AC 2011-1894: HOW TO DESIGN A DESIGN PROJECT: GUIDANCE FOR NEW INSTRUCTORS IN FIRST AND SECOND YEAR ENGINEERING COURSES

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Introduction

This paper is not an attempt to promote the use of Project-Based Learning (PBL) in engineering, nor even promote the use of projects within engineering science courses. There are already many excellent papers that justify the benefits of PBL[1,2,3,4]. This paper was written to assist new faculty, or those new to PBL, to design appropriate projects for a course.

The original motivation for this work came from the re-development of curriculum at seven Atlantic Canadian universities that share a common two year engineering program which leads to completion of two more years at Dalhousie University. All seven have begun to implement a design-project core of courses throughout all common semesters in the first two years. Change has been initiated as a result of new accreditation guidelines published by the Canadian Engineering Accreditation Board[5].

The greatest challenge in implementing PBL in existing courses is overcoming the level of discomfort instructors have with the teaching methods. This problem is exacerbated by the widely different class-sizes and physical resources in all seven campuses in the Dalhousie program. In order to help engineering faculty in Atlantic Canada adopt new teaching styles, guidance for PBL teaching in the first year is essential. While the immediate intent of the project is to aid faculty in the 7 target programs in Atlantic Canada, this problem is present in many universities where faculty are unfamiliar with PBL teaching approaches.

There are two reasons why you might continue reading this paper. 1) You may be interested in finding out if you can implement a complete project within your existing introductory course in engineering. Typically, your existing first course in engineering involves graphics, or statics, or mechanics of some kind and you feel that a project is needed. Otherwise, 2) It may be that your department chair or dean has made it clear that your course MUST have a design project added in order to satisfy some broader aims of the educational curriculum. Either way, you need to quickly become comfortable with a new teaching model.

The paper is based on experience acquired in teaching PBL courses in Engineering Design and Graphics (1st year students) and Project Design (2nd and 3rd year students). In addition, the lessons are based on experience introducing projects in *content-rich* courses for Engineering Statics (1st year students), Fluid Mechanics(2nd and 3rd year students), Mechanics of Materials(1st, 2nd and 3rd year students), Engineering measurements(3rd year students). The class sizes have ranged from 10 students to more than 250.

Process-Learning or Content-Learning

Once we've accepted that a project is to be integrated with a course, we really must sit down in the shade under a leafy tree (preferably in July, when there is time to think with few students around) and contemplate WHY? It is fine to have the broad aims set out by program committees, but when you are the instructor who has to face the students trying to struggle through an activity or assignment, you need more than general guidelines. Why do a project? Is the aim to give students experience in the ***process*** of “doing a project” (in what I will refer to in this paper as “process-*rich*” courses), or is the aim to support and enhance application of the course ***content*** (to be referred as “*content-rich*” courses). Either of these are valid reasons for Project-Based Learning, but they lead to very different trajectories.

The difference between a project that is focussed on “process” versus one with focus on “content” is illustrated in Figure 1. In the figure, the horizontal axis represents the level of “management complexity” , or the level of difficulty that the students will encounter in simply running the project. A multi-semester project with 5 student group members having different class schedules, with both an external project client and a faculty advisor, a project budget, and the expectation of prototype construction and testing would entail a very high level of management complexity. By comparison, a single lab session with an *ad-hoc* group and a simple task would have a very low level of management complexity.

The vertical axis in Figure 1 represents the level of “technical complexity” in a project. Projects that employ a high degree of analysis using advanced theory and modelling would entail a very high level of technical complexity. A single lab period where a single theoretical concept is tested would entail a relatively low level of technical complexity.

Projects that might fall in the upper right hand corner of the figure would have a very high level of management required during their execution, as well as a great deal of technical sophistication. Senior capstone projects that have student group work for a full academic year supervised by an external "client" would certainly typify this sort of project.

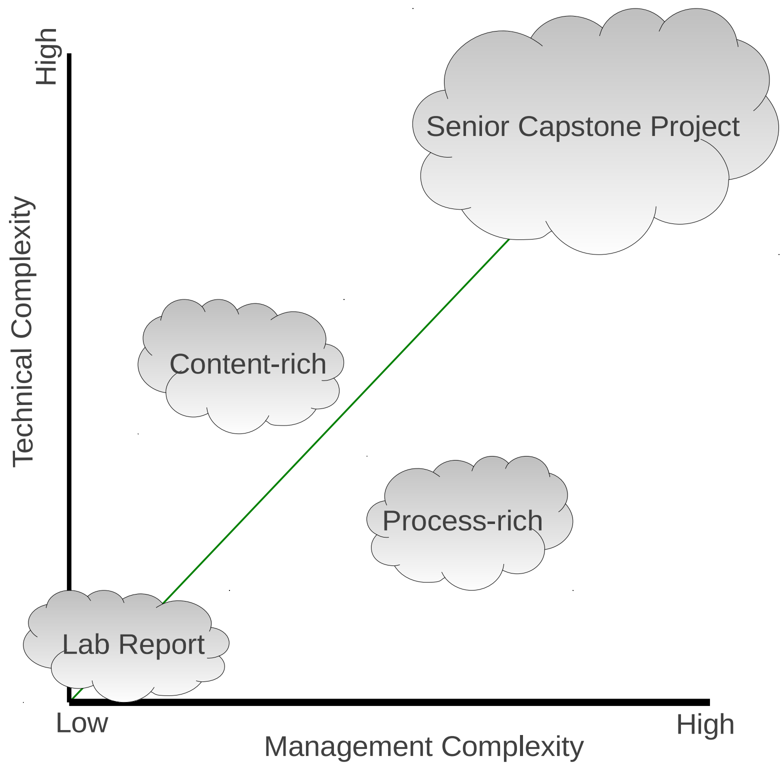

Figure 1: Axes showing the relationship between project technical and management complexity. Projects referred to as "process-rich" employ high management complexity, while those "content-rich" may substitute management for technical complexity.

