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IMPLEMENTING THE "KNOW-HOW" SKILL SET IN ENGINEERING DESIGN

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ABSTRACT
Based on a series of previous studies to identify the design engineering body of knowledge [1], methods are being sought to effectively implement a "know-how" skill set within the Mechanical, Automotive, & Materials Engineering curriculum. Aside from acquiring competence in the standard engineering sciences and analytical methods, greater emphasis is being put on establishing an innate feel for machinery, precision measurements, manufacturing methods, team based project work and a range of professional practice issues. Lack of sufficient exposure to an experiential knowledge base is being overcome though a series of "dissection and rebuild" laboratories, plus team projects with shop-intensive content requiring conceptualization, planning, detail design, manufacturing, prototype assembly and testing. The Capstone Design experience is being implemented in a "virtual company" environment. Student engineering design teams report to a management board constituting the diverse interests of a typical corporation. These include senior engineering, expert consultants, the manufacturing division, finance & marketing, and clients. Acquiring the range of skills necessary for success in such a challenging endeavor necessitates some fundamental re-thinking and adequate preparation in the earlier years of an engineering program.

Keywords: Know-how, Capstone, Practicum, Design, Manufacturing, Dissection

1 INTRODUCTION
Typical Canadian engineering curricula are largely based on engineering sciences and mathematics, and thus are largely "theory" based. As a result, the underlying need to provide an upcoming mechanical engineer with industrial and design office experience is being ignored. The University of Windsor is in the midst of implementing the above-mentioned concepts with the intent of establishing an optional series of three separate one week long "manufacturing & technology camps". These would take place during a co-op work term and be carried out at a nearby Applied Arts and Technology College. St. Clair College's Ford Center for Excellence in Manufacturing (FCEM) is one of Canada's premier technical college facilities. It is extensive and modern; a $CAN 32.6M, 9300 m^2 facility. Additionally, at least one complete and formal laboratory course in manufacturing technology is planned for all engineering students using the same venue. With adequate preparation in the technological aspects, parallel to absorbing the classical theory in chalk and talk lectures, mechanical engineering graduates are becoming adept at providing the broad ranging skill-set demanded of the emerging class of design engineers. These individuals are now replacing the once separate specialists staffing manufacturing, product design, drafting, and analysis

divisions within companies.

2 CANADIAN ENGINEERING ACCREDITATION BOARD REQUIREMENTS

The latest Canadian Engineering Accreditation Board (CEAB) requirements, in effect for 2003 graduates onwards, has a built-in an element of team based design practicum. It leads away from widespread and undesirable final year project practices that were often simply individual research paper exercises, or involved undergraduates as minor participants in various professors' research activities. Alternately, the projects might have constituted an extension of work done for co-op employers. The revised provisions now state:

“The engineering curriculum must culminate in a significant design experience which is based on knowledge and skills acquired in earlier course work and which preferably gives students an exposure to the concepts of teamwork and project management. A research project may be interpreted as engineering design provided it can be clearly shown that the elements of design, as noted in the [following] definition, are fulfilled in the completion of the project.”

“Engineering design integrates mathematics, basic sciences, engineering sciences and complementary studies in developing elements, systems, and processes to meet specific needs. It is a creative, iterative, and often open-ended process subject to constraints which may be governed by standards, or legislation to varying degrees depending on the discipline. These constraints may relate to economic, health, safety, environmental, social or other pertinent interdisciplinary factors.”

“Appropriate content requiring the use of computers must be included in the engineering sciences and engineering design components of the curriculum”.

2.1 Product Design Model

In an effort to truly adhere to the spirit of these directives, the mechanical engineering program at the University of Windsor has for a number of years been building towards an engineering practicum delivery that melds these requirements and the wishes of industry partners. The outermost loop (design and production) cannot be properly implemented nor practiced until the student has partially mastered the inner loop (engineering sciences), which in turn is built upon an innermost core (mathematics, basic sciences).

An outline of changes and additions to the Windsor mechanical engineering program, outside the usual curriculum, is presented as a template to other engineering institutions wishing to implement similar modifications to their program. Much of the Capstone Design organizational structure and metrics developed within the mechanical program are now being formalized into faculty wide baseline requirements at Windsor.

3 EXTERNAL SUPPORT

A partial transformation towards the above stated goal has already been achieved. Generating the versatile design engineer requires certain investment and infrastructure changes. Support from industrial partners and government, exploiting synergies between educational institutions, and champions within the university academic hierarchy are necessary elements. At Windsor strong corporate support via the DaimlerChrysler 3E fund, infrastructure expansion from an SSI government / industry fund, cooperation with the neighboring St. Clair college offering 3-year B. Technology diplomas, an extensive co-op and internship program, and strong faculty support for Capstone Design endeavors all contribute to the educational profile envisioned.

