

A Design Experiment for the Fluid Mechanics Laboratory

James M. Munro
Department of Chemistry and Chemical Engineering
South Dakota School of Mines and Technology

Summary

The Design-Build-Test (DBT) concept was used in creating a novel experiment for a junior-level fluid mechanics laboratory. In the experiment, student teams are presented with a unique design objective involving transport of a liquid with known or measurable properties and must design, build, and test a pump and piping system to achieve the objective. The experiment is part of a larger project to integrate design concepts throughout the chemical engineering curriculum at South Dakota School of Mines and Technology (SDSM&T).

Introduction

Traditional undergraduate laboratories in chemical engineering provide students an exposure to concepts of engineering science learned in the classroom, but do not provide open-ended, design experiences similar to what graduates might face as chemical engineers in industrial positions. The traditional experiments in a unit operations laboratory tend to be created around fixed pieces of equipment. The procedures, data collection and analysis, and presentation of results tend to be nearly identical for every team of students assigned to conduct a particular experiment, resulting in students taking a "cookbook" approach to laboratory experiments.

In the 2001 survey of recent graduates in chemical engineering at SDSM&T, graduates responded to the question "What could have been better in the chemical engineering program?" with comments such as "More freedom on lab experiments instead of following like a recipe;" "Implement and practice more 'hands-on' troubleshooting labs;" and "Exposure to more modern equipment control systems".

While the traditional chemical engineering laboratory experiments provide valuable exposure to process equipment and unit operations, they do not provide students with open-ended design experiences that include economic factors. The Accreditation Board for Engineering and Technology (ABET) accreditation criteria require that graduates of engineering programs possess "an ability to design a system, component or process to meet desired needs."¹

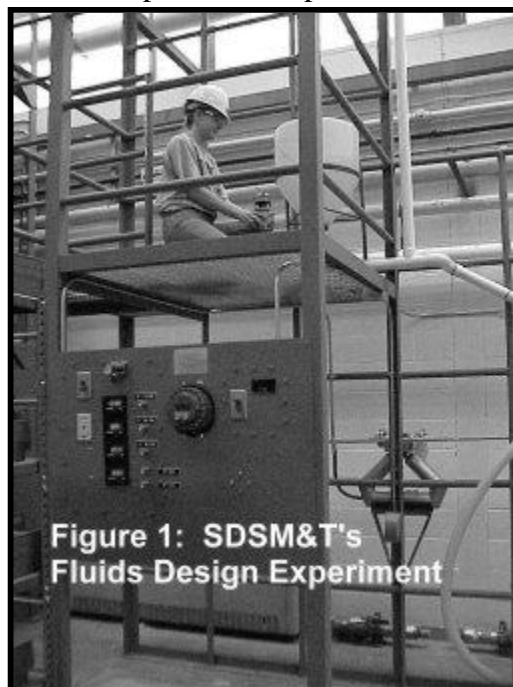


Figure 1: SDSM&T's
Fluids Design Experiment

The faculty of the chemical engineering program at South Dakota School of Mines and Technology (SDSM&T) has begun to change this situation with the development of open-ended DBT experiments within the laboratory curriculum. The first of the DBT experiments to be developed was a pump and piping design experiment described here.

Background

The baccalaureate program in chemical engineering at SDSM&T has as part of its mission to prepare students "to become practicing chemical engineers, ready to enter the workforce and make immediate contributions."

Until recently, baccalaureate programs in engineering have traditionally used laboratory experiences to reinforce engineering science theory presented in lecture classes. Design concepts were presented in a senior capstone design course. In the last fifteen years there has been a move toward integrating design experiences throughout the curriculum in response to ABET accreditation requirements for engineering programs. A number of engineering programs have developed courses or methods to introduce design at early stages of the engineering curriculum, or even at the secondary or elementary school level.^{2,3} In their text *Teaching Engineering*, Wankat and Oreovicz note that "hardware projects, which mix design and laboratory skills, can be extremely motivating because students can see what they have designed."⁴ The freshman level projects often involve inexpensive materials or kits from which students construct some article (for example: bridges, egg carriers, rubber-band powered vehicles) to meet a performance standard.