The characteristics of a "process-rich" project are very different from the "content-rich" projects, even if the specific design task is the same. Take, for example, a typical project in a first-year graphics course: *Design a mail-box for a rural road delivery in a Canadian winter*. A process-rich project would emphasize the students working in groups, group dynamics, idea generation, setting out project tasks and deadlines, budgeting, reporting and communication, and may culminate in presentation of results in a formal "live" presentation. In reality, the practical details of the solution presented by a project team in this "process-rich" project are secondary to the learning. Presumably, the marking scheme for the project would reward the design process more than the design product. Whether or not the group has developed a really viable mail-box design, or even the level of excellence of their drawing has little bearing on how much they learned by working through the steps of the project.

In contrast, the same project: "D*esign a mailbox...*" in a content-rich introductory graphics course would stress the quality of the design drawings, the adherence to drawing standards, and the level of detail in the modelling. The evaluation of the quality of the student learning could have little to do with how the results were achieved, or how the project team managed their time and communications so long as the students learned proper use of the drawing tools and could demonstrate the production of an excellent product.

Designing a Design Project

For the instructor, it is important to decide whether learning the "process" of design or the technical "content" of the course is a priority before developing the project. One way to help make this decision is to consider the learning outcomes of a project, and how they serve the newly-adopted list of "Graduate Attributes" for Canadian engineering programs. Table 1 shows a list of the 12 Graduate Attributes defined by the Canadian Engineering Accreditation Board[5]. For each of these, a set of indicators is being developed for use at Dalhousie by a Graduate Attributes Working Group. The list of indicators shown is an early draft, and it was created based on work done at the University of Saskatchewan by Dr Malcolm Reeves [6].

In Table 1, the Graduate Attribute Indicators which are shown in bold text are those determined to be central to a recent project in a first-year course at Dalhousie. Discussion with the teaching faculty for a new project in a first-year Mechanics of Materials course in 2011 at Dalhousie University led to this prioritization of attribute indicators for the project. Using this priority list, a project was created that emphasized and measured the performance in only those indicators.

It can be tempting to include almost all of the indicators in the matrix of Table 1 when considering a project. For instance, every project where students work in groups can be said to help them to develop their S*kills for individual and team work.* The issue here is whether or not the indicators and attributes are actually being taught in the course, and if they should be seen by the faculty and students as a priority. In the example of Table 1, it was the consensus of the teaching faculty that the project focus on the analytical and problem investigation skills rather than the process and professionalism attributes. In this example, the list of key attribute indicators is clearly weighted towards the *content-rich* indicators rather than the design *process-rich* indicators.

The list of attributes and indicators that are priorities in a design project can help to steer the content of the project, its implementation, and the evaluation of student work. For example: in a first -semester course "Engineering Graphics and Design", suppose the project task is *"Design a Mailbox...*", and one of the key attribute indicators is *" Knowledge of mathematics to the level required for fluency in the techniques of analysis and synthesis that are relevant to the broad field of engineering."* For new students, this generic statement of attributes gives them no useful insight into what is expected from them for the project. We can translate this general indicator into a clear task for the specific project such as: "*Calculate the total surface area of all sheet metal in your mailbox design and the total mass of the unit*" Either of these calculations would be reasonable for first-year. If we were using the same project in a higher level course, perhaps the task could be: "*Calculate the maximum side-load for the post on which the box is mounted".*

The specific indicators shown in Table 1 are typically generic so that they will be consistent through all 4 years of the student program. As a result, they are not adequate for development of specific content guides for project design, nor are they directly helpful for students in first year. Table 2 shows an example translation from the generic attribute indicator to a testable criteria that was used in the information kit delivered to students at the start of a project.

In Table 2, the column "*Testable Performance Requirements for students*" was communicated to students, and formed the basic grading criteria for a project grading rubric. By using this approach, the instructors' objectives were clearly articulated to students, they could be tied to explicit "deliverables" for students in the project, and it could be defended on the basis of desirable Graduate Attributes.

Up to this point in the design of a project for students, the specific subject of the design has been irrelevant. Once the criteria in Table 2 have been established, it should be possible to take almost any prospective problem and formulate a project.