3.1 Infrastructure

Windsor's Mechanical, Automotive, & Materials Engineering department possesses a new separate facility, the Center for Automotive Research and Education (CARE), an outgrowth of past University-Industry cooperation [3]. It is reserved for mechanical engineering students in their final three semesters, plus graduate students (in separate labs). Present undergraduate infrastructure includes a semi-private design office with CAD terminals, a large project assembly hall, a mechanical dissection laboratory and meeting / presentation room. Limited machine and power tools are currently available for student use. The regular mechanical engineering technologist's shop and the faculty's larger technical support center, located in the main engineering building, see extensive use. A $CAN 7.5M facilities expansion, partly for design practicum activities, is underway as a result of a Provincially funded Strategic Skill Initiative (SSI) grant that was awarded based on past interaction and program support from industry. An 1850 m^2 expansion to CARE, with 300 m^2 of dedicated student machine shop area, a "Capstone Design / Manufacturing Processes Laboratory", a second project assembly area and a doubling of Dissection Laboratory space is in the detailed planning stage, with ground breaking to follow shortly. Other teaching and research facilities are to be similarly enhanced with further curriculum changes to follow.

4 DESCRIPTION OF WORK

4.1 Curriculum

4.1.1 Dissection laboratory - common exercises

As examples, present curricula and infrastructure for the Automotive specialization includes an introductory mechanical dissection lab, where third year students are each provided with a 5 HP gasoline engine and assigned their own workbench and cabinet space. In lieu of textbooks for this and the subsequent capstone design course, they must provide their own hand tools and are encouraged to purchase measuring instruments such as a electronic calipers. Access to specialized tools and instrumentation, eg. vehicle computer scan tool, engine dynamometer, emissions analyzer, infrared temperature probe, sound meter, optical tachometer, metrology equipment is provided, as are production engineering drawings of the engine to gain familiarity with GD&T. The student's course requirements are to run and test their unit's performance, disassemble the engine and its subsystems (eg: carburetor), and answer a comprehensive set of questions related to functional requirements and engineering detail of the various components, manufacturing processes, tolerances and materials of construction. Further, the class visits the actual production facility and assembly line where their engine was produced prior to commencing engine re-assembly and verification testing.

4.1.2 Group projects - disassembly & rebuild.

Subsequent to this experience, group projects are selected by the students. These entail the disassembly and repair / rebuilding of specific automotive components. Requirements include photographic documentation and a descriptive text of their process and findings, presented in poster format and / or instruction manual as deemed appropriate. Typical projects range from (but are not limited to) rebuilding worn auto engines, transmissions, or generating suspension - steering - brakes assembly / disassembly manuals. This laboratory intensive portion of the course, worth 50% of the final grade, is given alongside the normal lecture component, where the operating theory of vehicle systems is presented.

4.2 Capstone Design Project

A subsequent two-semester final year Capstone Design course capitalizes on such earlier practical experience. Year three students, having gained sufficient exposure, now interact with fourth year students, in preparation for the transfer of responsibility for their international design competition projects. Typical projects are the Society of Automotive Engineers Formula SAE®, Mini-Baja®, and Supermileage® vehicles, and similar high profile organized competitions. Students often prepare in advance, throughout the intervening co-op term on evenings and weekends. A small group of faculty, technologists and an administrative officer provide technical support / organization for fundraising. Industry funded projects are also acceptable if they meet the CEAB requirements. One condition is that the student cannot be paid for the work done, but the industrial partner may provide financial support for hardware, etc. Matching funds are usually available through government sponsored university-industry initiatives. Other projects may be forthcoming from faculty sponsors as part of a research endeavor, or directly from students on their own initiative. In either case, the criteria and assessment procedures are based on the identical CEAB requirements.

4.2.1 Project group formation

Student project teams are hand picked by the faculty advisors after sifting through a round of competitive applications where the students describe their skill-sets, motivation and background. Selection is loosely based on the homogeneous interest - heterogeneous GPA method described in Dutson [4]. Size is restricted to a manageable 4-10 core members depending on project complexity. Teams constituting the most ambitious projects are carefully screened to avoid anyone falling in the bottom third of the GPA rankings for reasons of reliable commitment and balancing of their academic workload. Leadership is split between a technical head and team manager for the larger projects. Members are tasked with the design / engineer / build responsibilities for specific sub-assemblies and manage non-credit helpers drawn from the lower years, when such help is forthcoming. Increasingly, especially for high-profile projects, such helpers present themselves from the technical college through to the third year level, mainly by word of mouth. A select few non-credit students are admitted to technical design meetings (discussed below). These individuals generally slot into future leadership roles. For example, the 2004 Formula SAE technical head had been a prolific helper for the past three years on two different projects.

