A Student Driven Multidisciplinary Knowledge Integration Teaching Program

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Abstract *— Traditional engineering curricula always face the challenge of finding a way for the students to integrate, by themselves, the knowledge they learn as completely separate compartments in every class, let alone the integration of the different disciplines of engineering. This work presents an experience that, for the first time in Venezuela, faces this challenge by translating the full responsibility to manage and complete a multidisciplinary engineering project to a group of students. Based on the international Formula SAE competition, a multidisciplinary group of engineering students is organized as a small company and given the responsibility to manage an engineering project from beginning to end. The students must conceive, design, build, test, develop and put into competence a race car in one year of work. In the technical aspects, they must develop a high-tech vehicle integrating many areas of engineering. This forces the student into a very demanding work-like environment and brings the need for the integration of knowledge and the most needed multidisciplinary interaction. Yet, the success of this program lies on the fact that the whole responsibility of its success is translated onto the same students that are learning from it. Besides the technical aspects, the group of students must secure funds by contacting sponsors and negotiating with them. They must also manage economic, human and technical resources available so as to assure the completion of the project by the deadline of the competition. A multidisciplinary team of professors oversees the work of the group and provides some guidance. Along its three years of work, the program has evolved, by students' initiative, into elective courses and has produced and financed eight thesis works in three different majors. Overall, the program shows how translating the responsibility onto the students and providing a good motivation (in this case a race car) can provide an excellent tool for assuring knowledge integration, team work, management experience, and self-confident students, plus a way to obtain funds for investment into quality teaching.*

Index Terms *— knowledge integration, engineering curricula, multidisciplinary, Formula SAE, small company format..*

INTRODUCTION

One of the greatest challenges of today's engineering education is to provide the student with the tools and skills required to face an ever changing and more demanding work environment. Engineering curricula has diversified to include more and more topics related to new technology, leading to specialized courses that, due to time and resources constraints, end up as unconnected knowledge compartments. This, as Smith [1] points out when referring to automotive engineers, results in young professionals who do not have a good dominion of the whole. The integration of the knowledge is left for the student to do by himself at the workplace. Furthermore, Smith [1] states that young engineers lack the general viewpoint when designing, have seldom built something with their own hands, lack teamwork and communication skills, and are unable to manage their time. Along the same lines, Short [2], studying American universities, states that objectives and contents in most engineering curricula are defined according to the research and knowledge generation of each university, without much relation to their changing environment and thus departing from actual requirements of the working force. Engineering schools must, therefore, enforce an effective relation of the students with engineering practice while at the school, providing skills and tools that will make them more competitive in the job market.

At Universidad Simón Bolívar (USB), Venezuela, the curricula and the whole educational process of Mechanical, Electrical, Materials, and Chemical Engineering were evaluated with the SECAI (Engineering Majors Quality Evaluation System) methodology by the Columbus Program, a cooperative program between the European Community and several Latin-American countries. This study [3] showed good rankings for the engineering teaching at USB. Yet, it evidenced the problems already described and added an unbalance between theoretical class work and practical hands-on work. Also in this study, and based on the employers' feedback, a need to improve teamwork and management skills was highlighted.

Milani [4] reports an even deeper problem, relating to cultural issues about Venezuelan society and its relation to its engineers. There is a lack of confidence on their capacity to generate technology and solutions adapted to local needs. Milani [4] ascribes this fact to a historical unbalance in Venezuelan economy, supported by extraordinary oil industry incomes, which favors the importation of technology in detriment of local engineers' talent and formation. Furthermore, though he pinpoints the root of the problem in deeply established cultural issues, Milani proposes a solution that passes through the reinforcement of the confidence and development of an attitude favorable to the rupture of these paradigms in engineering students while at the university. It is necessary to topple the idea that all problems are already solved and that the solution can be either found in a manual or standard, or purchased from someone.

Based on a study of the needs for 21st century engineers (Huang, [5]), the People's Republic of China set a curricular reform whose goals are the establishment of an active teaching model, where the student stops being a passive receptor and becomes and active participant, using techniques that promote problem solving, cooperative learning, and social practice. Professors must become advisors and organizers, while the learning responsibility and effective study lies on the students. The main idea is transforming indirect experience by a direct one, with the purpose of reaching greatest achievements and development of knowledge and skills as well as attitudes and values.

