# UNIFIED ENGINEERING: A PRACTICAL CONTACT OF STUDENTS WITH ENGINEERING METHODS AND INTERDISCIPLINARY PROBLEMS

Jesus F.A. Romero – jesus.romero@ufabc.edu.br
Universidade Federal do ABC - UFABC
Rua Santa Adélia, 166. Bairro Bangu.
CEP 09.210-170 – Santo André - SP - Brasil
Cícero R. de Lima – cicero.lima@ufabc.edu.br
Universidade Federal do ABC - UFABC
Rua Santa Adélia, 166. Bairro Bangu.
CEP 09.210-170 – Santo André - SP - Brasil

***Abstract:*** *This work describes the experience developed in the Unified Engineering disciplines offered as a part of eight undergraduate programs at the Brazilian Federal University of ABC (UFABC). The UFABC offers a two year common basic curriculum that engineering students must accomplish. The Baccalaureate of Science and Technology (BC&T) is the elementary grade that can be followed by specific professionalizing courses to accomplish an engineering grade in some of the following areas: Bio-engineering, Management Engineering, Aerospace Engineering, Environment & Urban Engineering, Information Engineering, Materials Engineering, Automation & Robotics Engineering, and Energy Engineering. Afterwards BC&T, the Unified Engineering disciplines make part of an integrative set of disciplines which main objective is to introduce the students to the basis of the engineering career, the engineering methods and professional thinking. The projects practical issues are performed on the LEGO Mindstorms NXT platform, which portability and roughness allow students to perform several interdisciplinary experiments with other electrical or mechanical components. Experiments described in this paper highlight engineering fundamental concepts such as technical communications, teamwork, project management and project formalization. Thus, the main objective of this work is to report the methodology applied in the Unified Engineering disciplines in order to develop in the students a holistic view of the engineering technologies and a knowledge base and skill set that enable a successful project development. Also, a general description of the proposed activities and discipline syllabus are presented.*

***Palavras-chave:*** *Engineering Education, Interdisciplinary Approach, Project Methods, Lego Mindstorms NXT Platform*

## 1 INTRODUCTION

One of the main issues in engineering education, especially in a developing country context, consists in attend industry challenging demands concerning science knowledge, technology abilities, and high professional qualification. In this sense, continuous efforts are necessary to find better paths to keep the university playing a main role in this process. Additionally, the concept of professional qualification itself changes constantly, especially with the aspects related to the abilities of coordinating information, interaction with people, and dynamic interpretation of social and environmental conditions (National Academy of Engineering, 2004), (Howell,2009). The Federal University of ABC (UFABC), a new public university in Brazil, represents a decisive opportunity of dealing with the definition of a modern and suitable engineer profile (Lynch et al., 2009), (ROMERO et al., 2009). In this sense, the strategy must consider some obligatory disciplines in order to maintain equilibrium between the different engineering courses contents and a common base curriculum that every engineering student must accomplish, the three years term Baccalaureate of Science and Technology (BC&T) (FEDERAL UNIVERSITY OF ABC, 2006). As a first approximation, the discipline "Introduction to Engineering" intends to introduce some conceptual and ethical capacities of the engineer professional by means of different lectures, presentations, practical activities and, especially, a social contact with the regional reality (ROMERO et al., 2009). Subsequently, the disciplines "Unified Engineering I" and "Unified Engineering II" are offered to the students in order to establish practical and interdisciplinary abilities. The adopted methodology in the Unified Engineering courses includes all four main lifecycle phases of a technological project, Conceive-Design-Implement-Operate (CRAWLEY et al., 2006), focusing in the interdisciplinary approach needed in the student profile (National Academies Press, 2004), (HOWELL, 2009). The "Unified Engineering I" course outline is composed by practical topics that are decisive for personal and team success in an engineering environment such as technical communications, teamwork and project management. On the other hand, the "Unified Engineering II" course outline focus the engineering project formalization based in different types of mechanical and electrical forms.

The main objective of this work is to describe the education methodology applied in the Unified Engineering disciplines at a new Brazilian public university (UFABC) in order to develop in the students a holistic view of the engineering technologies, and a knowledge base and skill set, which allow to obtain a successful project development.