Table 1: Graduate Attributes and Indicators for ENGN1012 Design Project 1

	Attribute Indicators					
	1	2	3	4	5	6
Knowledge Base for Engineering	**Knowledge of mathematics to the level required for fluency in the techniques of analysis and synthesis that are relevant to the broad field of engineering.**	**Knowledge of the physical sciences, life sciences, and earth sciences underpinning the broad field of engineering, and appreciation of scientific method.**	Knowledge of the areas of engineering science that support the broad field of engineering.	Knowledge of the technical areas comprising a recognized engineering discipline.	Knowledge of materials and resources relevant to the discipline, and their main properties, and ability to select appropriate materials and techniques for specific objectives.	Knowledge of how new developments relate to established theory and practice, and to other disciplines with which they may interact.
Problem Analysis	**Ability to identify and define the nature of a technical problem.**	**Ability to understand and work from underlying principles in tackling technical problems.**	Ability to break down a problem, process or system into manageable elements, for purposes of analysis or design.	Ability to make appropriate simplifying assumptions to achieve a solution.	Ability to perceive possible sources of error, eliminate or compensate for them where possible, and quantify their significance to the conclusions drawn.	Ability to engage with ill-defined situations and problems involving uncertainty, imprecise information, and wide-ranging and conflicting technical and non-technical factors.
Investigation	**Ability to perform research and seek advice from appropriate sources, including advice on latest applicable technologies.**	Proficiency in a range of laboratory procedures in the discipline, and strong grasp of principles and practices of laboratory safety.	Ability to make appropriate measurements, analyze and interpret data and form reliable conclusions.	Ability to investigate a situation or the behaviour of a system and ascertain relevant causes and effects.	Ability to develop and construct mathematical, physical and conceptual models of situations, systems and devices.	Ability to utilize such models for purposes of analysis and design, and understanding of their applicability and shortcomings.
Design	Ability to elicit, understand and document the required outcomes of a project and define acceptance criteria.	Ability to define reasonable and achievable functional specifications, using engineering methods and standards, and to check the design solution against the user needs and requirements.	Ability to quantify the engineering tasks required to implement the chosen solution for simple systems and systems with multiple interacting components.	Ability to conceptualize and define possible alternative engineering approaches and evaluate their advantages and disadvantages.	Ability to synthesize components of a design into an integrated whole.	**Ability to ensure that the chosen solution maximizes functionality, safety and sustainability, and identify contraints, risks, tradeoffs and any possibilities for further improvement.**
Use of Engineering Tools	**Ability to produce clear diagrams and engineering sketches in both traditional and electronic form.**	Fluency in current computer-based document-processing and graphics packages.	Awareness of current tools for analysis, simulation, visualization, synthesis and design, and competence in the use of a representative selection of quality tools currently in use in the specific engineering discipline	Ability to locate, catalogue and utilize relevant information, including proficiency in accessing, systematically searching, analyzing and synthesizing material from relevant publications.	Ability to assess the accuracy, reliability and authenticity of information obtained either from the literature or from experiments.	Appreciation of the accuracy and limitations of such tools and the assumptions inherent in their use; ability to verify the credibility of results achieved.
Individual and Team Work	Ability to manage time and processes effectively, prioritizing competing demands to achieve personal and team goals and objectives.	Ability to earn the trust and confidence of colleagues through competent and timely completion of tasks.	Capacity to communicate frequently and effectively with other team members.	Capacity to mentor, and accept mentoring from others, in technical and team issues.	Capacity to recognize the value of diversity, develop effective interpersonal and intercultural skills, and build network relationships that value and sustain a team ethic.	Capacity for initiative and leadership while respecting others' agreed roles.
Communication Skills	**Ability to maintain a professional journal and records and to produce clear and well-constructed engineering documents.**	**Ability to communicate effectively in both informal and formal oral and written presentations to technical and non-technical audiences.**	Ability to be effective in discussion and negotiation and in presenting arguments clearly and concisely.	Capacity to critically read, understand and interpret both technical and non-technical information.	Ability to represent engineering issues and the engineering profession to the broader community.	Capacity to hear and evaluate the viewpoints of others and to respond appropriately.
Professionalism	Familiarity with the constituent association's code of ethics, and other codes of ethics relevant to the engineering discipline and field of practice, and commitment to their tenets.	Awareness of standards and codes of practice relevant to the discipline and field of practice.	Awareness of legislation and statutory requirements relevant to the discipline and field of practice	Awareness of the responsibility to protect and consider the public interest in all actions and decisions.	Commitment to present a professional image in all circumstances, including relations with clients, suppliers and stakeholders as well as professional colleagues.	Commitment to honesty, integrity and intellectual rigour combined with a readiness to tackle new issues in a responsible way.
Impact of Engineering on Society	Acquisition of broad educational background and/or general knowledge necessary to understand the place of engineering in society.	Appreciation of the imperatives of safety and of sustainability, and approaches to developing and maintaining safe and sustainable systems.	Appreciation of the interactions between technical systems and the social, cultural, environmental, economic and political context in which they operate, and the relationships between such factors.	Ability to interact with people in other disciplines and professions to broaden knowledge, achieve multidisciplinary outcomes and ensure engineering components are properly integrated.	Appreciation of the nature of risk, both of a technical kind and in relation to clients, users, the community and the environment.	Awareness of the need to plan and quantify performance over the life-cycle of a project or program, integrating technical performance with social, environmental and economic outcomes.
Ethics and Equity	Awareness of and commitment to the adherence to ethical, OH&S and quality standards.	Ability to build and maintain network relationships that value and sustain a team ethic.	Ability to treat all persons fairly, without bias, and with respect.	Ability to demonstrate the need for a high level of professional and ethical conduct in engineering.	Ability to recognize the value of cultural diversity and apply appropriate practices.	Ability to develop and maintain the trust and confidence of colleagues.
Economics and Project Management	Introductory knowledge of the conduct and management of engineering enterprises and of the structure and capabilities of the engineering workforce.	Knowledge of business principles and appreciation of their significance.	Knowledge of project management techniques and ability to apply them effectively in practice.	Ability to incorporate cost considerations throughout the design and execution of a project and to manage within realistic constraints of time and budget.	Ability to assess realistically the scope and dimensions of a project or task, as a starting point for estimating costs and scale of effort required.	Ability to comprehend, assess and quantify the risks in each case and devise strategies for their management.
Life-long Learning	Awareness of and commitment to Engineers Nova Scotia's continuing professional excellence requirements.	Ability to take charge of their own learning and development, and commitment to undertake appropriate learning experiences.	Demonstration of a record of improvement in non-engineering knowledge and skills to assist in achieving engineering responsibilities.	Ability to recognize limits to their own knowledge and to seek advice, and/or undertake research, to determine what more they needed to know.	Demonstrated commitment to the importance of being part of a professional and intellectual community.	Ability to critically review and reflect on their own capabilities, invite peer review, benchmark against appropriate standards, and determine areas for development.