4.2.2 Course format

Only four formal two hour class lectures are held each semester. Topics covered are listed in Table 1. These presentations are made by the course coordinators, usually in conjunction with other faculty members and invited experts. The Capstone Design "semi-formal" technical meetings follow a "virtual company" model. The six permanent members of the engineering management board (Table 2) host and score the meetings for effectiveness. These meetings occur on a rotating basis; three groups are processed every week at the scheduled class time. This allows the entire class (approximately 70 students) to be examined monthly. Each group presents three times per semester at a semi-formal review and all groups present to the entire department's faculty, in lieu of their final exam during the regular exams period. Groups are scored

Table 1. Capstone lectures & formal class gatherings

Gathering	Semester 1 - Topics	Semester 2 - Topics
1	Course outline - Rules + Evaluation	Semester 1 Debriefing
2	Project Management	Manufacturing Processes
3	Library Research	Geometric Dimensions & Tolerances
4	Technical Writing	Design for Manufacture & Assembly
5	Presentation Techniques	Design for Environment
6	Project Presentations	Poster Presentations

Table 2. Semi-formal design meeting evaluations

Evaluator	Weighting
Faculty 1 - course coordinator	25%
Faculty 2 - instructor	25%
Faculty 3 - invited technical expert	-
Technologist 1	12.5%
Technologist 2	12.5%
PhD. Graduate assistant 1	12.5%
Ma.Sc. Graduate assistant 2	12.5%

and given feedback on each such occasion. Second semester "finals" take the form of group poster presentations to the department faculty and formal "show and tell" demonstrations. Written Semester 1 group reporting constitutes:

〈 Project outline, timeline, budget
〈 Interim progress report
〈 Semester report - specified format (2.5 pages/member) or
  - competition design report format

Semester 2 written reporting:

〈 Post competition project binder
〈 Laminated project poster (0.2 m^2/member)
〈 "Show and tell" handout

4.2.3 Technical meetings

Teams must present quick and concise updates and are expected to be well prepared. Round-table discussions with technical drawings and hardware in hand are the order of the day. Budget and timeline updates are required. The purpose of the meetings is to inform, coordinate and resolve issues. The staff technologists provide an assessment of in-house capabilities and help prevent projects from going astray of practical realities. Meetings are heralded by a timer. Time allotment is initially larger, but gradually reduced to five minutes per member by the end of the first semester. This prepares everyone for formal presentations where the allotment is only 2.5 minutes per member. It reflects upper management corporate practice. Informal design meetings follow with the faculty / technologists / graduate assistants / administrative officer. They play dual roles as company management and technical experts.

4.2.4 Financial

Corporate cash and in-kind donations, like materials and machining time, are actively pursued by students and managed by the administrative officer. Most purchases are handled via the technologists who oversee daily operations. There is an expectation that the individual student contribution amounts to approximately CAN $125 per semester, the average textbook outlay. Major corporate student activities support funding, as the DaimlerChrysler Canada/University of Windsor - Excellence in Engineering Education (3E) program require a faculty sponsor and formal proposal. Local companies of all sizes are approached. A significant number contribute; some have provided steady support for many years. Often these are co-op employers. An average of nearly CAN $1000 per student is raised and spent on Capstone projects. This excludes in-kind donations, which are often an equivalent or greater amount.

4.2.5 Course metrics

Individual performance is based on lecture attendance, minor assignments linked to the formal lecture portion of the course, and the project notebook. Table 3 provides a summary.

Table 3. Capstone grading

Group Performance	Weighting	Individual Performance	Weight
Term Report	10 %	Log / Design Notebook	5 %
Final Presentation	10%	Lecture Attendance	3 %
Monthly Design Reviews	10%	Lecture Assignments	3 %
Project Results (Product)	50 %	Behavior & effort	9%
Total Group Mark (TGM)	80 %	Individual Total (IT)	20 %
Peer assessment factor	$F \cong 0.5$	IT + F*(PAP)TGM + (1-F)*TGM	100 %

Of the total grade, 80% is related directly to the project outcome. Approximately half this grade portion is shared by all group members, the other half is divided among the team via peer assessment. The format for peer assessment along with a sample evaluation, is shown in Table 4. Group members must jointly decide on a task list (left-hand column) and then assign their own interpretation regarding percentage of total effort spent on each task in the right-hand side column (individually). Group submissions with statements like “we all did equal work” are not accepted and penalized. Individual behavior and effort is noted and also used to rank team members.