In section 2 of this work, the UFABC curricula constraints related to the pedagogical project are presented, as well as a modern engineer profile. In section 3, the main characteristics and formal syllabus of the "Unified Engineering" disciplines are described. The disciplines main adopted platform and methods are presented in sections 4 and 5, respectively. Some concluding remarks and analysis close this article (section 6).

## 2 CURRICULA PLANNING CONSTRAINTS AND THE NEW ENGINEER PROFESSIONAL PROFILE

Considering the UFABC academic structure (FEDERAL UNIVERSITY OF ABC, 2006), an important curricula aspect is the selection of a suitable strategy in order to integrate all disciplinary contents and engineer professional outlines into each course curriculum (CRAWLEY et al., 2006), (LONG et al., 1998). Considering the UFABC pedagogical strategy, other aspects should be taking into account by the engineering programs (LEITE et al., 2007):

- Compatibility between the Post-BC&T engineering courses with BC&T. There must be considered potentially constraints between engineering and a scientific oriented curriculum designs.

- Compatibility contents with the guidelines proposed by the Brazilian Regional Board of Engineering, Architecture, and Agronomy (CREA) in order to guarantee legal professional attributions.

- Compatibility contents with the norms regulated by the Brazilian Ministry of Education in order to have an official accreditation.

- Intense interdisciplinary relations not only with the basic knowledge/scientific areas, however among the eight engineering specialties.

- High level of autonomy for the students on how to construct his own and personal curriculum. It must be considered that the BC&T curriculum is not strictly sequential. Once prerequisites are not strictly adopted in the case of UFABC, the sequence of disciplines is determined by student choices with the help of the advisors and professors.

UFABC understands that the dialog between research and development depends on an enlargement of the social conscience about the importance of a shared growth among several sectors (FEDERAL UNIVERSITY OF ABC, 2006). In the same context, the National Academy of Engineering (National Academy of Engineering, 2004), reports engineer main qualities of this new century. Among several attributes, the new engineer should be:

- Creative and guided for innovation, which suggests a professional with the capability of maintaining his skills and knowledge updated to recent scientific-technological advances, and he must sustain a ever-searching spirit to solve new problems and propose new solutions;
- A system designer, since the technologies go to progressively systemic approaches, integrating different human knowledge domains;
- A collaborator, because increasing complex systems and problems impose collective work, initiatives and actions;
- Disposed to embrace the cultural diversity, since the technology and the economy became completely global, the interchange and international bases of the companies lead to frequently cultural diversified teams working together on a same project.

As it can be seen, the complexity of the current innovations demands an intensive collaboration work between different types of engineers. Consequently, it is easy to recognize that veritably innovative products require diverse technologies and knowledge domains. Therefore, the engineer of the future, beyond of his specific graduation technological cognition, he should be familiarized with many other technologies and knowledge. In conclusion, it can be observed that an interdisciplinary approach, emphatically fixed in the root of the UFABC pedagogical model (FEDERAL UNIVERSITY OF ABC, 2006), becomes essential for the new engineer when combined with a "problem solver" characterization. In this sense, some engineering education aspects that must be considered in order to guarantee success in transferring the new engineering profile are reported in (ALMGREN, 2007):

- Disciplines that integrate theory with practice activities;
- Challenging research projects offered as early as possible;
- Collaboration jobs in project activities;
- Opportunity to dealing with risks, challenges and uncertainties in order to stimulate creativity and innovation.

In some degree, these pointed issues are being considered in the syllabus design of the disciplines "Unified Engineering I" and "Unified Engineering II", proposed to be a practical contact with the engineering methods. The main ideas and examples of activities and lectures of the disciplines are described in section 3.

## 3 THE ENGINEERING INTEGRATIVE DISCIPLINES

The Brazilian Ministry of Education's norms and regulations impose engineering curricula organization following three main disciplines types: introductory, disciplinary and specialization. In terms of UFABC courses, the adjustment of curricula imposes allocation of introductory engineering disciplines in the middle of the BC&T course term. The set of disciplines that plays a key interdisciplinary role in the engineering courses structure is composed by:

- Introduction to Engineering;
- Experimental Methods in Engineering;
- Unified Engineering I;
- Unified Engineering II.

The last three disciplines consider activities eminently experimental and intensely interdisciplinary, using the BC&T main scientific and technological concepts and advancing into engineering methods and topics.