Table 2: Graduate Attribute Indicators Applied for First-Year Projects

	Attribute Indicator	Testable Performance Requirements for students
Knowledge Base for Engineering		
	Knowledge of mathematics to the level required for fluency in the techniques of analysis and synthesis that are relevant to the broad field of engineering.	Student demonstrates ability to carry out correct mathematical analysis of the problem using calculus to derive analytical or discrete models. Analysis must be accurate and correct. This criterion is about how to apply maths to the problem.
	Knowledge of the physical sciences, life sciences, and earth sciences underpinning the broad field of engineering, and appreciation of scientific method.	Understanding of the classroom topics is demonstrated through explanations and appropriate analysis. Topics may include descriptive geometry, material bulk properties, units of measure, projections, basic mechanical properties, and other basic concepts including those in chemistry and physics. This criterion is about how to apply these concepts to the problems in design.
Problem Analysis		
	Ability to identify and define the nature of a technical problem.	Identify and define the nature of the technical problem and understand the underlying principles and where/how they are applied in the technical problems. This criterion is about knowing WHICH tools, theories and concepts to apply.
Investigation		
	Ability to perform research and seek advice from appropriate sources, including advice on latest applicable technologies.	Demonstrate skills in literature research from appropriate sources, including identifying relevant sections of textbook, commercial info, and academic journal sources. You will need to know how to FIND technical reference material, what is suitable, and how to decide what is credible or not.
Design		
	Ability to ensure that the chosen solution maximizes functionality, safety and sustainability, and identify constraints, risks, trade-offs and any possibilities for further improvement.	Develop possible alternative engineering approaches and evaluate their advantages and disadvantages. Ensure that the chosen solution maximizes functionality, safety and sustainability, and identify constraints, risks, trade-offs and any possibilities for further improvement. This criterion asks that you articulate a design approach that makes sense and motivates the rest of your analysis.
Use of Engineering Tools		
	Ability to produce clear diagrams and engineering sketches in both traditional and electronic form.	Draw clear Free-body diagrams, system schematics, mechanical drawings and engineering sketches in electronic form as appropriate.
Communication Skills		
	Ability to maintain a professional journal and records and to produce clear and well-constructed engineering documents.	Logbook: a clear and well-maintained engineering journal of ideas, notes on literature research, rough calculations, preliminary sketches, and other information.
	Ability to communicate effectively in both informal and formal oral and written presentations to technical and non-technical audiences.	Report: a clear written report based on the assignment template. The report must include drawings, sketches, calculations and other appropriate material in a professional-looking finished product.

Timing of *Content -Rich* or *Process-Rich* Projects

Before discussing the specific choice and deployment of a design problem, its useful to think about the schedule and timing. Should a term-long project be launched on the first day? Should you launch the project a few weeks before the end of the course? Should you hold multiple projects throughout? Your approach will be steered by the key graduate attributes upon which you have decided to focus.

Figure 2 shows an example time-line for a *Process-rich* project that lasts throughout one full semester. The dates and events are based on a project course taught to 2nd and 3rd year students at the University of Prince Edward Island by the author in 2009. The project topics are described in Table 3. The project deadlines shown were used in the course. The right-hand side of the figure shows example "faculty interaction". The dates and notes are representative of the trajectory of several project groups, and are not intended to reflect a particular project history.

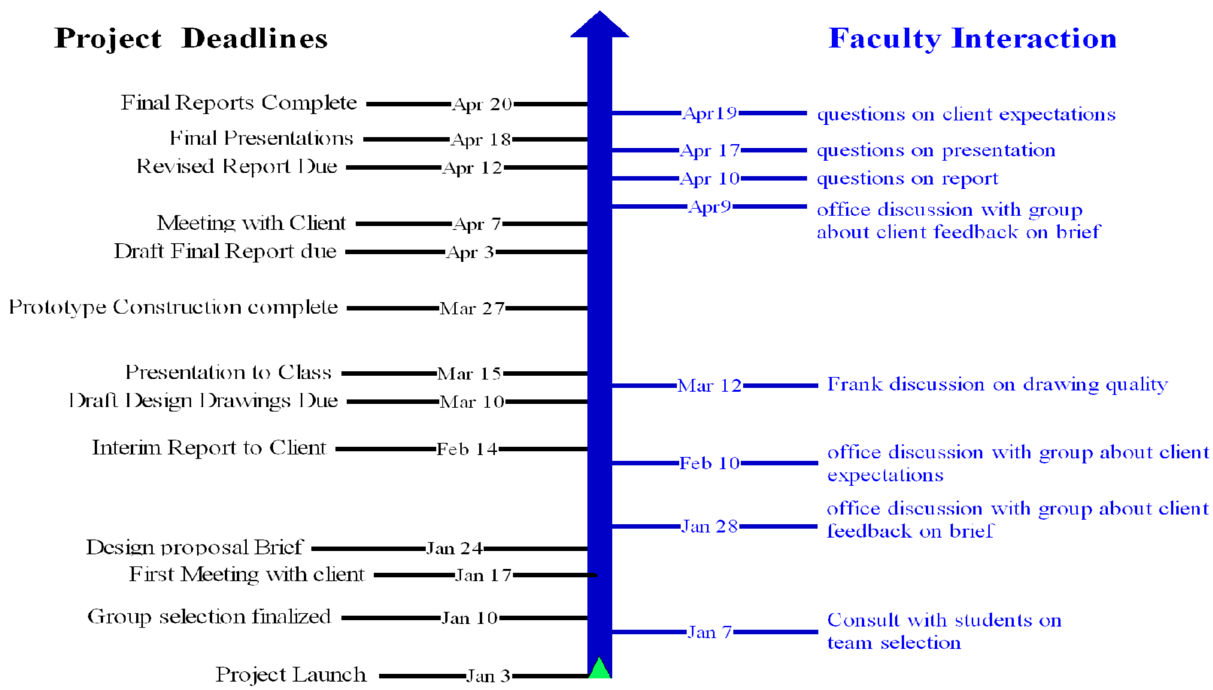

Figure 2: A time-line of deadlines and student/faculty interaction over the course of a term-long project in a 2nd and 3rd year design project course