Design concepts are being integrated into sophomore and upper level engineering laboratories, albeit at an apparently slower pace than at the freshman level. Marchese et al. have described a sophomore-level course of open-ended laboratory projects that incorporate a multidisciplinary approach to solving design problems.⁵ Al-Dahhan has described a series of lectures and a manual on selection of process components as a way of introducing design into the chemical engineering unit operations laboratory.⁶

Recently, a Design-Build-Test (DBT) approach has been used in undergraduate engineering laboratories.^{7,8} In most DBT projects, students are required to design an article, typically small and inexpensive, using design guidelines that include mathematical calculations. Allen et al., developed a curriculum in electronic materials that "abandon the cookbook" approach in favor of a multi-course sequence of open-ended laboratory experiences.⁹ Sherwin and Mavromihales have described a senior year DBT project in which students design, fabricate and test a cross flow multi-tube heat exchanger.¹⁰

Features of the experiment.

The Pump and Piping Design Experiment was created to provide the following features.

1. **Flexibility:** Every student team is assigned a different set of criteria and/or experimental conditions for their experiment. Students do not simply repeat the same experiment that was

done in a previous year or by a previous team. In the pump and piping design experiment, this variability can be introduced by specifying any of the following:

- the flow rate,
- the location and height of the discharge flow(s),
- by the number of operating hours per year,
- the annual depreciation rate,
- the cost of electrical power,
- the inclusion of certain valves, flow meters, spray nozzles, or other fittings in the design
- the inclusion of a permanently mounted piping loop in the laboratory.
- Cost factors for different pipe sizes, or detailed costs of each piping component.

For practical reasons, water is always the liquid to be transported, but it may be possible to adjust the viscosity of the liquid by the addition of small amounts of polymeric solutes. The student teams have the flexibility of choosing from a variety of pumps and pipe sizes which are stocked in the laboratory.

2. **Design:** Student teams are required to produce a design of their system, including the selection of specific items of equipment, using the Pipe-Flo Professional software by Engineered Systems, Inc. . Students compute the cost of the process they have designed, including both capital costs and operating costs. The teams are expected to present several alternate combinations of pump and pipe sizes to show that their design is the optimal one for achieving the stated objectives. Students are also expected to prepare a construction and start-up plan that includes safety practices, construction procedures, and start-up methods.
3. **Build:** Once a design is approved by the laboratory instructor, each team installs the pump of their choice, assembles the piping and connects the system as specified in their design. Students were observed and instructed in safe practices during the construction phase of their design.
4. **Test:** Once built, the student team tests their design by operating the equipment and measuring flow rates and power consumption to determine the validity of their design. Students must demonstrate safe operating practices during the testing phase of their project. If their process is either over-designed or under-designed, they may be given the opportunity to re-work their design to achieve their design goals

Equipment and Instruments

The major piece of equipment associated with the experiment is a three level structure that was erected in the laboratory for students to mount and access the piping system, and where the switches and electrical instruments were permanently mounted. The structure can be seen in Figure 1. Several pieces of equipment or instruments are permanently mounted on the structure, including the following.

- Mass (Coriolis) flow meter by Micro-Motion, Inc. and it's digital display panel. (0-20 gpm)
- Electrical Power (watt) meter. (2kW)

- Pressure transducers and digital displays with quick connect fittings. (0-15 psig, 0-60 psig, 0-100 psig, and 0-150 psig.)
- An I/P transducer for creating a pneumatic (3-15psig) signal to a control valve.
- Electrical switches for the master power switch and for the pump on/off switch.
- A small shell and tube heat exchanger to which the flow stream could be connected on either the shell or tube side.
- A 65 gal. Polyethylene feed tank.
- Two polyethylene receiver tanks, one on each of the elevated levels of the structure, along with PVC piping to drain those tanks back down to the pump feed tank.

Other components of the experiment are not permanently mounted and include the follow.

- Four centrifugal (single and multi-stage) pumps with nominal power ratings of 1/15, 1/2, 3/4 and 1 hp.
- An assortment of dial-type pressure gauges
- A selection of threaded galvanized pipe lengths in nominal pipe diameters of 1/4-inch, 3/8-inch, 1/2-inch, and 3/4-inch.
- A supply of threaded galvanized pipe fittings including elbows, couplings, unions, bushings and reducers.
- A supply of manual gate and globe valves and two pneumatic control valves

The pumps, pipes and pipe fittings are stored near the permanent structure where they are easily accessible by the student teams. Mounting bolts were placed in the floor so that students would have a location to securely mount the pump that they select for the experiment. In order to avoid problems with trying to exactly match the pump fittings to pipe, flexible plastic tubes with cam-lock fittings were used to connect the pump to the supply tank and piping.

