optimal solution is not easy to find. There is still another difficulty, which is the harmonization between the courses planning and the required project skills.
The experience that we carried out in the last two years, is to define a transversal learning-by-doing work which defines a complete design problem, starting from the client needs and going through the design, the material selection, the fabrication and the realization of the reduced models of the structure. The project is carried out by small groups (3 students) within an allocated time interval, and under the supervision of a teaching staff. The evaluation of each project is given on the basis of mechanical performance (mass-compliance criterion), of creativity and innovation, and of esthetic aspect. The conclusions obtained from the project evaluation can be used as a feedback in the optimization process.

2 LEARNING PROCESS

Learning in a structured educational setting may be thought of as a two-step process involving the reception and processing of information. In the reception step, external information (observable through the senses) and internal information (arising introspectively) become available to students, who select the material they will process and ignore the rest. The processing step may involve simple memorization or inductive or deductive reasoning, reflection or action, and introspection or interaction with others. The outcome is that the material is either "learned" in one sense or another or not learned [3]. To improve the efficiency of the learning process, some strategies can be adopted in the learning styles, such as:

- Before teaching theoretical material, phenomena and problems relate to the theory have to be first presented. For example, the design course could begin by describing problems associated with the design of buildings and bridges and artificial limbs. The students may be left sometime to think about the problems to see how far they can go before they get all the tools for solving them.
- The balanced scheme has to be established between conceptual information (intuitive) and concrete information (sensing). Instructors favor conceptual information-theories, mathematical models, and material that emphasizes

fundamental understanding. Sensors prefer concrete information such as descriptions of physical phenomena, results from real and simulated experiments, demonstrations, and problem-solving algorithms.

- The learning should be built on extensive use of sketches, plots, schematics, vector diagrams, computer graphics, and physical demonstrations in addition to oral and written explanations in lectures and readings.
- The ideas behind the theories and the technologies should be demonstrated by physical analogies and demonstrations to illustrate the magnitudes of calculated quantities. Examples from usual lives, human behavior and society mechanisms are very useful in illustrating design situations and structural behaviors.
- The general principles can be introduced by experimental observations, in order to enforce students (preferably working in groups) to get toward developing the ideas.
- Some free time should be provided for students to think about the material being presented (reflective) and for active student participation (active). During a lecture, time should be allocated for thinking and formulating questions. "One-minute papers" near the end of a lecture period, can be provided for students to write on index cards the lecture's most important point and the single most pressing unanswered question.

With the increase needs for efficient learning, especially with the large amount of knowledge that students have to compile and understand, new learning methodologies have been developed in recent years; some of them are briefly presented below.

2.1 Cooperative learning

Cooperative learning is a learning environment where students work together to learn, as opposed to competing with each other for marks [4]. Cooperative learning can be used for subject-based learning. In this framework, students are asked to work together to solve problems, discuss ideas, compare ideas about a concept, or do any task. Cooperative learning is generally based on small groups, that develop interdependent and self-directed works.

Academically weak students get the benefit of being tutored by stronger classmates, and stronger students get the deep understanding that comes from teaching something to someone else. Students who successfully complete a task own the knowledge in a way they never would from just watching a lecturer do it. Students who are not successful are put on notice that they don't know something they may need to know, so when the answer is provided shortly afterwards they are likely to pay attention in a way they never do in traditional lectures.

2.2 Problem-based Learning

Problem-based learning *PBL* is any learning environment in which the problem drives the learning [5]. That is, before students learn some knowledge they are given a problem. The problem is posed so that the students discover that they need to learn some new knowledge before they can solve the problem. This learning environment is active, cooperative, self-assessed, provides prompt feedback, allows a better opportunity to account for personal learning preferences and is highly effective. Some example problem-based learning environments include *Research projects* and *Engineering design projects* that are more than a synthesis of previously learned knowledge.

Posing the problem before learning tends to motivate students. They know why they are learning the new knowledge. Learning in the context of the need-to-solve-a-problem also tends to store the knowledge in memory patterns that facilitate later recall for solving problems.

2.3 Learning by doing

The basis of Learning-by-doing philosophy is to introduce the theory by productive works of the students [6]. Instead of the specified hours for typical courses, the students find something more productive to do with all that time. The only way a skill can be developed is practice: trying something, seeing how well or poorly it works, reflecting on how to do it differently, then trying it again and seeing if it works better. Students develop some skills during those contact hours by giving them guided practice in the tasks they will later be asked to perform on assignments and tests, that is *active learning*.

3 DESIGN LEARNING BY REDUCED MODELS

The design of products and structures is a complex procedure, necessitating multi-disciplinary knowledge not only in scientific and technical fields but also in economy and practice. However, the final design performance and cost is largely conditioned by the decisions made in the early stages of the design process, where very low information are available. Hence, it is mandatory to make appropriate technical choices since the beginning of the design process.