Table 3: Projects in a 2nd-year Process-Rich Course				
Client	**Project Description**	**Deliverables**	**Prototype**	**Testing**
Town of Stratford	Town of Stratford Wastewater Facility	Pipe flow model, process drawings, mechanical drawings	No	No
Department of Fisheries and Oceans	Abrams Village Harbour Expansion	Civil engineering drawings, Harbour layout drawings	No	No
PEI Energy Corporation	Hydrogen Bus LCD Information System	Wiring hookup diagram, Mechanical drawings, 3D CAD model	No	No
I.B.Storey Inc.	Ice rink water recycling system	Process diagrams, piping schematic, test results	Yes	Yes
UPEI Facilities	Duffy Science Centre Energy Audit	Energy usage data, catalogue of consumers	No	Yes
Maritime Electric	Utility Pole Guy wire installation program	Package of original Software macros	Yes	Yes
Maritime Electric	Protection Cage for High Voltage Tests	System diagram, logic simulation, mechanical drawings	Yes	No
XeroPoint Green Technology	Cooling system for testing of shipboard power equipment	Process drawings, Pipe flow model, mechanical drawings	No	No
Atlantic Veterinary College	Fixture for testing the strength of horse bones	Mechanical drawings,	Yes	Yes
PEI Bag Company	New Plant Layout for bag processing line	Time-motion study, floor-plan/ work-flow layout	No	No
Aliant Telecom	Voice Test Industrial Engineering Analysis	Time-motion study, employee interviews, data-flow model	No	Yes
PEI Energy Systems/ Fort Chicago	Soot removal from District Heat Economizer	Process diagram, material analysis, mechanical drawings	No	Yes

Throughout the term, there was very little student-initiated contact. The students in this course each had an external project client with whom they met 3 or 4 times through the term, but otherwise their contact other than regular class/lab time was minimal. For groups that were functioning well, this wasn't a problem. Unfortunately, it meant that poorly performing groups could easily avoid detection, thinking they would “pull-through” sometime before the end. From a teaching viewpoint, they were not getting the necessary attention they needed to learn better “process” skills. One of the symptoms of poor design process skill may have been an inability to see when things were going off the rails. Thus, the sort of time-line shown in Figure 2 is best suited to students who are already capable at managing the process of a design project, or where the primary content of the course is, in fact, guiding the process. It may not be suitable for students who are not experienced, such as those in a first-year course.

Figure 3 shows a time-line for a *content-rich* project course in first-year, second semester. In this case the course was "Engineering Statics". In the spring of 2010 it was taught for the first time with a project focus. The students had no formal training in project management, and the course intent was to support the technical content attributes, rather than the process and management ones. When the course was planned, it was decided that there would be 3 or 4 short projects (duration 3-4 weeks each). The projects were intended to be linked closely with the statics textbook. As the semester progressed, there were hands-on lab sessions where students carried out model testing to support their design calculations. The project task descriptions are shown in Table 4.

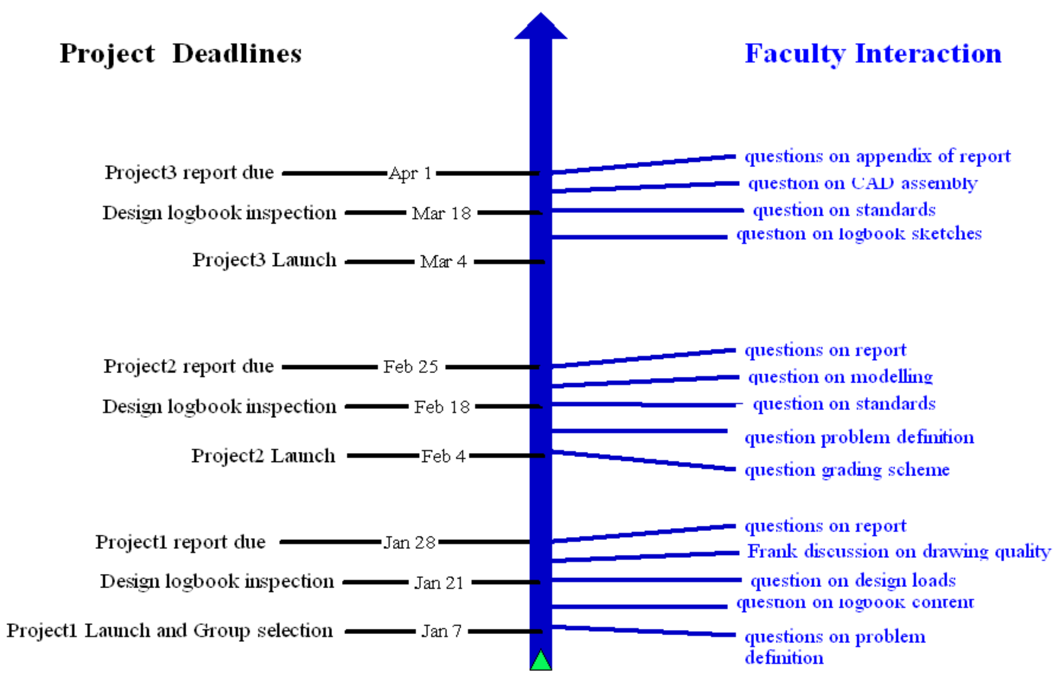

Figure 3: A time-line for a first-year project in a content-rich course showing project deadlines on the left, and representative student/faculty interaction on the right