Along time, there have been several attempts to shorten the distance between the classroom and the engineering practice at USB. On one side, there are laboratory courses with a theory-practice combination where the student is somewhat exposed to equipment, tests, and design. However, these are usually restricted to demonstrative practices and are limited by available time and resources. Electronics Engineering has a class called mini-projects where the student is faced to a modest engineering project from beginning to end, including building a prototype, and based on the solution of a real problem. For some time, a similar program was implemented within the last course of the design area in Mechanical Engineering. These programs, though limited by time and resources available in one trimester, allow the student to face a small engineering project in all its phases. One experience that deserves especial mention is the design and construction of the "Urban Car", finished in 1997, in which a group of undergraduate and graduate Mechanical Engineering students, worked under Prof. Pedro Pieretti to design and build a two-seater vehicle with power, size and handling that made it particularly attractive for its use in urban spaces. This project allowed 20 students to tackle a more complex problem. Yet, it was based on the work of 20 rather isolated theses, which prevented each individual student from observing the whole of the project.

FIGURE 1
F-SAE USB 2002 TEAM

Internship programs are also available for all majors. It includes a short, elective, six weeks internship and a long, mandatory, twenty weeks internship. The internship allows the student to face real world practice in a company, performing several tasks as a trainee engineer.

A different approach is taken by the Creativity Contest, organized every trimester by Design Professor L. Sabater and already in its 70th edition. Here, students are challenged to solve a particular problem and present their prototypes to a judge. The contest poses interesting and motivating creativity challenges, yet, it does not require a rigorous engineering approach.

More recently, in 2000, a group of students from diverse engineering majors of the USB proposed the participation of the university in the Formula SAE Series Competition, organized by the Society of Automotive Engineers. This competition started in 1981 with the participation of four North-American universities [6]. The first edition presented awards for best appearance, engineering excellence, design creativity, and on-track tests. The competition started with a four-page rule book and four participants, and has evolved to more than 100 pages in the rules book and 140 participants from around the world in 2004. Today, there are awards for best design, cost and manufacturing, sales and marketing, acceleration, handling and on-track races. The students are required to conceive, design, build, test, develop, and demonstrate a high-tech race car within one year of work, which will be measured up to 139 other cars. This provides a very demanding engineering challenge combined with a highly motivating objective.

A group of professors from three different departments embraced the student's proposal and led it to be structured in such a way that the students are responsible for procuring funds, manage the whole program and warranty its academic integrity. The following lines discuss the characteristics of the resulting program.

F-SAE USB PROGRAM

Universidad Simón Bolívar (USB) is a technological university, focused on basic sciences and engineering. It is defined as an experimental university, thus, it does not follow the classic and vertical deans, schools and departments organization but a horizontal matrix structure. This structure intends to promote operative flexibility, interdisciplinary work between professors and students, and a more efficient use of human and material resources. The matrix structure is based on academic and

FIGURE 2
F-SAE USB 2003 TEAM

research coordinators, in charge of planning, supervising, and evaluating the academic programs; academic departments, in charge of the physical execution of the programs; and the laboratories, as support units for teaching and research [7].

The matrix structure of USB promotes the interaction between students of different majors. Thus, it was natural that a multidisciplinary group of students proposed to participate in the Formula SAE competition [8]. The F-SAE USB Program was created, with the supervision of a group of faculty from the mechanics, energy conversion, and electronics departments that was receptive to the students' proposal. It is defined as an academic program whose goal is the profile enhancement of the graduates from the different majors available at USB, through the acquisition of knowledge and skills in both technical and management areas under the constructivist approach of hands-on learning. The program main objectives are to provide integration of the knowledge acquired along the different classes, to promote interdis-ciplinary teamwork, training on practical skills, and development of management skills.

The F-SAE USB program comprises two components, an academic one, the F-SAE USB Project, and a human one, the F-SAE USB Team.

The F-SAE USB Team is a student group registered with the USB Student Development Direction (DIDE, by its acronym in Spanish), created in 2001 and congregating approximately 60 active students from almost all majors at USB (mechanical, electronics, electrical, materials, production, geophysical, computing, and chemical engineering, plus mathematics, physics, architecture and urbanism). Its structure replicates a small engineering company, with a board of management consisting of one president, one vice-president, one technical director, one public relations director, one secretary, and 6 technical division chiefs. An Internal Constitution [9] defines the functions of every board member and of the board itself. The board is elected annually by the General Assembly from members that have proven their capacity and have reached the higher level within the membership scale. Its general functions are managing the design and construction of the vehicle, procuring sponsorships, managing economic and human resources, taking the Team to the competition, evaluating the performance of all Team members, and preparing a final report with technical and economic results by the end of the one year term. The rest of the members are located within one of the technical divisions or under one of the directors, depending on their specific functions and interests. All members are subject to continuous evaluation and can therefore go up, or down, in the membership scale, depending on their time and performance in the Team. The members on the higher level constitute the General Assembly, which votes the most important decisions based on reports by the Board of Management.