The electrical instruments are equipped with 4-20 mA electrical output signals so that the signals can be wired to a Camile® computer system for data acquisition and control. The Camile® computer system was obtained as part of a larger project to implement modern data acquisition and control systems into the chemical engineering curriculum and to upgrade several undergraduate experiments to be open-ended DBT-type experiences for students. Additional DBT experiments in heat exchanger selection and gas absorber design are planned as future additions to the undergraduate laboratory.

Implementation

The selection and piping system design experiment (Figure 1) was constructed in the summer of 2000. In the fall of 2000, two student teams were assigned projects on the experiment. In the fall of 2001, the experiment was integrated into the junior level fluid mechanics laboratory course. This course follows by one semester the classroom lecture course in fluid mechanics for chemical engineering majors.

Each student group was given a handout that described the nature of the experiment, the safety considerations, their unique design objectives and cost data. Typical objectives (in abbreviated form) given to the student laboratory teams were as follows:

- Create pump curves for several of the centrifugal pumps; then design a system to deliver 18 gpm to the receiver tank on the first elevated level.
- Evaluate the friction loss through a pneumatic valve by determining its resistance coefficient (K-factor), and then design the lowest cost pipeline to deliver 12 gpm through that valve and into the receiver tank on the upper level. The pipeline must include two gate valves, a globe valve, and must pass through the tube-side of the heat exchanger.
- Design the lowest cost system to pump 10gpm such that 4 gpm is delivered to the highest receiver tank and 6 gpm is simultaneously delivered to the lower receiver tank.

In each case, students were asked to perform the design calculations first, to visit with the laboratory instructor about their design prior to beginning any actual assembly of components, and finally to demonstrate to the instructor or laboratory assistant that their constructed design met the objectives. Each team had three laboratory periods to complete the experiment. Typically, the first period was spent designing the system, the second in building and testing their design and the third period was available for completing their laboratory report.

Project Evaluation

A survey was prepared to assess the effectiveness of the new experiment. The survey posed seven questions to students and provided space for written comments. Table 1 summarizes the results of the responses where 4=strongly agree and 0 = strongly disagree.

Survey statement	Mean score
1. The experiment was effective as a learning tool.	3.4
2. The experiment was just another cook-book lab.	0.6
3. The handouts were effective in conducting the laboratory exp.	2.1
4. The experiment helped reinforce the principles learned in the fluids lecture class.	3.4
5. I understand the basic principles of pipe and pump selection.	2.8
6. This experiment helped me to feel more competent to size pipes and select pumps for actual liquid transport systems.	2.7
7. Having the group physically assemble the piping components was a worthwhile experience.	3.6

The relatively high scores on question no.'s 1, 4, 5, 6, and 7 reflect a high degree of agreement with those statements that imply a positive learning experience for the students. The near-zero score on question no. 2 indicates that the experiment was clearly not perceived as a "cook-book" experience.

When asked to provide comments on the most positive aspects of the design experiment, students responded with comments such as the following:

- "I think it helps to allow students to really get a hands-on feel for design instead of following someone else's steps and learning very little."
- "The hands-on experience."

- "I really like the hands-on aspects of this lab."
- "Being able to put the system together; it's not just another existing system that you turn on and take readings."
- "Exposure to real-life situations you may run into in industry. "
- "Having to make decisions on pump and pipe size instead of being told what to do. Physically assembling a piping system."

When asked to provide comments on what could be improved with the experiment, the student responses included the following.

- "Better explanation of how to find pump curves and more parts to work with."
- "Give a practical tour of the apparatus."
- "More explicit instructions."
- "Efficiency data for the pump, and more components available for assembly."
- "Having better parts to build the piping system with."

What we've learned

We are generally pleased with how the experiment has been received by students and by the results we have observed in students completing their design, building and finally testing their design. We have observed that some students would prefer to design the pipeline "by hand," instead of with the Pipe-Flo® software. That is, they would prefer to enter formulas on a spreadsheet or simply to set up the equations with paper and pencil to compute the head requirements for the different pipe sizes. It appeared that these students were unsure of their skills in using Pipe-Flo® since it had been six months since they had used it in the fluids lecture course. Once these students did use Pipe-Flo® again, they seemed to appreciate its utility.

