DESIGNING A PETROLEUM DESIGN COURSE IN A PETROLEUM TOWN

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Until recently, the Department of Chemical and Petroleum Engineering at the University of Calgary offered undergraduate degrees only in Chemical Engineering and Chemical Engineering with a Petroleum Minor. As a result of a joint university and industry initiative, however, a new degree in Oil and Gas Engineering was added to the program in 1998.

The curriculum of the new Oil and Gas Engineering Degree was largely based on the advice of an industry advisory committee consisting of representatives from several major companies in Calgary's oil and gas sector. The committee identified the fourth-year Petroleum Design course as a key component of the new curriculum. This provided an opportunity for creating a course that draws on the high concentration of oil and gas companies and petroleum professionals in Calgary.

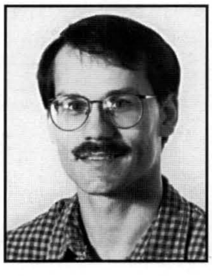
Now it was up to us to design the design course. First, we considered why design is taught at universities.

WHY TEACH DESIGN?

Perhaps the best way to answer the question is to examine the difference between undergraduates without design training and practicing engineers. "Academic" undergraduates will have taken a number of courses, each dealing with a specific topic area such as heat transfer, thermodynamics, or reservoir engineering. They should be familiar with fundamental principles of engineering science and are well versed in solving narrowly defined problems based on those principles. For example, they can find the pressure drop of a specified single-phase fluid in a given pipeline at given conditions. They will also have received some training in writing reports and making presentations.

Academic undergraduates are probably not fully aware of the interrelation of many topics covered in the undergraduate program. They have been trained to tackle problems individually and, at least in technical courses, they are rarely called upon to present their results in any format other than written assignments, short reports, or examinations. They have little or no experience with managing partial or contradictory data, conducting economic evaluations, and solving "design" problems. Here, a "design" problem is a problem that requires "the devising of an artifact, system, or process to best meet a stated objective."[1] For instance, "design a process to produce styrene for the Alberta market that meets the corporate economic hurdles." Note that design problems are open-ended; that is, the number of options and amount of detail that can be considered is limitless.

Practicing engineers deal primarily with design problems. They are usually selecting processes or choosing between competing technologies. Most of the methods and theories they learned in college are embedded in simulation software. Their hard-earned university knowledge is used primarily to check the simulation results for implausible results. But they must be aware of the interaction of all facets of their undergraduate knowledge. For example, is there heat loss from the pipeline and does the flowing fluid enter the two-



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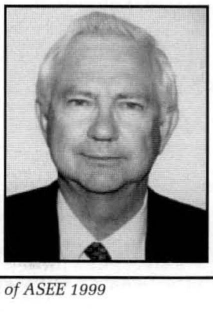

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phase region? Is erosion or corrosion possible at the operating conditions?

The university experience has been designed to give practicing engineers the tools to analyze problems and to adapt to new circumstances, for they *will* face new circumstances. Practicing engineers will often work on projects and technologies that were barely mentioned in college. They will usually be part of a team and will be expected to have good interpersonal and communication skills. They will often evaluate economics and will frequently present the results orally and in written form.

Until design was introduced into the engineering curricula, there was a glaring difference between the training undergraduate engineers received and the work they did as practicing engineers. In fact, universities are still criticized for training potential graduate students rather than potential industrial engineers.[2] Universities have responded in several ways. Some have introduced design case studies that are introduced in the first year and worked on in more detail throughout the program.[3] Many, including Calgary, have added a co-op or internship program where students work in industry jobs for terms of four to twelve months. Now, all accredited North American universities are required to offer design courses.

The final-year design course provides the best opportunity to teach design principles and bridge the gap between the university and industry. By this time, the students have learned many of the scientific principles they need to solve engineering problems. Many have completed an internship work term and are at least familiar with the industrial environment. The design course allows them to integrate the material from other courses and to work on an "open-ended" design problem. For this reason, it is sometimes referred to as the "capstone" course of an undergraduate program.[4]

ESSENTIAL ELEMENTS OF DESIGN COURSE PROJECTS

The comparison of an "academic" undergraduate with a practicing engineer highlighted the elements we wished to include in the design course. They are

- *An open-ended design problem*
- *Real data*
- *Experience relevant to industry*
- *Application and integration of all undergraduate material*
- *Teamwork*
- *Economic evaluations*
- *Use of commercial software*
- *Written reports*
- *Oral presentations*

We then selected projects and structured the course to include all the above elements.