Table 1 - Syllabus considered on the UFABC "Unified Engineering" courses

| Week | Contents and/or Developed Activities (Unified Engineering I) | Contents and/or Developed Activities (Unified Engineering II) |
|---|---|---|
| 01 | Program and activities schedule presentation (project-based approach).<br>*Activity 1: formation of working teams* | Program and activities schedule presentation (project-based approach).<br>*Activity 1: formation of working teams* |
| 02 | The method in engineering design: systemic approach, modeling of complex and interdisciplinary problems.<br>*Activity 2: projects proposal and definition of main project modules* | The method in engineering design: Rapid Prototyping and Embedded Electronic Systems.<br>*Activity 2: projects proposal, definition of main project modules and Project interdisciplinary index evaluation* |
| 03 | The LEGO Mindstorms kit as a work platform for interdisciplinary project.<br>*Activity 3: programming environments for LEGO Mindstorms kit (Matlab, Labview, Java)* | Definition of main disciplinary dimensions and project matrix for projects interdisciplinarity evaluation.<br>*Activity 3: development of matrix based project strategies* |
| 04 | Forms of communication in project development, the main roles of a team member in a technological project context.<br>*Activity 4: LEGO Digital Designer as a 3D design program (examples and exercises)* | Formalization in engineering projects: concepts, equilibrium points and agility.<br>*Activity 4: project formalization process (examples and exercises)* |
| 05 | The main disciplinary dimensions: Dynamics, Fluid Mechanics, Materials & Structures, Signal & Systems, Automation and Energy conversion.<br>*Activity 5: modeling, simulation, and prototyping operation exercises* | Projects Formalization through technical documentation.<br>*Activity 5: rapid prototyping exercises for circuits and solid modelling (Circuitry CAD and Solidworks)* |
| 06 | The project matrix concept for projects interdisciplinarity evaluation.<br>*Activity 6: project interdisciplinary index evaluation* | Optimization methods in engineering design.<br>*Activity 6: multidisciplinary optimization (examples and exercises)* |
| 07 | Evaluation of project proposals (part I): problem description, main goals and viability.<br>*Activity 7: project schedule assessment* | Evaluation of project proposals (part I): problem description, main goals and viability.<br>*Activity 7: project schedule assessment* |
| 08 | Evaluation of project proposals (part II): interdisciplinary approach and development of schedules.<br>*Activity 8: project schedule assessment* | Evaluation of project proposals (part II): interdisciplinary approach and development of schedules.<br>*Activity 8: project schedule assessment* |
| 09 | Definition of performance variables and project parameters (to be used in the project evaluation).<br>*Activity 9: performance-based project assessment* | Definition of performance variables and project parameters (to be used in the project evaluation).<br>*Activity 9: performance-based project assessment* |
| 10 | Project modules integration (hardware and software).<br>*Activity 10: performance-based project assessment* | Project modules integration (hardware and software).<br>*Activity 10: performance-based project assessment* |
| 11 | Main process variables quantification and performance evaluation.<br>*Activity 11: performance-based project assessment* | Main process variables quantification and performance evaluation.<br>*Activity 11: performance-based project assessment* |
| 12 | Exposition of the projects with oral presentation and final report submission.<br>*Activity 12: Participation in the final projects exhibition* | Exposition of the projects with oral presentation and final report submission.<br>*Activity 12: Participation in the final projects exhibition* |

As the challenge presented in modern engineering teaching consists in intensive demands concerning different disciplinary dimensions and a deep profile in solving complex real problems, the “Unified Engineering” disciplines focus on increase the skills and abilities needed to face new problems and technologies. Table 1 presents an example of “Unified Engineering I” and “Unified Engineering II” syllabus outlines within a three-month calendar.