Table 4: Peer evaluation example

Member	A	B	C	D	E	Sub %
Fund Raising	1	3	1	0	-	5
Engineering Analysis	2	5	0	1	-	8
Physical Design & CAD work	12	5	2	6	-	25
Manufacturing of Components	5	5	8	12	-	30
Assembly / Integration	0	2	2	8	-	12
Testing & Development	1	0	2	3	-	6
Preparing Presentations	3	1	0	0	-	4
Report Writing	0	2	5	0	-	7
Management & Organizational	2	0.5	0.5	0	-	3
Peer Assessment Percentage (PAP)	26	23.5	20.5	30	-	100

Each student must also keep a log / design notebook. It has to contain a dated summary of all design ideas, meeting minutes, sketches, notes, calculations, contacts, collected reference materials, etc. This project notebook must be updated weekly and submitted at the end of each term. One additional surprise evaluation is done during the term. A weekly log or day-planner of the hours spent on the project (even if the number is zero) is required. Conceptually, this record of activity would suffice as a basis for generating a line item detailed invoice, given the student were getting paid for services rendered as a contractor.

4.2.6 Team operations

Groups are expected to organize and hold their own weekly meetings and consult / work with faculty, technologists and outside suppliers or experts as necessary. The only formally dictated team structure is the appointment of a leader by the faculty coordinators after consultation. Larger teams are assigned a separate technical head and team manager. The students decide among themselves an appropriate division of responsibilities, and some may in turn supervise non-credit helpers. The faculty reserves the right to appoint new leaders should the need arise. Table 5 summarizes.

Table 5. Team Structure and Management

Executive	Course Coordinators + Faculty			
Management	Technical & Administrative Staff			
Leader(s)	Team Manager + Technical Head			
Level 2	Engineering Specialist(s)	Engineering Specialist(s)	Engineering Specialist(s)	Engineering Specialist(s)
Level 1	Non-Credit helpers			

All shops and facilities are open regular weekday hours. The graduate assistants provide limited access after hours and on weekends; however the use of machinery and specialized tools is more restricted at these times. Project coordinators / technical heads are issued building access cards and a key to the design lab. They are responsible for the actions of their team and for everyone's orderly conduct; such privileges can be terminated at the discretion of the faculty.

4.2.7 Project space assignment and working rules

The technical staff, in conjunction with the faculty, assign workspace in the project hall or other specific lab areas where a project can be expediently assembled. Keeping the project areas orderly and clean is mandated and failure to so results in grade reductions. Working calmly and safely, wearing protective gear (for example when operating a grinder) and following the instructions of the acting supervisor are mandatory. Technologists generally allow students to operate various equipment after some instruction or assessment of capability. Theft and other juvenile behavior is not tolerated. Reports of problems from technical staff are sufficient reason for reprimand and grade loss or ultimately expulsion. Project ownership is normally retained by the University unless mutual arrangements are made prior to reimburse expenses.

5 DISCUSSION AND OBSERVATIONS

It is important that faculty coordinators (in consultation with the technologists and GA's) clearly reserve to right to adjust the peer assessment should it be deemed the results negate the reality of the situation. Typically, group evaluations tend to see the largest spread on the strong teams and a near uniform distribution within groups that

have accomplished little. The peer assessment factor 'F' permits adequate tuning.
Association with the local technical college is still in relative infancy but growing rapidly. Adequate manufacturing and project assembly space dedicated to student use comes only with large capital investment - lessened somewhat by resource sharing. The expanding circle from basic sciences, to engineering sciences and finally the design and manufacturing engineering process as a whole is best approached in stages. Early exposure to the industrial environment via co-op terms and internships, followed by increasingly complex design projects with hands-on shop experience is desirable. The manufacture and execution of such designs is a very valuable experience for young engineers. It unequivocally teaches the necessary adequacy for functionality and the inherent value of simplicity for production. Dissection and reassembly of complex mechanical devices, while acquiring an understanding of the design tradeoffs made, is the forerunner to tackling much larger and complex design-build endeavors entailed by the Capstone experience. Acquiring excellent in house facilities, dedicated technical staff involvement and active faculty guidance and mentoring leads to success.

6 CONCLUDING REMARKS

Aspects outlined in Dutson [4] in a comprehensive review on teaching engineering design through project oriented capstone courses, research conducted by the authors [1-3], and concerted effort by industry and government to enhance the useable skill set of graduating engineers has made a mark on the delivery of engineering design and practicum at Windsor. The demand for graduates with real "know-how" is being met.

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