FIGURE 3
F-SAE USB 2004 TEAM

The Team develops several activities that can be grouped as technical, concerning prototype design and manufacturing; management, related to sponsorship negotiations, human and economic resources, marketing and divulgation through mass media and special events; and of extension, as the organization of the annual Automotive Management and Technology Congress, which already has three editions, and has become a rendezvous point for different sectors of the national automotive industry and the universities. The budget for this activities amounts to nearly US$90,000 per year, which is almost impossible for a public university in Venezuela to invest in any academic program of this sort. Yet, the self-management of this project by the students, the presence of a final product that be exploited, and the formation of professionals that answer to their needs, allow for the participation of important private sponsors that are willing to provide funds, materials and technical support. This approach then allows the implementation of a very complex, time and resource demanding program that assures an integral formation of the students, going beyond traditional classroom education, without demanding much investment from the university budget.

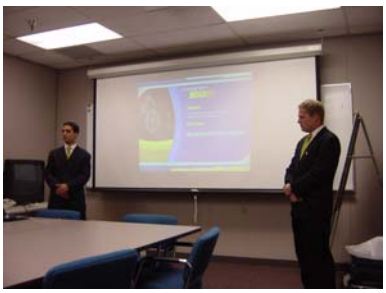

FIGURE 4
SALES PRESENTATION
F-SAE 2003 COMPETITION

The F-SAE USB Project is based at the Machinery Dynamics Laboratory. It is structured around three elective courses, Automotive Design I, II, and III, but also reaches other elective classes such as Vehicle Dynamics, Computer Aided Design, Internal Combustion Engines, and several special topics and mini-projects in electronics and materials. It is noted that most of this courses have been created by special request of the Team.

The Automotive Design classes are defined to cover conceptual, basic, and detail design of the car, as well as construction and testing. Beyond these technical aspects, these classes also cover issues relating to project management, group dynamics, leadership and marketing. These classes are fully handled by the students. Most classes are conducted by one or two students that perform as moderators for the discussions about different design proposals and solutions, organized according to the several subsystems that compose the vehicle. The in-class discussions mostly address

advantages and disadvantages, interaction with other subsystems, manufacturing processes, required resources, and progress monitoring. There are also a few introductory classes, which are closer to a traditional lecture, and several seminars to which experts are invited. Beyond this, off-classroom activities comprise most of the students' activities, requiring a dedication equivalent to a full time job (or more), which is possible only thanks to the high motivation levels provided by the end objective, to build a car and test it again the whole world. These activities encompass design, modeling, simulation, negotiating with sponsors, purchasing, manufacturing, assembling, testing, research, reading, etc., and are mostly developed at the laboratory, which provides a 24 hour – 7 days a week access. The evaluation of these three classes is rather complex, since every student is involved in different activities. Yet, the evaluation is based on technical reports, finished parts, overall involvement, administrative activities, and, though quite seldom, quizzes. In all cases, the students are involved in the evaluation process, particularly in evaluating the overall involvement of each member.

FIGURE 5
DATA ADQUISITION TEST ON
F-SAE USB 2004 CAR

Besides the projects developed in the elective courses, the program generates some needs that require a deeper study of a particular topic. In the first three years, this has led to the development of thesis works for 11 students, including design manuals, ad-hoc numerical codes for dynamic, kinematics and static analyses, experimental and numerical aerodynamic studies, material optimization for thermal and mechanical performance of the brake system, instrumentation and telemetry, a traction control system, and others. These developments have put the F-SAE USB car within the top 20 vehicles in the design event at the competition.

The F-SAE Project not only poses the needs related to actual engineering problems, it also provides funds, students and motivation. Thus, according to its needs, the Team has been able to involve, as advisors or "consultants", over 20 professors from different departments such as mechanics, energy conversion, electronics, materials, industrial technology, thermodynamics, and economic sciences. In the same way, the Team has also secured the support from several laboratories as Dynamics of Machines, Mechanical Energy Conversion, Models and Prototypes Development, Machine-tools, Electronics, and Fluid Mechanics.

ACHIEVEMENTS

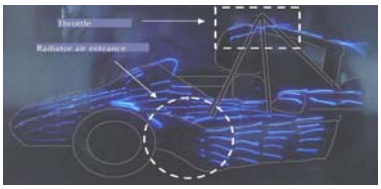

FIGURE 6
WIND TUNNEL TEST
F-SAE USB 2003 CAR

Along its first three years, the F-SAE USB Program has reached over 120 students, which talk about the interest of the students in participating. Three vehicles have been produced and one more is in the design stage. Furthermore, several specific achievements can be listed as a Rookie award in 2002; good placements in the design and cost events for 2003 and 2004; presence of international speakers at the Automotive Management and Technology Congress, as Carroll Smith, international automotive consultant, Steve Daum, SAE's Collegiate Design Programs Manager, and Kenneth Cunnefare, advisor of the Georgia Institute of Technology Motorsports Team; amongst others. Particular mention must be given to the widespread multiplicative effect of this program. Through the same promotional activities of the Team, and particularly through the Congress, several initiatives have come about. Within the USB there has already been participation in the SAE Aero Design West 2004 and the ASME Student Design Contest, and there are student groups pushing for the SAE Mini Baja and the ASME Human Powered Vehicle programs. In Venezuela, several other universities are experimenting with similar programs as Universidad Metropolitana, Católica Andrés Bello, Carabobo, Zulia, UNEFA, UNEXPO, and Central de Venezuela. Also through their participation in the congress, Universidad Politécnica de Madrid, Spain, and Pontificia Universidad Católica del Perú, have started their Formula SAE programs.