## 4 THE INTERDISCIPLINARY MODULAR PLATFORM

Mobile robotics and automation processes has been widely used in engineering education as a learning tool, as it provides a flexible platform tool to perform laboratory experiments in different complexity levels and within an interdisciplinary context (e.g. mechatronics, electronics, microcomputer, and control). On the other hand, rapid prototyping has been used in a variety of engineering education scenarios in order to provide practice knowledge of new advances in technology, to clearly apply and observe them in practice. In this sense, LEGO Mindstorms and CAD based prototyping has been successfully applied in “Unified Engineering” disciplines as an innovative platform that motivates students to practice and learn many necessary skills, like team management, interdisciplinary modeling and design-manufacturing relation understanding. The proposed engineering education methodology, based on LEGO Mindstorms platform, complemented with electrical and mechanical modules, focuses on developing creativity and practicing skill instead of just imparting knowledge.

The new version of the LEGO Mindstorms kit has a processing module (NXT) based on a 32-bit ARM7 microcontroller with 256 Kbytes FLASH, 64 Kbytes RAM, Bluetooth wireless communication, 4 input ports and 3 output ports. Additionally, the peripherals considers a contact, light, encoder, ultrasonic, and sound sensors and 3 DC motors (KIM & JEON, 2007), (BAGNALL, 2007), (SHARAD, 2007), (GASPERI, 2007), (FERRARI, 2007). The described platform supplies an education system suitable for interdisciplinary projects, as it can be seen in figure 1, a Mindstorm-based mobile manipulator robot developed in “Unified Engineering” disciplines.

Figure 1 – Robotic mobile manipulator a) CAD project schematic b) Implemented System

As the projects must attend different engineering areas and applications, the central controller must guarantee a minimum of computational power and flexibility. In this sense, the NXT processor can be programmed using a variety of options such as C language and graphical programming. Two C-based software development packages are ROBOTC

(ROBOT C, 2010) and BricxCC, which uses Not eXactly C (NXC) (BRICXCC COMMAND CENTER, 2010). Graphical programming alternatives include the LabVIEW NXT Tookit, NXT-G, Robolab, and the Microsoft Robotics Studio (MSRS) (SWAN, 2007), (TRAVIS, 2006).

In addition to the LEGO systems, the selected platform uses a free 3D modeling and building system called LEGO Digital Designer that allows students to virtually build 3D design models using a variety of LEGO blocks. This 3D design program can enhance the learning experience of students by providing meaningful design activities and mechanical forms. The laboratory experiments introduce the LEGO Digital Designer to provide students with hands-on team projects to design and build an automated system while applying concepts learned in the classroom (WANG et al., 2004).

In "Unified Engineering II", the students are challenged to develop multi-view and mechanical sketching skills, reinforcing the concepts of 2D & 3D geometry by dimensioning, and working drawings in SolidWorks software (LOMBARD, 2007). All proposed examples reinforce the Industry Design Cycle, where the CNC-based Rapid Prototype phase of the Industry Design Cycle is replaced by the LEGO NXT Kit.

## 5 THE PROJECT MATRIX CONCEPT FOR INTERDISCIPLINARY EVALUATION

Design projects analysis in undergraduate engineering curriculums is becoming a well accepted concept at the majority of engineering schools. However, as design engineering projects usually has more than one solution, with different complexity levels, particular attention must be given to the assessment methodologies selection in order to guarantee students increase in creativity and innovation abilities. Unified Engineering disciplines aim the construction of uniformly complex models based on the main goal of integrate elements of Dynamics, Fluid Mechanics, Materials & Structures, Signal & Systems, Automation and Energy Conversion, and complementary studies into a predetermined engineering report format to fully describe the solution of a given engineering problem. Hence, this proposal achieves a well performed design engineering project (from the students), and also a well project assessment and evaluation (from the instructors). In this context, it has great importance to develop a fair and reliable method for evaluating systematically to what level students are applying their knowledge. More precisely, in which cases the students extend their knowledge beyond the fundamentals. Furthermore, complexity in technological development projects can derive from different stages of the solution design, the development process, the technologies applied and other domains. In this sense, the proposed methodology consists of a domain mapping matrix in order to represent and analyze the project modules and their interactions both within and across disciplinary domains (DE GEUS, 1998), (DE MEYER, 2002). As an example, figure 2 represents the block diagram of a NXT-based robotic mobile manipulator developed in the Unified Engineering disciplines.

The mobile robot manipulator contains an artificial vision module and a robotic arm controlled through an operator that can access the image collected by the USB camera. In this case, a bomb squad robot application, when the operator identify a possible bomb, the USB camera will render the image and compare it with a pre-established standard to verify whether or not the object is a real bomb. Objectifying a visual evaluation of the interdisciplinary characteristics of the project, Table 2 presents the design matrix proposed by the students.