3.1 How to develop the Engineering Sense ?

The *Engineering Sense* is not, as one can imagine, a simple expression of rough or feeling-based choice and decision, but it is a consistent technical opinion based on logical and reasoning processes. The Engineering Sense can be interpreted as an engineering judgment by developing a logical reasoning, based on the scientific and technical knowledge, aiming to justify some technological choices or to validate an observed result. The tools of such a procedure are naturally, the scientific and technical knowledge, the practical experience and the comparative analysis.

Developing the Engineering Sense is even more difficult for new generations as numerical and graphical facilities become more « natural » than logical reasoning, especially for engineering students who have lost the *sense behind numbers* and who believe that *reality is just behind the computer screen*.

The application of logical reasoning can be inspired from natural creatures where the examples are infinite in numbers: the chicken legs has triangular form rather than rectangular to better distribute the eccentric weight; the egg shell corresponds to a design according to thin shell theory; the trees are vertically maintained by annular prestressing, etc…

3.2 Design process

The design process is the procedure allowing to build a system design that meets the specified requirements. This process can be described by a sequence of the following steps (Figure 1):

- **Specification of needs**
- **Problem analysis**: this part of the work consists of identifying the needs to be satisfied, as precisely as possible. The analysis of the problem is a small but very important part of the overall process. The output is a statement of the problem, and this can have three components: 1) a statement of the design

problem properly; 2) the limitations placed upon the solution; 3) the criterion for excellence to be worked to.

- **Conceptual design**: this phase of the design process takes the statement of the problem and generates broad solutions to it, in the form of schemes. It is the phase that makes the greatest demands on the designer, and where there is the most scope for striking improvements. It is the phase where engineering science, practical knowledge, production methods and commercial aspects need to be brought together, and where the most important decisions are taken.
- **Embodiment of schemes**: in this phase, the schemes are worked on in greater detail, and if there is more than one, a final choice between them is made. The end product is usually a set of general arrangement drawings. There is a great deal of feedback from this phase to the conceptual design phase.
- **Detailing**: this is the last phase, in which a very large number of small but essential points remain to be decided. The quality of this work must be good, otherwise delay and expense or even failure will be incurred: computers are already reducing the drudgery of this skilled and patient work and reducing the chance of errors, and will do so increasingly.

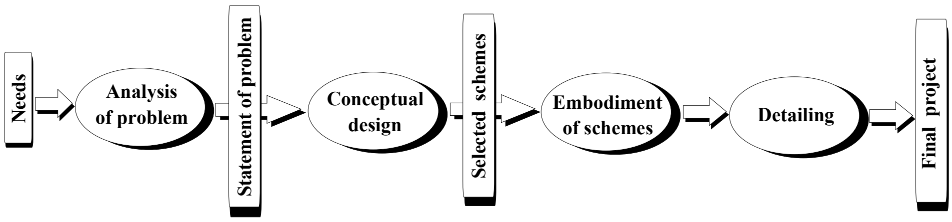

Figure 1. Design process

In a general way, there are three main difficulties in the design process, which are related to: 1) the generation of good schemes; 2) the securing of the best embodiment of those schemes and; 3) the evaluation of alternatives.

3.3 Transversal learning-by-doing

In the aim of developing the Engineering Sense for the IFMA students, a new learning experience has been carried out since two years in the framework of the credits *Design of products and structures* et *Material modeling and choices*. Starting from the specified needs, the engineering students develop their knowledge within the curriculum through the design and realization of structures that should meet the best performance with respect to the predefined needs. This work, realized by groups of three students, constitutes a transversal discipline which applies the theoretical courses in the department *Products and Structures*.

The transversal knowledge processing constitutes the main aspect of this work, where students have to involve all the materials learned or to be learned over the year, as shown in Figure 2. Moreover, this transversal learning-by-doing can also be seen as a problem-based learning, because at the design instance, they do not have all the necessary background to solve the problem. The integration of the whole design-to-construction process enhances their multi-disciplinary way of thinking.

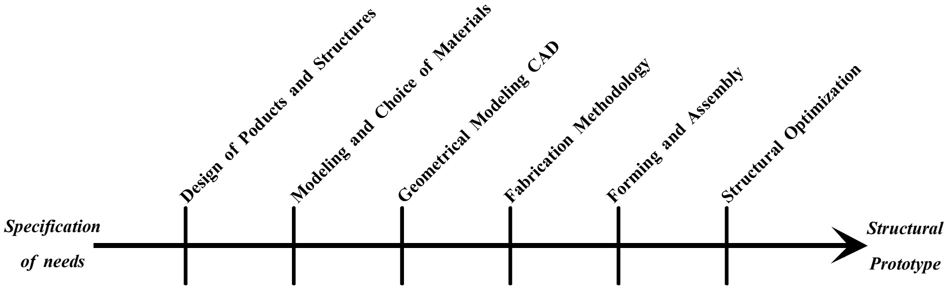

Figure 2. Transversal knowledge processing during the reduced model projects

This operation is carried out through five steps described below.