PROJECTS

The elements listed above apply equally well to any design course. The next step was to develop projects from the petroleum area that met the requirements of the course. What is involved in petroleum engineering? It encompasses a broad range of activities just as chemical engineering does. Petroleum engineers may be called upon to estimate the size of a reservoir and to predict production from a well or the reservoir. They may design waterfloods, miscible floods, steam floods, or even firefloods (underground combustion) to displace oil from the reservoir. They may drill, complete, or stimulate wells. They may design pipelines or separators, or work in a gas plant. Economic evaluations, land sale evaluations, and negotiation with joint-interest owners are also part of the job. Petroleum engineering even extends to offshore production and oil sands processing. What projects should we draw on from the broad range of activities?

To apply all the undergraduate material and gain a perspective of the industry, we desired projects that included downhole (reservoir) aspects as well as facilities (oil batteries, gas plants, etc.) and the wellbore (drilling and completions). The projects had to be of sufficient scope to require the work of a team of students for two four-month terms and yet not overwhelmingly complex for a group of inexperienced engineers. Most importantly, we wanted the students to deal with real data with all its contradictions and omissions.

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We decided to concentrate on projects involving relatively straightforward reservoirs, such as a sandstone reservoir or a homogeneous carbonate reservoir. But the projects themselves are broad and open-ended. We ask the students to examine an existing reservoir and evaluate its reserves and existing production scenario. The students then have a choice—they can recommend strategies to increase the value of the reservoir in its present state, or they can re-engineer the development of the reservoir. In other words, they could take all the knowledge of today and develop the reservoir as if it had just been discovered. The advantage of the second option is that depleted reservoirs with little remaining potential can still be used as projects.

In either case, the students are asked to design appropriate facilities, construct a drilling and completion program, and generate production forecasts as well as capital and operating cost estimates. They then compare the economics of several strategies and recommend the optimum development strategy for their reservoir. As in real life, the design problem statements are deceptively simple (see Table 1). Note that the progression from design statement to problem definition to evaluation of alternatives resembles typical chemical engineering design processes,[5] although the details differ.

With the help of several Calgary companies,[6] we assembled data sets that included the same information that practicing engineers deal with to assess reservoirs; that is, well logs, conventional and special core data, pressure data (including build-up test data), and PVT data. The students were able to access any other required data, such as well locations, completion data, and production rates, from a commercial database available at the department or from the AEUB (Alberta Energy and Utilities Board), a provincial regulatory agency.

It is these data sets that make our design course unique. In petroleum engineering, a major issue is describing the reservoir, its size, thickness, porosity, and permeability distributions, etc. This description and the associated reservoir maps are constructed from well logs and other available data. These data represent a tiny fraction of the reservoir and are often contradictory or incomplete. Hence, judgment and interpretation are critical. A considerable part of the first term of the design course is spent characterizing the reservoir. This evaluation draws on many of the petroleum engineering courses in our program, listed in Table 2.

TABLE 1
Example Design Problem Statements

- Design a gas-cycling scheme for the Brazeau Nisku D retrograde condensate reservoir.
- Design a waterflood for the Countess YYY sandstone reservoir.
- Optimize the waterflood on the Black Butte stratified sandstone reservoir.
- Evaluate a steam flood for the Sparky A heavy-oil sandstone reservoir.

TABLE 2
Required 3rd and 4th Year Oil and Gas Engineering Courses

3rd Year
- Numerical Methods in Engineering
- Heat and Mass Transfer
- Chemical Engineering Thermodynamics
- Partial Differential Equations
- Separation Processes I
- Drilling and Completions
- Oil and Gas Engineering Economics (3rd Year Design)
- Oil and Gas Reservoir Engineering
- Petroleum Production Engineering

4th Year
- Flow in Porous Media
- Oil and Gas Treating Processes
- Well Logging and Formation Evaluation
- Introduction to Well Testing
- Petroleum Design I
- Petroleum Design II
- Petroleum Engineering Laboratory

PROGRAM STRUCTURE

The Department of Chemical and Petroleum Engineering at the University of Calgary has a four-year undergraduate program (not including time spent on internship work terms). The program includes a three-part series of single-semester design courses starting in the second half of the third year and concluding at the end of the fourth year.