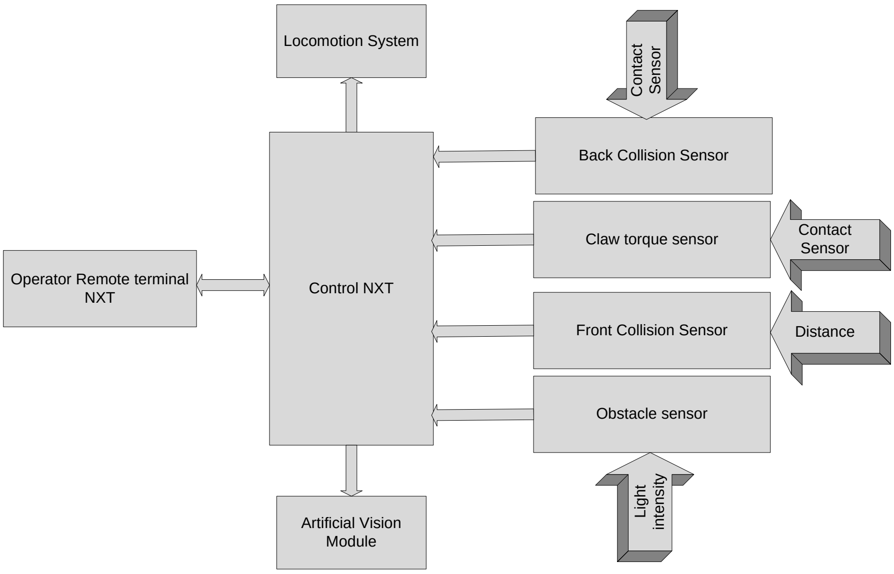


Figure 2 – Robotic mobile manipulator block diagram based on NXT Platform

A very important issue in this example is the quite evident interdisciplinary complexity presented in Table 2. Initially, the operator defines the direction commands to the robot, integrating the dynamics, power and structure dimensions with the signals received from the sensors. During the processing of the image, the USB camera signals are integrated with a recognition and sensing algorithms. Finally this whole process can be integrated into the robot automation system. The programming environment used to assembly the program and supervise the project is the LabVIEW software (TRAVIS, 2006) as it can be seen in figure 3.

Table 2 – Robotic mobile manipulator matrix project

| **Module** | **Signal & Systems** | **Dynamics** | **Automation** | **Energy conversion** | **Materials & Structures** | **Fluid Mechanics** |
|---|---|---|---|---|---|---|
| Locomotion System | X | X | X | X | X | |
| Claw torque sensor | X | X | X | X | X | |
| Control System | X | X | X | | | |
| NXT Actuators | X | | | | | |
| Communication System | X | | X | | | |
| Computational vision | X | | X | | | |

Considering a complete project methodology, the discipline “Unified Engineering II” focuses the importance of formalism and how its use can reduce the chances of errors. In this discipline, the formalization procedure is defined through the use of technical documents (block and flux diagrams, mechanical diagrams, domain mapping matrix, and others) within student project teams in order to better understand and control the project process. Every project must quantify a performance variable at the end of the course in order to validate the work results. The idea is to help students develop a factual scenario that show whether the initial objectives have been achieved.