Table 4: Projects in a first-year Content-Rich Course		
Project Title	**Project Description given to students at Launch**	**Initial Resources**
Project 1: Design a power line network for a new subdivision	The attached CAD drawings show the plot plan for a new subdivision. In the plan, there must be a grid of overhead power and data lines. What is the best arrangement of poles and wire, and what do you need to specify for cable stays to support the poles? Maritime Electric has a set of standard load guides to make sure that your installation doesn't exceed the load (force) limits on wire cable, and the supporting poles. You also must specify the tension of the cables to accommodate the correct sag. You need to analyse the network of poles and wires to ensure that the grid is strong enough to withstand the conditions.	CAD drawing, 4 references, Report template
Project 2: Raise a Tower	Bergey Wind Co builds a very successful 10kW wind turbine. The turbine can be installed on a 120ft tower. However, the final installation typically relies upon the rental of a large crane, and this is not possible in some remote locations such as small islands. Watch the video examples of two tower-raisings. The tilt-up example is only a wind monitoring tower, so it is much lighter than the actual Bergey tower (the turbine at the top of the Bergey 10kW tower is more than 1/2 ton). The manuals provided by Bergey for their 10kW system give weights and sizes for major components. They also show details for the tilt-up installation of small systems. Your job is to work through the design of a tilt-up option for the larger systems using one of the standard towers sold by the company. Your design will include sketches of the structure (or structures) that may need to be built to modify the base and mounts for the tower, as well as calculations of the wire sizes, and forces on all components to verify whether or not a tilt-up system is feasible for the existing tower designs.	2 Videos of tower raising, 3 product brochures, Tower installation manual, Report template
Project 3: Tensegrity Structures	The design of structures in "normal" buildings leads us to construct the sort of familiar arrangements as seen at the CARI rink and pool. These use the same large elements for both compression and tension, in most cases. There is another class of structure that are often called "Tensegrity structures" or just "tension structures". They are used in some applications, but they are often considered "exotic". We are going to design and build one. A big one. One to put in the campus Quad...	Matlab program for Tensegrity geometry, 3 references
Project 4: Tubular Rails Inc.	Have a look at the company websites for a conceptual rail-less transit system. From what I have read, the company that proposes this technology wants to build 400ft long rail cars having rail guides built onto the bottom and sides. these guides will be led over a series of wheels that are built into fixed stations every 100-feet apart, thus ensuring that the cars are always supported by 3 or 4 of these ground rings. The idea is that you don't have to built long rails, but instead erect these series of towers. While I'm not sure if I accept the blanket claim that this lack of rails will save money, at least you'll have a lighter moving vehicle by leaving the motors and mechanical gear on the ground, so all that moves is the payload, passengers and a light shell. There seems to be quite a bit of controversy about this. I don't know if it is a good idea... do you? For this project, do a conceptual design of the motorized drive system. Assume that the cars are 400 ft long, and that the rail on the cars are steel, and the rollers on the ground are also steel.	Company website

Process was not key in the first-year, *content-rich* statics course. Students were kept to a tight time constraint that was managed by the faculty through frequent contacts. They were given detailed instructions, and initial literature resources to get them started. Expectations for the deliverables emphasized content rather than form and process, and the indicators shown in tables 1 and 2 were clearly given priority. The students were seen to be taking an active role in asking questions related to the project both inside and outside of regular class times. The opportunities for corrective measures to ensure the students were on track were thus frequent compared with the opportunities in the term-long project shown in figure 2.

Content-Rich Project Delivery

Course delivery in university is a very personal issue to each instructor. We all have our own style, and comfort level with different techniques. Despite this, in a *content-rich* design project course, we can establish the framework for delivery of the project with certain components that will give structure to the experience and will be complementary to an individual professor's classroom style.

The projects used in a first-year *content-rich* course as shown in Figure 3 and Table 4 were common throughout the class. The students received detailed instructions of the project, a catalogue of initial research resources, and templates for report-writing and a grading rubric shown in Table 5. The grading rubric followed the Indicators shown in Table 2.

The essential elements that can aid in the delivery of a project to students are:

- **Problem statement:** for both content- and process- rich projects, the format and detail of the initial project introduction is important. It is just as possible to provide too much detail in the introduction as it is to provide too little. Table 4 shows the introductory text that students saw in a first year course at UPEI in 2010.
- **Initial resources:** Students are not expert in the project topic. It is helpful, and may result in a better experience for students if there are some guiding documents provided.

In most cases, it is reasonable to expect students to find more resources than the original set, but a starting list may be a good idea for the content-rich project. Table 4 describes the basic initial resources for each of 4 project examples.

- **Deliverables:** Students need to know what they are expected to produce. In many cases, if the project is their first experience, they will have no idea of the depth or format that is required. A combination of example reports, example drawing sets, and a template or style guide can help clarify what the final product should look like. This can be augmented with a detailed grading rubric as shown in Table 5.
- **Discussion Forum:** In a recent project at Dalhousie University for first-year students in a mechanics of materials class, there were 62 project teams and 250+ students. Each project group was given a discussion forum of its own, and the entire class was given an open project discussion forum. All of the teaching faculty were able to answer questions in all of the forums. Over a 3 week project, there were 994 messages posted in the discussion boards, with 254 of them in the common discussion. Faculty responses in all forums numbered more than 150 posts. Over the duration of the project, fully 30% of all student time spent using the course management site was spent in the discussion forums. The discussion forum was very well received by students, and its availability allowed faculty to identify and correct numerous misunderstandings of both project content and course theory.

Thus, for the *content-rich* first-year course, the expected deliverables were set by the instructor, and there were minimal intermediate communications required from the students, but frequent contact time to discuss the project in lectures and labs and online forums. Most of the interactions between faculty and students were in support of their learning the theory or tools needed to complete the design. The content of the design was closely tied to the textbook, in this case a commonly used text in engineering mechanics.

