PRESSURE FOR FUN:
A Course Module for Increasing ChE Students' Excitement and Interest in Mechanical Parts

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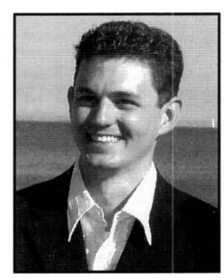
Chemical engineering as a profession grew in the late 19th century out of collaboration between chemists and mechanical engineers working to develop large-scale industrial processes. To this day chemical engineers working in the process industries are closely involved not only with particular chemical processes—and unit operations such as reactors and separators that can accomplish these processes—but also with mechanical devices such as pumps and valves that enable the transport of materials. We have found, however, that skill or even familiarity with mechanical components is often undeveloped in first-year chemical engineering students, even though they are often the best and brightest science and mathematics students at the high school level. The first- and second-year curriculum is often theory intensive, and the practical exposure that does take place is more in the traditional science subjects, complemented by some experimental work using basic pilot-scale unit operations. By the time they reach their senior year, we find many students, although academically relatively successful, still struggle to connect reality to theory. In addition, a large segment of the class is relatively intimidated by the prospect of working in a plant environment.

In the Department of Chemical Engineering at the University of Cape Town (UCT) we have been considering for some time how best to modify our curriculum to afford first-year students better exposure to mechanical aspects of chemical engineering. It was fortuitous that the opportunity arose to design—specifically for chemical engineering students—a five-week module that would form part of the mandatory first-year mechanical drawing course. Previously this part of the course dealt with the interpretation of chemical engineering flow diagrams, but recently it was decided to move this material to the second year to integrate it more closely with core chemical engineering courses.

In discussion among a group of academic staff, we decided that our objectives for this module would not be primarily focused on detailed content knowledge, but rather on changing students' attitudes toward this aspect of chemical engineering. These were the objectives for the new module:

- *Get students excited about mechanical things.*
- *Develop students' ability and confidence to explain how things work (and the desire to learn more).*



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- *Help students start building a sense of "mechanical intuition."*
- *Provide familiarity with equipment diagrams and hardware.*
- *Develop students' ability to link the "real world" and theory.*

This is a rather different set of objectives compared to what chemical engineering lecturers usually design courses around. How do you explicitly design a course module for excitement? This paper describes how we went about meeting this curriculum development challenge. The new course module ran for the first time in 2004, and is now an established feature of the first-year B.Sc. (chemical engineering) program at UCT. In this paper we focus on the process of setting up and evaluating the course during its first year.

APPROACH TO COURSE DESIGN

We found a useful rationale for running this type of course in the classic work by Woolnough[1] regarding practical work in school science. He argued against the widely held belief that practical work should be done for the sake of theory, and that conceptual understanding will be an automatic outcome of successful practical work. Instead, he suggested that practical work is better understood as having its own end, either to develop skills, to develop the ability to conduct investigations, or to simply get a feel for important physical phenomena. The module we developed fits clearly in the latter category, with the chief aim being to allow students physical interaction with the mechanical aspects of chemical engineering.

In recent times a number of innovative courses have been reported on that offer such hands-on experiences to first-year chemical engineering students. For example, Barritt, *et al.*,[2] describes a highly successful multidisciplinary project that involved small groups of students in the design, manufacture, and operation of a pilot-scale water treatment plant. Moor, *et al.*,[3] also ran a multidisciplinary project for first-year engineering students, this time involving the design of a reverse osmosis system, with the collection and interpretation of experimental data from an existing rig. Willey, *et al.*,[4] designed a first-year project that involves experimentation with a sequential batch-processing system. Most of the courses reported in past literature, such as those described here, incorporate relatively sophisticated design projects that run over a long duration. Our aims were more limited as we had a large class and a short period of time. We therefore decided to focus on our primary objectives, which were centered on changing students' attitudes toward working with mechanical artifacts.

To meet these objectives, we adopted a particular teaching approach that included small class size, group work, and excellently trained facilitation. Additionally, the activities were planned to give students a sense of accomplishment and encourage experiential learning and unsolicited experimentation. In traditional terms, this resulted in a combination of practice and some tutorial in one class period, without the use of a lecture period. Assessment was based on a combination of individual and group assignments, and contributed 10% toward the final mark for the mechanical engineering course in which this module was located.

By concentrating on the primary objectives of the course, content topics that suited these objectives could be chosen and a rapid movement between topics undertaken if necessary. We chose to use valves, pumps, pressure, and flow regimes in our activities. The intended objectives, however, remained focused on excitement and learning how to explain, rather than on content.