Student comments about a lack of piping components have resulted in additional components being purchased for the next semester. The comments about needing better (more explicit) instructions were noted, but are not likely to result in any more formal instructions being given. Students are provided with a binder of manufacturer's data on the pumps, flow meters and other components. They are encouraged to ask questions if needed. However, we are reluctant to provide specific instructions that might negate the open-ended nature of the experiment. We do intend to provide more explicit instructions about what is expected in the design phase of each project. These instructions will, for example, spell out that a design should be modeled using Pipe-Flo® software, and that students should prepare several designs in order to definitively show which one achieves the technical objectives at the minimum total cost.

We had been concerned about how much time it might take students to physically assemble their piping system. This turned out to not be a problem, as the piping was usually accomplished in less than 90 minutes, once the students had made their design and were ready to work. Perhaps the biggest problem in the assembly phase was the use of a pipe thread sealant to prevent leaks. The sealant we purchased was moderately effective at eliminating leaks, but turned out to be extremely sticky and difficult to clean from hands and pipe fittings upon disassembly. We will be evaluating other thread sealants for use in future semesters.

Conclusions

An open-ended design experiment for the fluid mechanics laboratory was developed taught and evaluated in the Chemical Engineering program at South Dakota School of Mines and Technology. Students were able to accomplish the objectives of the experiment within a three week laboratory period by designing, building and testing a pump and piping system to meet a unique objective.

Acknowledgements

The authors gratefully acknowledge the Dow Corning Foundation for their sponsorship of the Materials, Automation, Processing and Simulation (MAPS) laboratory project within the Chemical Engineering program at South Dakota School of Mines and Technology. In addition, we gratefully acknowledge Micro-Motion, Inc. for their gift of a Coriolis Mass Flow meter for use on the experiment.

References

1. ABET Engineering Accreditation Criteria, Criterion 3: Program Outcomes and Assessment. <http://www.abet.org>.
- 2 Dixon, David J., L. G. Bauer, J. M. Munro and J. A. Puszynski "Use of Simulation Software Packages as a Teaching Tool in the 4-year Chemical Engineering Integrated Design Project," Proceedings of the 1999 Annual Meeting of the American Institute of Chemical Engineers, Dallas Texas, November, 1999.
- 3 Crawford, R. H. , et al. "An Engineering Design Curriculum for the Elementary Grade" Journal of Engineering Education, April 1994, PP 172-181.
- 4 Wankat, P.C, and F. S. Oreovicz, Teaching Engineering, McGraw-Hill, Inc., (1993).
- 5 Marchese, A. J., et al. "The Sophomore Engineering Clinic: An Introduction to the Design Process through a Series of Open Ended Projects" Proceedings of the ASEE 2001 Annual Conference, Albuquerque, NM, June 2001.
- 6 Al-Dahhan, "Integration of Design and Selected Process Engineering Components into the Unit Operations Laboratory." Proceedings of the ASEE 2001 Annual Conference, Albuquerque, NM. June, 2001.
- 7 Elger, D. F., S. W. Beyerlein and R. S. Budwig, "Using Design, Build, and Test Projects to Teach Engineering," Presented at the 30th ASEE/IEEE Frontiers in Education Conference, Kansas City, MO, Oct., 2000.
- 8 Elger, D. F., R. S. Budwig, and W. W. Beyerlein, NSF grant: DUE-9952308. "Using Design, Build, and Test Projects in a Wind Tunnel to Improve Engineering Education." Award Abstract from NSF web pages. Project dates: April 1, 2000 to February 28, 2002.
- 9 Allen, E. A., E. D. Green and A. Muscat "Development of an Interdisciplinary Curriculum in Electronic Materials and Devices: Cooking without Recipes" Award Abstract from NSF web pages. Project dates: September 1, 1995 to August 31, 1998.
- 10 Shervin, K and M. Mavromihales "Design Fabrication and Testing a heat Exchanger as a Student Project." Proceedings of the ASEE 2001 Annual Conference, Albuquerque, NM. June, 2001.

JAMES M. MUNRO

Dr. James M. Munro is a Professor of Chemical Engineering at SDSM&T. He is a registered professional engineer in South Dakota. He holds a BS in Chemistry and an MS in Chemical Engineering from South Dakota School of Mines and Technology and a Ph.D. from the University of Utah. He worked for the Dow Corning Corporation for three years and for Hoechst Celanese for 1 year. He teaches fluid mechanics and transport phenomena courses at the undergraduate and graduate levels, an undergraduate process control course, and is engaged in creating meaningful laboratory experiences for undergraduate students in engineering.