The grading rubric was a worthwhile tool. An example is shown in Table 5. The rubric presented was given to students at the start of a project, and students were frequently reminded to look in the rubric for answers to questions of content. The example in Table 5 is condensed from an even more detailed rubric employed in a first-year project at Dalhousie University. The

Table 5: ENGI1202 Design Project Report Rubric

		Expert 5	Competent 3	Novice 1	score Out of 5
Knowledge Base for Engineering					
20%	Student demonstrates ability to carry out correct mathematical analysis of the problem using calculus to derive analytical or discrete models. Analysis must be accurate and correct. This criterion is about how to apply math to the problem.	All applications of the theory, in explanations, in illustrations, in explanatory examples, in assumptions made, and in specific calculations are completely correct and original. Analysis has been taken to a very high degree of difficulty, and done soundly.	Applications of the theory are substantially correct and original. All work is explained, and there are No errors in any of the calculations or descriptions, but level of detail in calculations does not surpass that given in textbook and resources provided by the instructors.	Application of the theory is largely correct but basically follows the text content in a step-by-step fashion. There may be some important sections of the theory or analysis missing, or misunderstood.	
20%	Understanding of the classroom topics is demonstrated through explanations and appropriate analysis. Topics may include descriptive geometry, material bulk properties, units of measure, projections, basic mechanical properties, and other basic concepts including those in chemistry and physics. This criterion is about how to apply these concepts to the problems in design.	Report and appendices have clear, insightful description of concepts and methods used in analysis. Explanations are of "textbook" quality in clarity and accuracy. Simplified examples of the design problems show that the student is exceptionally fluent with the theory, and it's application in relevant examples, and understands the limitations/strengths of the different analytical approaches.	Report and appendices have clear description of concepts and methods suitable for use in analysis of cable stress/strain, and torsion based on textbook and classroom content with sufficient explanations to show that the student understands the theory presented in the course text.	Report and appendices have description of concepts and methods suitable for use in analysis of cable stress/strain, and torsion based on textbook. They are substantially correct in content, but may have several conceptual errors, or be missing a significant portion of the appropriate theory. Student has essentially followed the textbook examples, but had trouble converting theory into a unique application.	
Problem Analysis					
10%	Identify and define the nature of the technical problem and understand the underlying principles and where/how they are applied in the technical problems. This criterion is about knowing WHICH tools, theories and concepts to apply.	Original, clear and concise, well-explained, statements of the technical issues in the design. Trade-offs in the design issues are clearly explained as is the users requirements for the system. Evidence that the student has thought deeply about the problem and has developed novel ways to solve it.	clear and concise, correct statement of the technical issues in the design.	minimal evidence that the student understands the technical issues in the design. Several major technical issues have been missed.	
Investigation					
10%	Demonstrate skills in literature research from appropriate sources, including identifying relevant sections of textbook, commercial info, and academic journal sources. You will need to know how to FIND technical reference material, what is suitable, and how to decide what is credible or not.	student has shown the connection between the design problem technical challenges and theory contained in the textbook, references provided, and extensive additional research. More than 8 additional relevant research materials are cited, and actually used in the model analysis. The limitations of each of the differing theoretical or analytical approaches to the technical issues are discussed and the justification for methods used is clearly explained	student has shown the connection between the design problem technical challenges and theory contained in the textbook, references provided, and some additional research. More than 4 additional relevant research materials are cited, and actually used in the analysis.	student has failed to show the connection between the design problem technical challenges and theory contained in the textbook, references provided, or has applied them incorrectly.	
Design					
10%	Develop possible alternative engineering approaches and evaluate their advantages and disadvantages. Ensure that the chosen solution maximizes functionality, safety and sustainability, and identify constraints, risks, trade-offs and any possibilities for further improvement. This criterion asks that you articulate a design approach that makes sense and motivates the rest of your analysis.	Damn, I wish I'd thought of that! it is bloody brilliant!	a reasonable design solution that captures most of the desired design outcomes is presented. Sufficient detail is given to, if needed, find parts suppliers and carry out detailed design in future using this report as a guide.	Nope. It won't work, or the student hasn't made the case that the proposed design is suitable.	
Use of Engineering Tools					
20%	**Draw** clear Free-body diagrams, system schematics, mechanical drawings and engineering sketches in electronic form as appropriate.	excellent, accurate, professional grade drawings using SolidEdge .dft, meeting all common drawing standards for engineering detail drawings. Figures in the text are clear, attractive, and help to explain or highlight the ideas. Nothing is simply clipped from the internet, or other sources.	drawings using SolidEdge .dft, are largely correct, and accurate, but may have some minor inconsistencies. Figures in the text are clear, and help to explain the ideas. If any hand sketches are used, they are of high quality. Labels and notes in drawings are clear.	drawings are of poor quality, incorrect, difficult to read, or simply copied from internet or other sources. What drawings are present may not help to illustrate key points to make the design clear.	
Communication Skills					
5%	**Logbook:** a clear and well-maintained engineering journal of ideas, notes on literature research, rough calculations, preliminary sketches, and other information.	significant notes and calculations, done by hand, all pages dated and signed, clean legible. Think: Leonardo DaVinci's notebooks.	good, clear, complete notes of most work done on the project. All entries dated and signed, and all is legible, but simple.	some notes of work done on the project, but more than one major component is missing. All entries dated and signed, and all is legible.	
5%	**Report:** a clear written report based on the assignment template. The report must include drawings, sketches, calculations and other appropriate material in a professional-looking finished product.	publishable. Bloody amazing. A thing of beauty and a joy to behold.	no major errors, fewer than 3 minor typographical errors, complete graphics and figures are included in text and report follows style guidelines	more than 10 grammatical , clarity or logic errors, or major components missing or corrupted.	

example rubric was the only one used for the project grade, and it was applied to the final result submitted at the end of 3 weeks. There were no intermediate grading steps of student progress through the project.

