Project based learning for metrology education using reverse engineering

T Pinto¹, C Ahrens and R Schroeter  
Mechanical Engineering Department, Federal University of Santa Catarina  
Campus Trindade, CP 5053, Florianopolis, SC, Brazil, 88090470  
E-mail: tiago.pinto@labmetro.ufsc.br

Abstract. This paper describes and discusses an undergraduate course with focus on metrology and manufacturing using the project based learning approach. With reverse engineering of a mechanical system the students have to perform several presentations describing the phases of the work from system and parts selection, technical drawings from geometry measurements, materials definitions and quality control planning. Requirements, contents of students' seminars and examples of measurement systems are described. A study on the methods of evaluation in the engineering course shows the positive impact of project based learning for manufacturing and metrology education using reverse engineering.

1. Introduction
It is agreed that engineering education should include a set of learning experiences that allow students to build deep conceptual knowledge, develop the ability to apply technical and professional skills fluently, and engage in authentic engineering projects. Nevertheless, engineering courses and teaching methods are often not well aligned with these goals [1,2]. In problem-based and project-based learning (PPBL), learning is student-centered, collaborative self-learning, focusing on real-world issues, and involve students engagement. In contrast to classical learning, engaging the PPBL approach involves students in research to solve complex problems [3]. Several examples can be found of engineering courses using the Project-Based Learning approach [4,5].

The main contribution of this paper is the description of an engendering course called Manufacturing and Metrology Laboratory that uses the PPBL in conjunction with the reverse engineering approach. Reverse engineering is used, as defined in [6], for investigation of components and their interrelationships of a system chosen by the students. This approach requires the use of several measurement instruments and measurement data interpretation that deepen the student’s metrological knowledge and skills.

2. Manufacturing and Metrology Laboratory course description
While in the traditional learning process of the Mechanical Engineer the manufacture of a product is taught directly, that is, from the design to the final product, in Reverse Engineering (RE) approach the opposite is done, a product is already available in the consumer market and the goal is define the engineering ingredients that were used to reach that product [2].

The methodology uses two main types of activity, one focused on professors presenting lectures and consultancies to support the development of the work and another focused on the students that hold a set of seminars in which they present the evolution and the accomplishment of their works. In these seminars teachers with complementary knowledge make contributions for future presentations and
students evaluation. These seminars also represent an important part of the collective learning process and are key components for the assessment of student learning. Students must choose a system or subsystem of interest, following several rules, to study along the semester. This process is described below in each planned seminar. Since 2008 almost 200 systems were studied, ranging from home appliances, musical instruments, mechanical and car parts to medical instruments, utensils and prosthesis.

On the first day of the semester, all teachers involved in the course are present and present the objectives of the course, its working characteristics, work schedule, evaluation criteria and the formation of the work teams with up to six students. There are five main students presentation listed on Table 1 and described below.

### Table 1 – Contents of students seminars

| Week | Event                                                                 | Grade % |
|------|-----------------------------------------------------------------------|---------|
| 2    | Seminar 1 on system and parts selection                              | 5       |
| 4, 5 | Seminar 2 on history, patents, disassembly, system and parts function, planning | 10      |
| 8, 9 | Seminar 3 on technical drawing, tolerancing and material definition. | 20      |
| 13, 14 | Seminar 4 on manufacturing processes and quality control planning. | 20      |
| 17, 18 | Seminar 5 on retrospective and factory layout.                     | 20      |
| 17   | Monography                                                            | 15      |
| 1-18 | Presence in class                                                    | 10      |

2.1 **Seminar 1 System and parts selection** – each group presents up to three product proposals (or systems), using in the presentation a hierarchy of interest of the group. From this presentation, teachers and students elect, by consensus, a system and its four components (or parts) on which the concepts of RE will be applied. The system and the three components chosen must have a degree of complexity that is compatible with the level of knowledge and the evolution of that level during the student training process in the semester. The system and its components cannot have been studied in previous semesters and must contemplate at least three large families of manufacturing processes according to DIN 8580 and two different types of materials, preferably one metallic and one non-metallic.

2.2 **Seminar 2 History, patents, disassembly, system and parts function, planning** - history of product development with their respective components on which they are applying the ER, related patents, function and operation using engineering concepts and tools like software simulation, conscious disassembly, market study and number of parts for manufacturing, hypotheses of material types, hypotheses of manufacturing processes, planning and work schedule.

2.3 **Seminar 3 Technical drawing, tolerancing and material definition** - detailed designs of the parts from performed measurements, with emphasis on the elements needed for the function and performance of these products. Critical elements must have dimensional and geometrical tolerances. At that time the materials of such products should already be specified. The definition of the materials should also be based on measurements of their characteristics.