Both chemical and oil and gas engineering undergraduates are enrolled in the same third-year design course. Equipment sizing, cost estimation, and profitability analysis are introduced in this course, and the textbook used is *Plant Design and Economics for Chemical Engineers.*[7] The students are assigned group projects worth 25% of the course grade. A chemical engineering project involves optimizing a given process and a HYSYS[8] simulation of the process is provided. An oil and gas engineering project involves assessing various strategies for developing a given reservoir. In this case, an EXODUS[9] simulation of the reservoir is provided. The projects give the students an opportunity to practice engineering design principles and engineering economics on a problem of limited scope. The projects also serve to introduce the simulation software used in the fourth-year design courses.

In the fourth year, the chemical engineering and the oil and gas engineering students enter different design classes: Process Design I and Petroleum Design II, respectively. The students taking a petroleum minor can choose between the two design courses. While the design courses are run separately, we modeled the structure of the petroleum design course on the long-standing and very successful chemical engineering process design course.[10]

In both cases, the Design I course is intended to be a first-pass design where the students can evaluate "their" process or reservoir and perform preliminary design, costing, and economics. The level of detail is similar to a budget cost estimate; that is, shortcut methods are employed and costs are accurate to approximately ±25%. In the second fourth-year course, Design II, the students work on the same project but to a greater level of detail, similar to an AFE (authorization for expenditure) cost estimate. In this case, detailed design methods are employed and manufacturer's quotes are obtained on major equipment, and costs are expected to be accurate to ±10%.

STRUCTURE OF PETROLEUM DESIGN COURSES

Petroleum Design I • The students are given one week to form a group (3-4 students per group) and choose their top three projects from a list provided in the first class. The key here is that the students are free to make up their own groups. We do not force students into groups, thus avoiding personality conflicts during the term. The projects are allocated as much as possible on a first-come-first-served basis. As a result, the better-organized students tend to get the projects of their choice. One disadvantage of this approach is that the poorer students tend to get concentrated into groups that will struggle with the course. On the other hand, these same students cannot coast through the course hidden in a group of otherwise good performers.

Once the projects are chosen, the students review their data sets, analyze what they can, and search for missing information from a petroleum database, AccuMap,[11] in the literature, at the AEUB, or through industry contacts. They use well logs and core data to construct cross-sections, structure maps, and appropriate pay maps of their reservoir. They determine volumetric reserves, and using pressure and production history, they perform a material balance to obtain a second reserves estimate. They usually reach this point at the midterm of the course. After the midterm, they use analytical techniques (such as decline analysis, solution gas models, and Buckley-Leverett-Welge waterflood predictions) to assess various development scenarios.[12-14] They also size and cost surface facilities (such as oil batteries, gathering systems, water plants, and gas plants), estimate drilling and completion costs, and evaluate project economics using the techniques learned in the Design I course.

The students are required to meet once a week with their project supervisor, a faculty member. Typically, each faculty member involved with the course manages two to four projects. The students, individually or as a group, are free to visit the supervisor more frequently. These visits tend to increase exponentially as the midterm approaches. The midterm consists of a six-page report and a five-minute oral presentation given to four supervisors or faculty members. One representative of each group presents a GANTT chart of their work schedule, discusses findings to date, and indicates what each member of the group is working on. The supervisors can then ask any group member a question on any part of the project. The group members are expected to be familiar with all aspects of their project, although leeway is given for detailed questions.

The midterm has a number of positive aspects. It informs the supervisors of the progress of each group. It is a milestone that forces the group to have achieved some results; otherwise, the students (being human) might leave it to the end. Finally, the midterm allows the course coordinator to identify any personality problems within the groups. The students also make individual in-class presentations on their part of the project. The presentations allow the course coordinator to identify "coasters," students who did not contribute to the project, and they give each student practice in making individual presentations.

The final phase of the Petroleum Design I is a preliminary design report. This brief, typed report summarizes the reservoir evaluation, development strategy selection, forecasting, facilities design and costing, and preliminary economic indicators. The students are also expected to produce cross-sections, reservoir maps, and facility schematics.

Petroleum Design II • By the end of Petroleum Design I, the students are expected to have a good understanding of their reservoir description and history and to have come up with some promising development strategies. In Petroleum Design II, they correct errors from Design I, simulate the reservoir, usually on EXODUS, and simulate their facilities on HYSYS. With the reservoir simulator, they are expected to obtain a history match of the pool production to date and to generate forecasts for several development strategies. They are asked to create a PFD of the facilities, a P&ID drawing of one piece of equipment such as a heater-treater, and to obtain quotes for major pieces of equipment. They are also asked to prepare a simple drilling and completion program and estimate capital and operating costs for the project. They then evaluate the project economics and perform some risk and sensitivity analysis. The Design II course is intended to duplicate as closely as possible the steps an engineer employed by an oil and gas producing company goes through to evaluate capital projects.