Process-Rich **Project Delivery**

In the *Process-rich* projects of Figure 2 and Table 3, the project content was governed by the student's interpretation of client requirements. Since the course was primarily intended to teach the process of design, including communication with the client and interpretation of the client's needs, there was no justification for requiring each student group to do a specific type, or even degree of analysis. Each project was unique to each group, and an effort was made to balance the expectation of deliverables so that groups had a similar experience. To a large degree, however, each group determined what they had to do through the project. The message to students was simple: *You have to do whatever is needed to get the job done*. As a result, some projects had detailed mechanical drawings, some had electrical circuit simulation, and some had time-motion studies, as summarized in Table 3.

Key resources and activities that can be used to lead students in *Process-Rich* projects are:

- **Problem statement:** As was stated in the preceding section, for *process- rich* projects, the format and detail of the initial project introduction is important. A comparison of the problem list for the *process-rich* examples in Table 3 compared with the *content-rich* ones from Table 2 shows a marked difference. For students in a *process-rich* project, it is an important step for them to create the problem statement themselves.
- **Initial resources:** The initial resources in a *process-rich* project can be minimal. The acquisition of this information is itself an important task for the students..
- **Client Meetings:** Students can be given initial contact meetings with their client, and from those meetings be required to interpret the client's needs in a formal project proposal to the instructor and client. Subsequent client meetings can be managed by the team as a formal requirement of the course. Minutes for all meetings should be taken by the project group and made accessible to the faculty, and the project client.

- **Reporting:** Unlike *content-rich* projects, there are numerous required progress reports and intermediate deliverables through the term give structure to the process for the students. Table 6 shows the grading weight of each intermediate step.

Table 6: Grading scheme for Process-rich projects	
Process Deliverables	**372 Value**
Project proposal Draft	5%
Project Implementation Plan	5%
Formal Proposal	5%
Preliminary Design Brief	5%
Detailed analysis and construction drawings	10%
Prototype construction progress report	5%
Report of Prototype testing	10%
Final Presentations	5%
Final Report	30%
Group Participation	20%
Total	**100%**

- **Workshops:** Through the semester in a project course at UPEI, “SuperGroup Wednesdays” became a useful event in learning. These sessions brought together three different project teams working on different, but somehow complementary projects. The teams were assigned a seminar room and given a faculty “facilitator” who encouraged the teams to present their progress to the other student teams, and offer criticism and advice on all issues of the project to each other.   On each weekly session, a project group would be partnered with another two groups that they did not meet in recent weeks.
- **Deliverables:** Students need to know what they are expected to produce, even in the *process-rich* projects. Just as in the *content-rich* projects, a combination of example reports, example drawing sets, and a template or style guides can help to give guidance and maintain the quality of student output. This should be augmented with a detailed grading rubric specific to the project tasks, and created in consultation with client and students. Each deliverable in the example of table 6 was given its specific grading rubric to demonstrate to students the unique intent of each intermediate deliverable. Each grading rubric was developed to suit the graduate attribute indicators that were the focus in the intermediate steps.

- **Presentations:** Often, these are some of the obvious activities for student project teams in *process-rich* courses. They take up a great deal of class time, and the value of them in improving the student ability is arguable.
- **Discussion Forums:** Online forums have less potential benefit in process-rich courses where the projects are unique than they do in the earlier content-rich projects.

In each team in the 2nd and 3rd year *process-rich* courses at UPEI in 2006-2010, the project participants had a similar experience of learning the path through a project, including issues with planning, tracking of resources, communication with clients, and management of inter-group personalities. The design project evolution was simply not suitable to treatment in a 3-4 week project. All student groups took the entire semester to develop, and personnel management issues arose over time in each project group. Faculty interaction was devoted to reinforcing or guiding students on these topics.

Creating a Project

The best advice to new faculty who are faced with introducing a project to teaching is simple: Give it a try. If the purpose is clear, if it is understood why the students must do a project, and if the appropriate resources are available, students will have a valuable learning experience.

Frequently, the first thing we think about when coming up with a project for an engineering course is arguably the least-important component... the specific design task. If the structure described in this paper is employed in preparing a project, then the results for the students should be comparable. In the past 5 years of PBL in first-year courses, some of the project topics used have been:

- a shell/tube heat exchanger
- water treatment device for remote communities
- kite system for aerial photographs
- backyard rink zamboni
- safety system for Electrical equipment testing
- roof drain water recycler
- modifications for a small harbour
- “home grown” barn
- sustainable cottage
- system to increase bus rider-ship
- on-line cleaning system for District Heat Economizer,
- information system for the operating status of a Hydrogen Bus

- time-motion of online technical support employees
- grey-water collection and cleaning system for ice rink
- revision of building ventilation
- layout for bag manufacturing plant
- energy savings strategies for town owned assets
- bending apparatus for horse bone testing
- cooling system for AC motor drive for hybrid tug,
- ice rink spectator seat-heater using waste heat from the ice chiller plant
- Pill crusher for Nursing Staff,
- A Batch Waste Water Treatment System
- design of an eyelid holding device for optometrist
- aquaculture water filter,
- volatile gas soil sampling train,
- Evaluation of potential products for recycled plastics .

In all of the projects, the degree of student learning was less dependent upon the specifics of the problem than on the planning and implementation of the course structure. Any of the above projects could have been successfully delivered as c*ontent-rich* or *process-rich*. In most cases, the projects that turned out to be unsuccessful were ones where the expectation and delivery did not fit the course. The planning described in this paper can help the development of effective projects for engineering students.

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