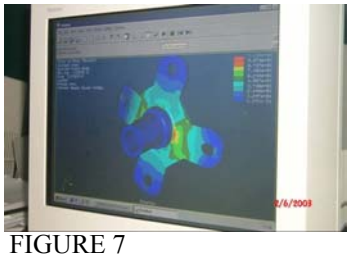

FIGURE 7
FEM REAR SPINDLE
F-SAE USB 2003 CAR

Some technical developments of the Program, some of which have been done for the first time in Venezuela, are a full experimental and analytical aerodynamic study of the car; design and manufacturing of an ad-hoc brake system (including discs, calipers, and master cylinders) with non traditional weight and stress efficient mountings; an on-board data acquisition system; wireless telemetry; electronic traction control; a series of design codes for thermodynamic, kinematics, static and dynamic analyses; non-traditional energy absorbing structures; and others. Currently, a particular effort is being made into the design and testing of shock absorbers specifically adapted to the F-SAE USB 2005 car. Many of these results have been published in 8 technical papers presented in national and

international conferences, further enhancing the training of the students in preparing this kind of reports.

FIGURE 8
CHASSIS WELDING
F-SAE USB 2003 CAR

By evaluating the performance of the F-SAE USB Team members, it is possible to note an increase in initiative and creativeness, development of interdisciplinary teamwork aptitudes and improvement in communicational skills, both in Spanish and English. The students develop a greater integration of the knowledge acquired along their class-work, since they are forced to solve problems that require the use of more than one specific area, and in most cases even have to interact with students or professors from different majors. The project requires the use of advance analysis in finite elements, internal combustion engines, computational fluid mechanics, 3D computer aided design, manufacturing processes, alternative materials, instrumentation, electronics, heat transfer, etc. It also requires hands-on work, since every part designed has to be built, assembled, tested, and evaluated, thus providing a complimentary expertise that most professionals only acquire after years of professional practice. It is also clear that, since the knowledge is revisited or obtained as an answer to a problem posed by the student needs, and since it is the student himself who looks for it, there is a better understanding and retention of it.

One of the more relevant characteristics of an F-SAE graduate are his/her managerial skills, which are not commonly addressed in an engineering major. These students have managed an engineering project with a budget of nearly US$90.000 (not counting salaries and workmanship), with a team of about 60 “engineers” and over 20 “expert consultants”, with very demanding technical requirements, and very stringent time constraints. They have negotiated with CEO’s of large companies and know how to “sell” their product.

Furthermore, the F-SAE students have developed high-tech designs and have measured them up against their peers from all over the world, thus are aware of their capability and have confidence on what can be done locally.

In a crisis economy, as today’s Venezuelan economy, many Team members are able to find jobs even before graduating. While many engineers are unemployed, most F-SAE USB graduates are inserted into the work force or are studying graduate programs. A good percentage of them is either working or studying overseas, which speaks of their quality, though is an unfortunate fact for the country.

CONCLUSIONS

The F-SAE USB Program represents the result of the work and effort of the students, who are the motor of this initiative, supported and supervised by the USB. The program is a complement to traditional education that allows development of technical and management skills, training the student in an environment that replicates real world engineering under economic, technical, and time restrictions.

The program develops multi and interdisciplinary teamwork, hands-on skills, knowledge integration, and a connection between theoretical development and its practical implementation.

The development of a high-tech device and its measurement against the best peers from around the world breaks the paradigms of lack of confidence in local inventiveness and capabilities with the available resources.

Program graduates have a positive attitude toward facing new challenges and generating new technology, beyond simply consuming pre-made techniques, making them entrepreneurs able to generate new jobs and work areas.

The generation of a highly motivating product, a race car, allows an extra involvement of the students and the possibility of recruiting sponsors that provide funds for a program that would not be feasible otherwise.

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2003: Sclumberger, Bosch, Banco Mercantil, Pinturauto, ELECON, TRIAUTO Procter and Gamble, Continental Airlines, SAP, BMW.

2002: PDV, CITGO, Schlumberger, Lincoln Electrics, Banco Mercantil, ELECON, Asociación de Amigos de la USB.

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