The Design II course includes weekly meetings with the supervisor, a midterm, individual presentation, and a final report. A final oral group presentation is also required after the winter term exams are finished. It consists of a half-hour formal presentation followed by a fifteen-minute question period. We describe it as a "formal" presentation because not only are supervisors and students present, but also other faculty members and practicing engineers from industry. In fact, as many as 300 letters go out to major companies, inviting them to send interested engineers to these final-project presentations; typically, 20 to 30 practicing engineers attend. The atmosphere is one of thesis defense. The students all participate in the presentation and then collectively face questions, first from other students and guests (industrial participants and other faculty), and finally from the project supervisors. Students are graded for the final presentation as well as the midterms and

TABLE 3
Grading Scheme for Petroleum Design II

	% of Final Grade
A. Design Project Report	
• Project Organization	5%
• Process Flow Diagram (PFD) and P&ID	5%
• Reservoir Maps	5%
• Technical Content	25%
Calculations, diligence, and accuracy; design methods and approach; figures and graphs; clarity of approximations and design factors	
• Economics	5%
• Summary, conclusions, recommendations	5%
Total Report	**50%**
B. Weekly Meetings	5%
C. Midterm Examination	15%
D. Classroom Presentation	10%
E. Final Oral Presentation and Project Defense	20%
Total	**100%**

project reports. An example of the grading system is shown in Table 3.

OTHER CONSIDERATIONS

Use of Software • A significant issue in undergraduate education is the use of commercial software, especially process and reservoir simulation packages. Most practicing engineers use commercial software rather than writing their own programs or solving lengthy calculations by hand, yet it is vital to understand enough of the underlying theory to recognize when the simulation results are misleading and to identify appropriate optimization strategies to test on the simulator. As educators, we want to avoid promoting the blind acceptance of the results obtained from commercial software.

We avoid this potential trap by emphasizing hand calculations in the Design I course. Applying hand calculations to a reservoir problem, for example, forces the students to think about the principles of fluid flow, thermodynamics, and material balances. With hand calculations, it is often easier to recognize a result that violates common sense, such as an unrealistically high injection rate for a given permeability-pay. The hand calculations also provide a check on the simulation results of the Design II course. For example, if a 30% recovery factor is predicted by hand and a 50% recovery is predicted in a simulation, can the simulation output be believed?

With appropriate hand calculations and common-sense checks, the students can use the commercial software listed in Table 4. Training is provided for AccuMap, EXODUS, and PEEP. The students usually have been exposed to FAST, WELLFLO, and HYSYS in other courses. The software training is given outside normal class time.

Since simply learning to use commercial software can be time consuming (especially reservoir simulators), it is critical to have teaching assistants who are well versed in the use of the software. Our teaching assistants are graduate students currently enrolled in petroleum engineering. One challenge facing the program is securing a stream of graduate students with suitable backgrounds to act as design-course teaching assistants. We are attempting to attract part-time Masters of Engineering students who work in local industry.

Use of Lectures • The students entering the petroleum design course have quite varied backgrounds. Some are in the oil and gas program, while others are taking the petroleum minor. Some have internship or other industry experience, while others have none. As a result, there are different gaps in the knowledge and experience of each student. In Design I, we use the lectures to fill these gaps, with a strong emphasis on applied engineering. For instance, we spend several lectures on waterflood design leading to the programming of a waterflood forecast on a spreadsheet. The program is based on the Buckley-Leverett-Welge method.[12] Voidage replacement, injectivity calculations, sweep efficiency estimation, and waterflood pattern selection are also covered. There are also several lectures devoted to process design. Since the necessary material is already covered in the process design course, these lectures are held in common. A list of lecture subjects is given in Table 5.

In Design II, the lectures are even more applied, such as artificial lift design. Most lectures in the second term are given by industry or service

TABLE 4
Commercial Software Used in Petroleum Design II course

AccuMap[11]	well information data base
EXODUS[9]	reservoir simulation
IMEX, STARS, and GEM[15]	reservoir simulation
HYSYS[8]	process simulation
FAST[16]	well test analysis
WELLFLO[17]	wellbore hydrodynamics
PIPER[16] and PIPEFLO[17]	pipeline hydrodynamics
PEEP[18]	petroleum economics