3.3.1 Client needs

As a first step, the client requirements are presented to the students as well as the evaluation criteria and available materials. They can then identify the design needs and the performance to be measured. In 2003-2004, the reduced models consist in designing a bridge crossing a river, where the geometrical overview is given in Figure 3.

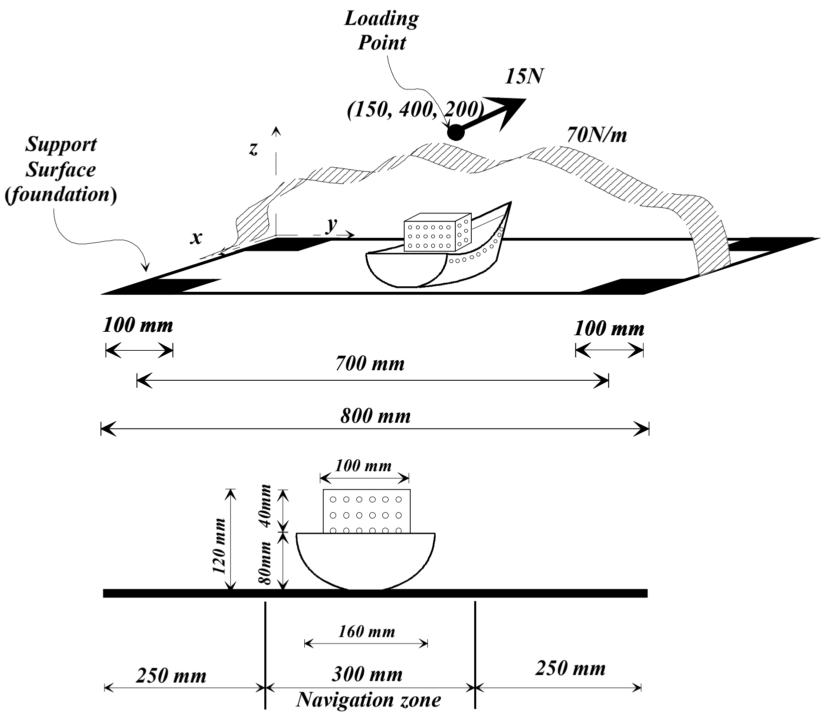

Figure 3. Geometrical overall requirements for the bridge models

3.3.2 Conceptual design

Few weeks of reflective work are given to the students to develop their ideas. They can then use their *engineering sense* to elaborate the basic concepts. In order to enforce generation of new ideas, the scheme of each conceptual design has to be approved by the teaching staff, in order to protect the originality of the concept.

3.3.3 Construction of the structures

By using the specified materials and tools, the construction of the structures is performed according to the predefined conceptual design, registered in the above stage by the teaching staff. Some solutions are shows in Figure 4.

Figure 4. Selection of reduced models

3.3.4 Testing and evaluation of structures

The evaluation of different structures is based on several criteria, such as:

1. Conceptual design of the structure, creativity and originality of the work.
2. Use of materials and fabrication facilities.
3. Structural performance: cost against rigidity.
4. Esthetic et care given to construction.

3.3.5 Modeling and optimization of the designed structures.

In the last step, the built structures are modeled on computers and then analyzed under the applied loads. The comparison between model and reality allows the students to face the model errors and justifications. At the end of this learning-by-doing experience, the structures have to be optimized by improving the design in order to better fit to performance criteria.

3.3.6 Synthesis and difficulties

This learning-by-doing experience has gained a lot of interest from the engineering students, who have put a large energy in the realization of these structures. This experience has also allowed for deep understanding of a number of structural concepts relative to load flow within mechanical systems. From another point of view, the construction of structures allows the students to see the real difficulties in fabrication, assembly, modeling and organization within the project. Learning from his own errors and mistakes is not always intuitive, but it is the only way to optimize performance. However, it has been observed that engineering students still have difficulties to develop the sense of multi-disciplinary thinking, as the major part of them concentrates the effort on only one aspect of the design: either structural or material.

4 CONCLUSION

A transversal learning-by-doing experience has been carried out at the French Institute for Advanced Mechanics IFMA. The aim is not only to deal with a specific project work, but to compile the learning courses, as well as problem-based learning. The outcome of this learning-by-doing experience is extremely positive, and shows that it contributes largely in developing the Engineering Sense for the engineering students at our school.

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