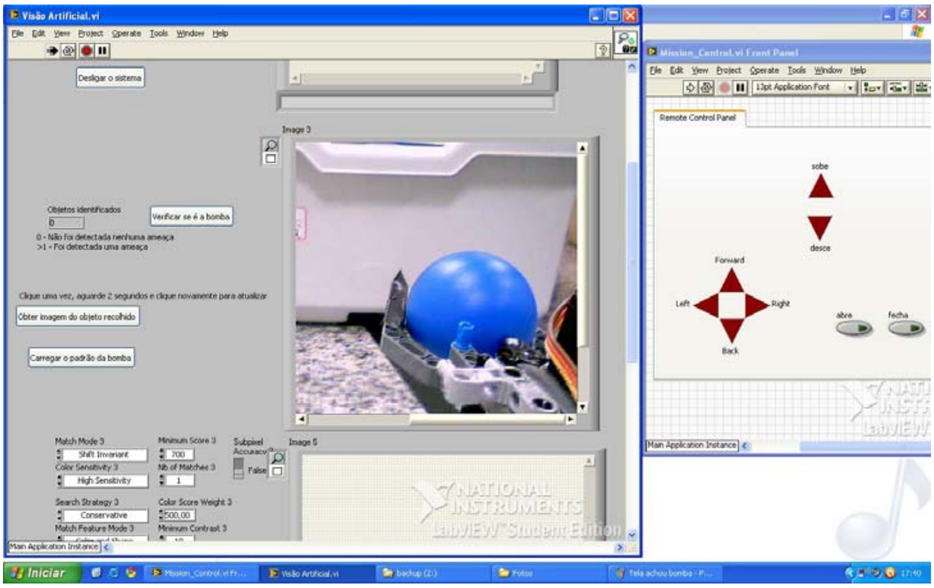


Figure 3 – Robotic mobile manipulator LabVIEW based supervisor

## 6 CONCLUSIONS

This article describes the engineering education initiatives at a new public university in Brazil, in special the disciplines “Unified Engineering I” and “Unified Engineering II”, of the engineering curricula. The first applications of the syllabus developed for the disciplines indicates three main results: (i) a contribution to maintain an integrated curriculum where all students develop interpersonal skills, and also product, process, and system building skills through CDIO concepts; (ii) a complete methodology related to the students development of abilities in interdisciplinary and complex problems. iii) a mapping project approach related to the students development of abilities identification of constraints across disciplinary dimensions by providing a basis for communication and learning across discipline domains.

Future stages of this study will consider more perceptive interpretation of engineering introductory disciplines in early stages of the BC&T curriculum and the possibility of a curriculum based on clearly disciplinary prerequisites. Noting that the resulting outcomes of a study program are difficultly predictable, and these results also depend of the individual decisions taken by the students. An interesting perspective concerns the flexibility of the pedagogical project being implemented in UFABC: it can easily take into account the suggestions resulting from the first courses applications.

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# ENGENHARIA UNIFICADA: UM CONTATO PRÁTICO DOS ESTUDANTES COM MÉTODOS DE ENGENHARIA E PROBLEMAS INTERDISCIPLINARES

**Resumo:** *Este trabalho descreve a experiência desenvolvida nas disciplinas de Engenharia Unificada oferecidas como parte de oito cursos de graduação da Universidade Federal do ABC (UFABC). A UFABC oferece dois anos de currículo básico comum que todos estudantes de engenharia devem realizar. O Bacharelado de Ciência e Tecnologia (BC&T) é o grau elementar que pode ser seguido por cursos específicos profissionalizantes para realizar um determinado curso de engenharia em algumas das áreas a seguir: Bioengenharia, Engenharia de Gestão, Engenharia Aeroespacial, Engenharia Ambiental e Urbana, Engenharia de Informação, Engenharia de Materiais, Engenharia de Instrumentação, Automação e Robótica e Engenharia de Energia. Posterior ao BC&T, as disciplinas de Engenharia Unificada fazem parte de um conjunto de disciplinas integrativas cujo objetivo principal é apresentar aos alunos a base da carreira de engenharia, os métodos de engenharia e o perfil profissional. Os projetos práticos são realizados na plataforma LEGO Mindstorms NXT, cuja portabilidade e robustez permitem que os alunos realizem várias experiências interdisciplinares complementando o kit com outros dispositivos elétricos ou mecânicos. Todos os experimentos desenvolvidos destacam os conceitos fundamentais de engenharia, tais como comunicações e trabalho em equipe, gestão de projetos e formalização do projeto. Assim, o objetivo principal deste trabalho é relatar a metodologia aplicada nas disciplinas de Engenharia Unificada, a fim de desenvolver nos alunos uma visão holística das tecnologias de engenharia e um conjunto de habilidades que permitam o desenvolvimento bem sucedido de projetos interdisciplinares. Adicionalmente, uma descrição geral das atividades propostas, assim como o programa da disciplina, são apresentados.*

**Key-words:** *Educação em Engenharia, Abordagem Interdisciplinar, Métodos de Projeto, Plataforma Lego NXT Mindstorms.*