TABLE 5
Lecture Topics

Design I	*Design II*
Project Management	Digitizing
Geology/Geophysics	Coning
Core Analysis	Drilling
Log Interpretation	Completions
Mapping and Volumetrics	Artificial Lift
PVT and Material Balance	PFDs and P&IDs
Primary Production Forecasting	Separators
Waterflood Design	Compressors
Reservoir Simulation	Pumps
Block Diagrams and PFDs	Risk and Economics
Gas Treating	
Process Design Calculations	
Petroleum Economics	

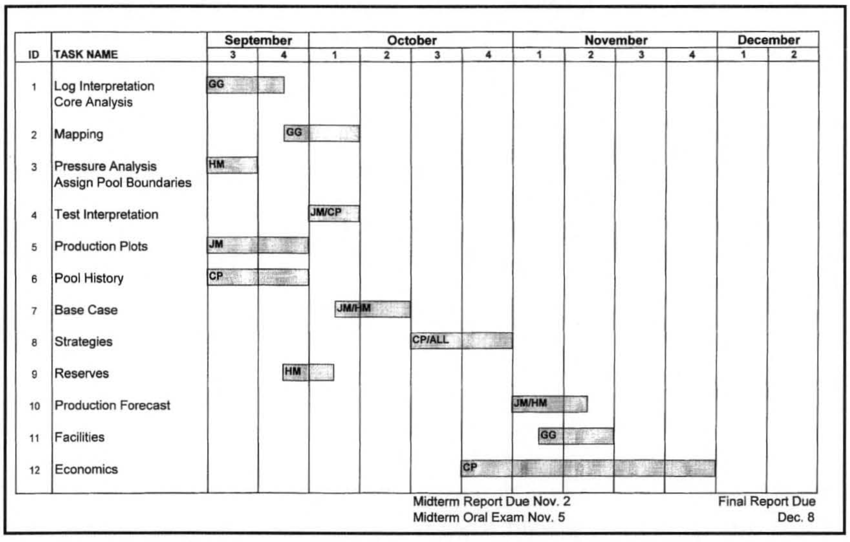

***Figure 1.** GANTT chart for a Petroleum Design I project.*

company representatives. Hence, the students can learn from experts in a given field and develop contacts for work on the project or in the future.

Project Management • Another issue in a design course is how much time to devote to project management. Is it appropriate for the students to prepare detailed schedules, critical path analysis, etc., for their project? In our opinion, the students have too little experience to prepare a meaningful schedule at the beginning of the project. Instead, we ask them to prepare a simple GANTT chart outlining the major tasks and assigning duties and target dates to each group member. An example chart is given in Figure 1. We have found that this simple chart is sufficient to identify potential bottlenecks and ensure a fair allocation of tasks. It also demonstrates that unless certain tasks, such as log interpretation, are completed early in the project, it will be nearly impossible to complete the project on time.

SUMMARY AND FEEDBACK

The major advantages and disadvantages of the approach to design taken at the University of Calgary are summarized in Table 6. In general, the feedback from the students has been very positive. Examples of anonymous student comments are

- *An excellent course that provides an overview of industry tasks required for oilfield development.... Course generally covered at a high pace.*
- *Challenging but very interesting and makes students look for other resources of information*
- *Course provides opportunity to learn a lot about general engineering practices (petroleum). Incorporates all aspects of reservoir engineering to production engineering.*
- *Good course to get experience of what working as a reservoir engineer is like.*
- *Very useful for "hands on" experience that will be used in industry. Maybe a little too much work.*

TABLE 6
Advantages and Disadvantages of the Petroleum Design Courses

Pros	***Cons***
Use of industry data	
• realistic design problems	• time consuming to prepare data sets
• students faced with real data	• dependent on industry cooperation
Team teaching	
• topics taught by industry experts	• difficult to maintain continuity in lectures
• students interact with practicing engineers	• lectures not always delivered at optimum time
Use of faculty supervisor	
• allows close supervision of each group	• increases teaching load of faculty
• grading by consensus	
Use of analytical methods	
• encourages understanding of underlying physics	•limited application to complex situations typically faced by design engineers
• encourages "common-sense" checks	
Use of software	
• broad application	•encourages button-pushing solutions
• training for work in industry	• learning software is time intensive
	• an experienced TA is essential

These comments are representative of the students' responses to the request to "please provide general comments about the course." Negative responses have not been withheld. In all, 13 students out of 20 responded to the request, and half of the responses referred only to other issues, such as teaching. The course was rated as 6.1 out of 7, compared with a faculty average of 5.5 out of 7. The comments and ratings indicate that students believe they have gained broad and relevant experience.

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