2.4 **Seminar 4 Manufacturing processes and quality control planning** – determination of the manufacturing processes and phases, such as: casting, machining, forming, among many others, done in a very detailed way for each one of the pieces of the group. For the critical elements with dimensional and geometrical tolerances, quality control procedures as well as the instrument specification and acceptance interval must be presented.

2.5 **Seminar 5 Retrospective and factory layout** - summary of all the work done during the semester, indicate the fulfillment of the suggestions made by the teachers throughout the presentations, show the proposal of layout of the factory to produce the pieces and the quality control checkpoints. Finish with an assessment of the course, highlighting positive points and those to be improved. The date of these
seminars also coincides with the presentation of the final and complete report of the course, in electronic and printed form.

During the entire course several measurement instruments and systems were used for the difference phases during the semester. In the next chapter a description on metrology and measurement activities in different phases of the course are described.

3. Metrology and Measurement activities
The use of metrology concepts and measurement systems and instruments are used mainly on three phases of the course: part geometry definition, material definition and quality control planning.

3.1 Geometry definition
For the definition of the geometry of each chosen part of the system several measurement instruments and procedures are used. Generally usual instruments are used, like a calliper, but parts with complex geometry demands more energy from the students to make a good technical drawing. Some examples of measurement systems that the students use are: calliper, micrometer, scale, photographs carefully taken to transport complex geometry to CAD software with some scale information in the scene, Cartesian coordinate measurement machine, measurement arm, measuring microscope, stereo vision with fringe projection and industrial computed tomography. Some of these measurement systems can be used on the University, mainly in the research laboratories that students should look for themselves the opportunity to do the measurements. The biggest challenge in this phase is to use properly the measurement data available to develop a good technical drawing. Another big challenge is to make students be aware of that geometric dimensioning and tolerancing cannot be defined directly through measurements, but they must investigate function and the interrelationships of components to properly tolerate the parts.

3.2 Material definition
For specific material definition in the technical drawing, the material hypothesis are discussed since the first seminar, always looking for a more restricted definition until the seminar 3 where the specific material must be specified. For such a specification several measurements are made in a similar way the geometry definition is done, the students must look for experiments that can restrict at a maximum the material hypotheses. These measurements range from simple visual inspection to highly advanced measurement systems. Some measurement systems and experiments commonly used include: visual inspection, flame test for polymers, spark test, Archimedes density, metallography, hardness and infrared spectroscopy. Several other information are also used to help define the materials, including: machinability, field of application, compatibility with lubricants and between materials and price.

3.3 Quality control planning
Based on the geometry definition and tolerancing the quality control planning is developed. At least one critical element of each part must be controlled through defining the specific measurement system or instrument. The measurement uncertainty goal is defined as $1/10^{3}$ of the tolerancing interval and a measurement system is selected with maximum error that respect this rule and the correct measuring range. Correct sensors must be selected to properly touch the part of interest (e.g. flat and round sensor of a micrometer to measure pipe thickness). When needed, accessories also must be specified. Jigs can be specified to quality control, but a CAD drawing must be done to illustrate its use. All the information for quality control planning must be compiled in a form. The positions of Quality control checkpoints must be defined in the layout planning for the seminar 5.

4. Discussion
The described course has a high demand of the students outside the classes, because they need to perform the measurements, data interpretation, research, seminars development and presentations. They must use a multidisciplinary approach to develop their work that they are not used to. Before and
at the beginning of the course the students have some degree of expectation and mistrust. But, is expressive their development during the semester, especially to defend their work and decisions orally. An independent study on the methods of evaluation in the engineering course, from the perspective of the students, was recently made. The methods of evaluation were classified, from best on top, as seen in table 2.

| Position (1 best) | Method of evaluation          |
|------------------|-------------------------------|
| 1                | Practical work               |
| 2                | Week exams                   |
| 3                | Theoretical work             |
| 4                | Theoretical seminars         |
| 5                | Discursive exam              |
| 6                | Objective exam               |
| 7                | Surprise exams               |

The described course in this paper, Manufacturing and Metrology Laboratory, is considered in this study as a Practical work, receiving the best position in the evaluation. Some comments were also included in the study and some of these are transcribed below:

“"I can better retain the content when it is passed several times, which occurs in the elaboration of a work, seminar and practical activities...”

"6 years after graduation, I still remember what I did at the machining seminar and at LaMaMe's work, the rest went to space." LaMaMe is the Manufacturing and Metrology Laboratory course.

"Anything that gets you out of the comfort zone works."

5. Conclusion

This paper describes an engineering course called Manufacturing and Metrology Laboratory that uses the project based learning in conjunction with reverse engineering approach. A system is selected by the students’ team and reverse engineering is used for investigation of components and their interrelationships. This approach requires the use of several measurement instruments and measurement data interpretation that deepen the student’s metrological knowledge and skills. The feedback of the students and from a study on classification for methods of evaluation shows the preference for the practical approach used in this course.

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