Class and Group Size

The class of nearly 100 students was split into five groups of approximately 20 students, and each group was allocated a weekly 85-minute session over the duration of the five-week course module. Each session was attended by two or three tutors and the course organizer. Each class made use of student teams ranging in size from two to four members. In most cases students continued with the same team for two successive classes. An introductory chemical engineering course running concurrently had given the students sufficient group-work practice, so this aspect posed no difficulty by the time they began this module in the second semester of their first year.

Facilitation by Tutors

One vital component of the course was facilitation by tutors. Students were asked to operate unlike they had in any previous school or university situation. Such unfamiliar expectations occasionally caused students to balk at requests. Additionally, with little experience in a potentially intimidating situation, students often had no idea where to begin or how to proceed after achieving a portion of the activity. Our solution was to handpick tutors and train them in facilitation (also known as coaching). The primary role of the tutors was to closely observe student teams and offer guidance when necessary.

The tutors were mainly graduate students who were selected based on previous experience with tutoring and an observed ability to patiently facilitate the group process. Tutors were given a short manual on facilitation and practiced a short role-play illustrating typical situations. Detailed tutor notes were provided for each class including a time schedule, jobs for specific tutors, likely problems student teams would encounter, and topic-specific reference material for tutors to use as prompts while facilitating. One example is the specific list of difficulties when taking apart and re-assembling a hand pump. Before each week's class, the tutors met to go over the activity, practice it themselves, and discuss the reference materials for the topic and facilitation tactics for the activity.

The environment within the classroom was also an important consideration. From the initial description of the module to the manner of facilitation, students were told they had freedom to experiment, try things out, or "fiddle." The class organizer and tutors made a careful effort throughout the module to create an environment "safe" for experimentation, in particular for the students most nervous about physical parts and equipment.

THE ACTIVITIES

Each week students were presented with a different activity, with the final "challenge" taking place over two weeks. The assessment was integrated throughout the module.

Industry Parts

The introductory class consisted simply of pairs of students taking apart large-scale components from industry and attempting to intuitively figure out the item's main purpose and interpret the mechanical design. Students were allowed the time to construct their own ideas. An important element was giving each student practical experience with physical parts. Most of the parts were nothing more complicated than valves, yet the novelty of valves weighing 20 kg was clearly demonstrated with an initial comment, "This is a pump, right?" After the activity, a handout with information on each type of valve was given. During class we tried not to criticize or correct students' ideas, but instead encourage each pair to complete the line of thinking themselves. For assessment purposes, each student was required to submit rough notes and a written explanation of how the mechanical part worked.

Hand Pump

At the start of the second class each pair of students was given a cheap, transparent pump and bottle: the kind often used for liquid hand soap. Starting with observation, continuing with disassembly and reassembly of the pump, and ending with directed experiments, pairs needed to discern the working principles of the pump. Each pair was instructed to create a one-page diagram explanation of the physics principles underlying the pump's operation, and how those principles are utilized by the mechanical parts. This report counted as 30% of the assessment mark for the module. An example of a particularly good student response is reproduced in Figure 1.

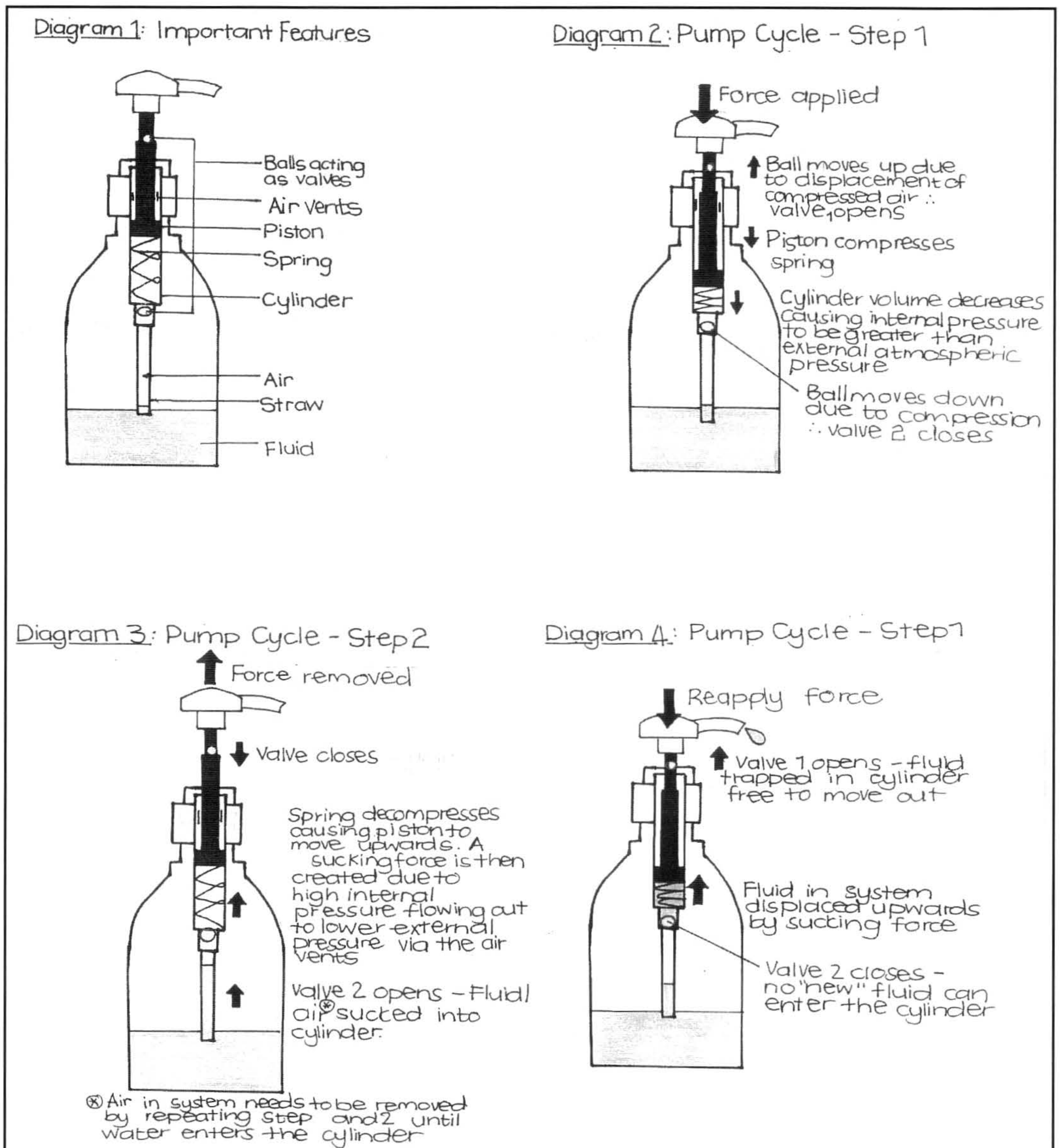

Figure 1. *Explanation of hand pump by student pair. The illustrated mechanism is an example of a reciprocrating pump, a type that is also used to extract H_2O and oil from under the ground.*

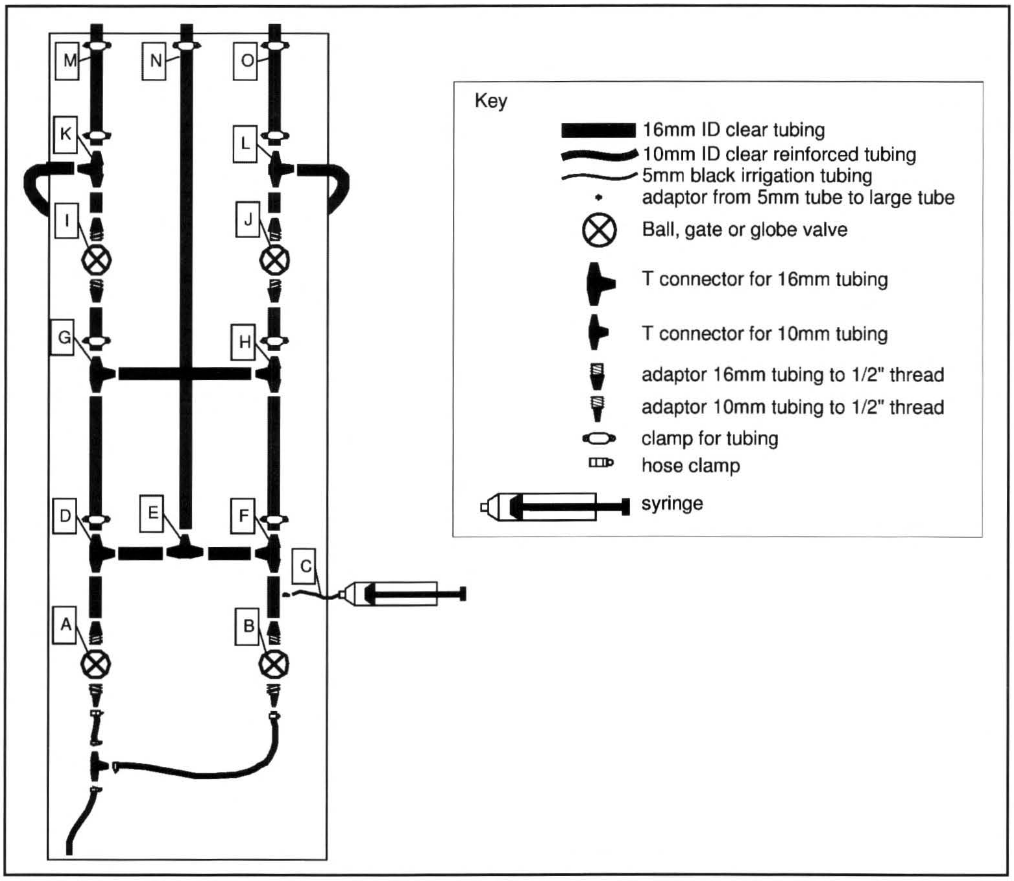

Figure 2. *"The Challenge" rig setup.*

Figure 3. *Students participating in "The Challenge."*

Within this class and the whole module, students were faced with the need to come up with their own answers. When students asked questions about the pump, tutors—rather than provide the answer immediately—encouraged students to "try it and see what happens." Similar to other activities in this module, free experimentation was required to discover the workings of the mechanism.

Creating a detailed explanation of a relatively simple pump allowed students to build confidence by being able to complete a task to a reasonable degree of satisfaction. Only in written feedback afterward were student misconceptions noted.

Mechanical Drawings

In a reverse from previous exercises, the next class began with sets of mechanical drawings for six types of pumps. Each group of three or four students had a limited amount of time to work backwards from the drawings for two types of pumps to discover how the pumps operate. The previous hands-on experience with a reciprocating piston pump (the hand pump) provided a base for interpretation of the pump drawings. Partway through the class, students were rearranged into new groups, such that no one in the new group had encountered the same pumps. Then, in a very restricted time, each student was required to explain the pumps they knew to others.

THE CHALLENGE

The final project was a bit of a competition and a fun way to complete the experience. We named it "The Challenge." For both the fourth and final classes, a custom-designed but inexpensive rig was provided for each team of three to four students. A diagram of the rig is shown in Figure 2. For the first day, students were required to complete a preparation worksheet and then experiment with the rig to demonstrate concepts relating to pressure, head, laminar and turbulent flow, and Reynold's number.

For "The Challenge," students worked to control the motion of a bead in a system of pipes using pressure changes (Figure 3). Students had to experiment with the equipment to learn the effect of closing and opening particular valves. The activities were carefully designed to be initially difficult, but easily accomplished through effort, teamwork, and practice.

Many unplanned learning points arose as a result of the physical activities. For example, as dye flowed through the system of pipes, with water and dye flowing from the lower left to the upper left of a "D" shape, a trickle of dye left the main flow to slowly swirl in the loop on the right of the "D." A student remarked that they had no idea any water would leave the main flow.

The final competition was run as a sporting event with team names, an elimination tree structure, stopwatches to record times, and a prize for the winning team. A video camera captured the event and projected it onto the big screen behind the two competing teams. The other students cheered as their classmates competed (shown in Figure 4). For assessment purposes each team was required to submit a brief report on "The Challenge," and this counted as 30% of the module grade.

EVALUATION OF THE MODULE

From simple observation of students during the module, it appeared that they had gained both confidence and interest in finding out how mechanical things work. In particular, we noticed students' enthusiasm with the activities and high levels of verbal interaction within student teams as they sought to explain what they had deduced. We needed, however, to find a way to more systematically gauge the success of the activity in meeting its objectives, and therefore administered a short Likert-type survey to all students before and after the module. Five statements were provided, and students were asked to indicate their response on a scale of (5) strongly agree, (4) agree, (3) uncertain, (2) disagree, or (1) strongly disagree. Ninety-two completed questionnaires were returned. Table 1 (next page) shows the change in the mode (most frequently reported response) for each statement. A more complete indication of the range of responses is given in Figure 5.

The largest change observed was question 1, "explain"; most students (51%) began not knowing if they could explain how a mechanical object works to someone else or not. The responses "agree" and "strongly agree" moved from 38% before the module to 97% after the module. Question 2, "intuition," began with the greatest "disagree" of all questions at 15%. After the module this was reduced to 3%, although this question retained the largest number of "uncertain" responses, with 27%—indicating students who did not have the confidence to claim mechanical intuition in the other questions. The combined responses "agree" and "strongly agree" to "intuition" moved from 42% to 73%. Student interest in how things work, Question 3, started high and had nowhere to go; this group of students began and remained a curious

Figure 4. The winning group celebrates.

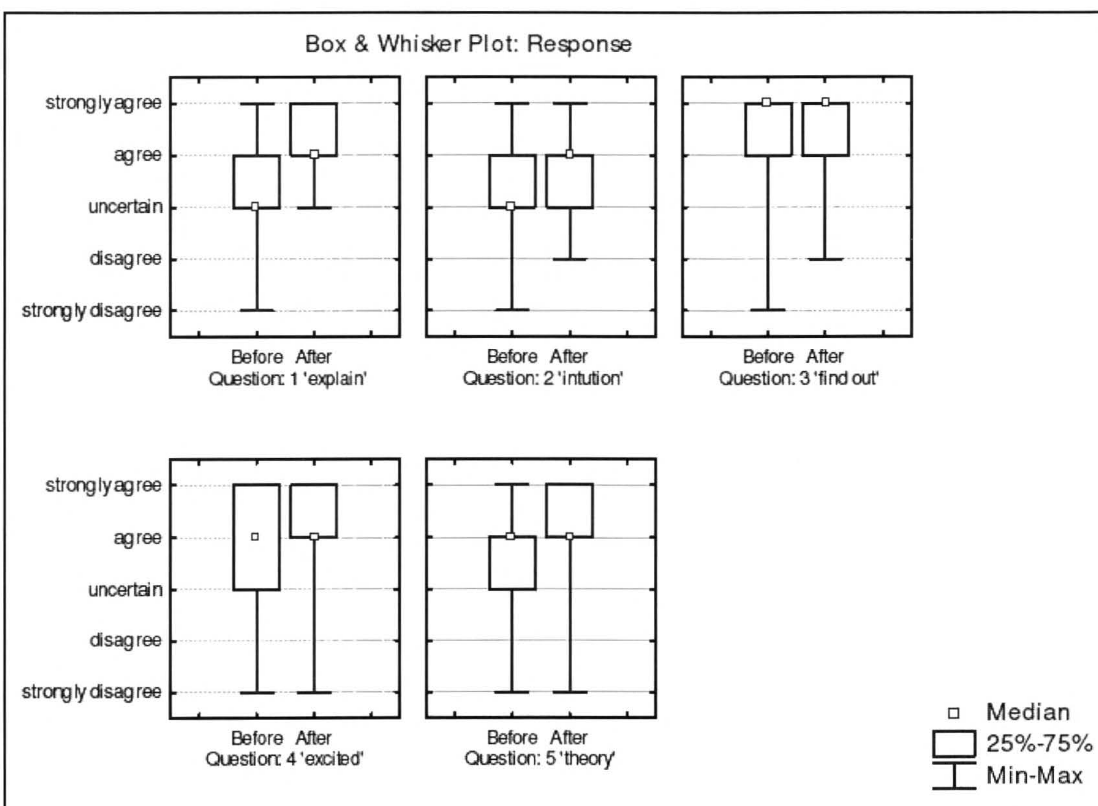

Figure 5. Box and Whisker plot of survey responses, N = 92.

TABLE 1
Modal Responses by Students, Before and After Module, N=92

#	Question	Reference in text	Mode Before	Mode After	Δ
1	I can explain how a mechanical object works to someone else.	"explain"	uncertain	agree	↑
2	I have an intuition that allows me to understand mechanical things.	"intuition"	uncertain	agree	↑
3	I am interested in finding out how things work.	"find out"	strongly agree	strongly agree	↔
4	I am excited to do a practical or job that involves mechanical things.	"excited"	agree	strongly agree	↑
5	I can connect chemical engineering theory to an image in my mind of what actually happens.	"theory"	agree	agree	↔

bunch. Question 4, "excited," saw only a small decrease (3%) in those "uncertain" about working with mechanical things. Nevertheless, the combined responses "agree" and "strongly agree" moved from 67% to 78%. For the final question, "theory," the combined responses "agree" and "strongly agree" moved from 64% to 86%.

CONCLUSION

In this paper we have reported on the development and evaluation of a new module in our chemical engineering undergraduate program, which has the primary objective of getting students excited and confident about working with mechanical artifacts. It has been shown that the module successfully increased students' confidence and perceptions in their ability to work with and explain mechanical things. It was also great fun for the students, tutors, and the course organizer. The module is now fully established in the program, and makes an important contribution to the development of degree outcomes.

It was a fairly radical move to design a course module around attitudinal objectives (excitement, etc.) rather than the more conventional content-based design. Even with the current focus on outcomes-based design, this is still often a neglected aspect of curriculum development in chemical engineering. We hope that the descriptions of the activities given in this article will encourage others to try them out with their first-year students.

ACKNOWLEDGMENTS

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