DESIGN COMPETITION FOR SECOND-YEAR STUDENTS*

A Retrospective

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After spending their high-school years solving theoretical problems for which there are always some sort of defined "right answers," students tend to arrive at the university with the belief that there is a right answer to *everything*. In the practical world, however, there is an inestimable number of ways of going wrong while the number of ways of going right are preciously few. This is one reason why our department includes formal practical training throughout all stages of the curriculum. A less formal exercise, but also serving the same purpose, is our annual "Second-Year Design Competition."

The Competition provides students with a genuine challenge in process engineering, allowing them to show off their ingenuity in the face of a strict set of constraints. It also offers an entertaining spectacle for the onlookers, good cash prizes for the winners, public humiliation for failure, and triumph for the victors. It has become a keenly anticipated highlight of the academic year.

In this paper we will look at some of the more successful Competitions from the past dozen years, the organization needed to mount them, and how they have benefitted both the department and the faculty of engineering as a whole.

Organization • Normally, the class of about eighty students is asked to form into groups of two students each. Solo entries are permitted, but the complexity of demonstrating

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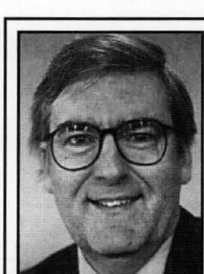
the design usually requires two people. About a month before the Competition date and just before a mid-semester break, each student is given a handout describing the Competition rules and constraints. They then have a break of one or two weeks in which to design their entry. In most cases there is some equipment used to test the entries and the essential features of this are put on display in a special cabinet in public view. This cabinet also contains Competition memorabilia such as photographs of the past events and actual parts of winning entries from previous years.

Prizes and Sponsorship • We make a point of inviting an industrial sponsor to the Competition. The sponsors, whose products are in some way relevant to the Challenge, donate prize money in return for a novel form of lunchtime entertainment and the opportunity to put their company name in front of potential clients. Sponsors have always been eager to attend and to make some observations of their own at prize-giving time.

Designing the Competitions • *"Using familiar materials for unsuitable purposes in an impossible time frame in front of a noisy crowd"* is the basis of the design Competitions. Many entries have been taken from the domestic environment and given a twist such as the "Egg Separator," the "Cut-the-Soap," and "Transporting the Beer" Competitions. Conventional process engineering has inspired three tasks in the form of water pumping, pneumatic conveying, and heat exchanger design. Risk engineering gave us the "Bursting Disk" and "Extinguish the Flame." Nearly any familiar con-



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cept can be made into a competition topic by imparting an awkward constraint. We never seem to be short of ideas.

We choose second-year students deliberately. These students are still at the beginning of the course and have not yet studied subjects such as unit operations, thermodynamics, and control. Lacking the formal benefit of these skills, second-year students offer refreshing novelty because they are still essentially free from the constraints of conventional wisdom and are not so sophisticated in outlook that their designs are conservative and predictable. This increases the likelihood of the unexpected.

Judging • To be successful in all respects, as a spectacle and as an assessable effort, the Competition must have a definite criterion for winning or losing, and for best visual impact, this criterion should be immediately obvious to the spectators. Devices or processes that fail or succeed spectacularly are best. Criteria which involve lengthy calculations of some performance index are less so. For this reason, we have endeavored to move away from measuring an optimum such as "performance per unit weight of entry," preferring a design to simply work well despite, or because of, its size.

Prizes • The winning team, the runner-up, and the most deserving team receive prizes made up from the entry fee, which is usually $5 per team, plus $300 to $400 donated by the sponsor. The winners also receive certificates that document their accomplishment in suitable style. Students tend to value these certificates as much as the cash.

Academic Assessment • A potential 5% bonus marks in Chemical Engineering II are offered for participating in the Competition. Students do not have to participate, but we find that offering such a bonus gives them the necessary incentive, which they may not have otherwise. As a result, the majority of the class participates.

MOST MEMORABLE COMPETITIONS

The Explosion Vent Bursting Disk (1992)

The task was to design a vessel and equip it with a bursting disk such that it would vent safely, an explosion occurring inside the vessel. The conditions were:

The vessel would receive by injection through a port, a precise amount of liquid fuel (e.g., 2 ml of acetone). The explosion would then be vented safely by blowing off the integral bursting disk. The loudest report as measured by a pair of sound pressure meters would win.

To reduce risk to the participants, all operations were handled by a departmental technician suitably equipped with full-face mask and gloves. To guard against the vessel already containing fuel (which might augment the sound level achieved), the technician also fired the spark before fuel was introduced into the vessel. A premature explosion would disqualify the entry. To guard the spectators, a circular plexiglass panel open at the top was placed around the entry.

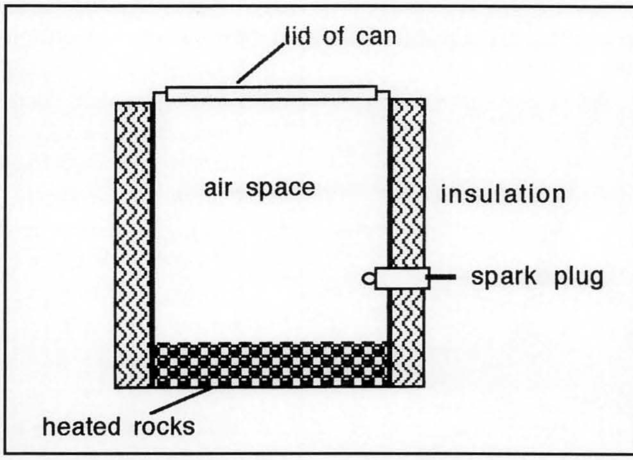


Figure 1. *Schematic diagram of the winning entry in the Bursting Disk Competition of 1992.*

In their design, the students had to consider several things: a means of vaporizing the fuel so as to achieve a good fuel/air mixture; the volume of the vessel required to achieve a good fuel/air ratio; the area of the bursting disk; and its firmness of attachment to the vessel.

The winning entry was a 4-liter paint can containing a handful of rocks that had been previously warmed in an oven (see Figure 1). Foam insulation around the can helped keep the rocks warm until the time of the test. The lid of the can acted as the bursting disk. When tested, this entry gave a maximum sound pressure of over 100 dB at 3 meters, with the lid being blown vertically to a height of about 5 m.

An entry that did not win, however, was more spectacular. It consisted of a paint-solvent can of about 4 liters and not much else. The bursting disk was the cap of the can, which was comparatively small at about 40-mm diameter. When tested, the entry gave out a tremendous bang and simply disappeared. At this point the spectators looked left and right for the missing can, then realizing that there was only one direction it could possibly have gone, they simultaneously looked up to the see the can still heading upwards and getting smaller all the while. The can naturally fell to earth again, heading for a space that spectators hurriedly cleared. The base of the can was found on the test table. As a result, the entry was disqualified because the bursting disk failed to vent the explosion safely. The judges suspected that the can had been filled with oxygen.

The Egg Separator (1988)

A quieter competition required students to design a device that would automatically separate the white from the yolk of an egg. A whole unbroken egg would be inserted into the device, and all operations after that would occur automatically, with the result that the white and the yolk would be delivered into two waiting recepticles, *e.g.*, two petri dishes. The students had to design a device that would break the egg and allow its contents to flow and to separate as they did so. Understanding and exploiting the properties of unusual fluids was the major challenge of this exercise.

Several entires failed because their operation required manual intervention, most often to break the egg. Some failed because the egg would not flow across the separating device, or if it did, the yolk broke.

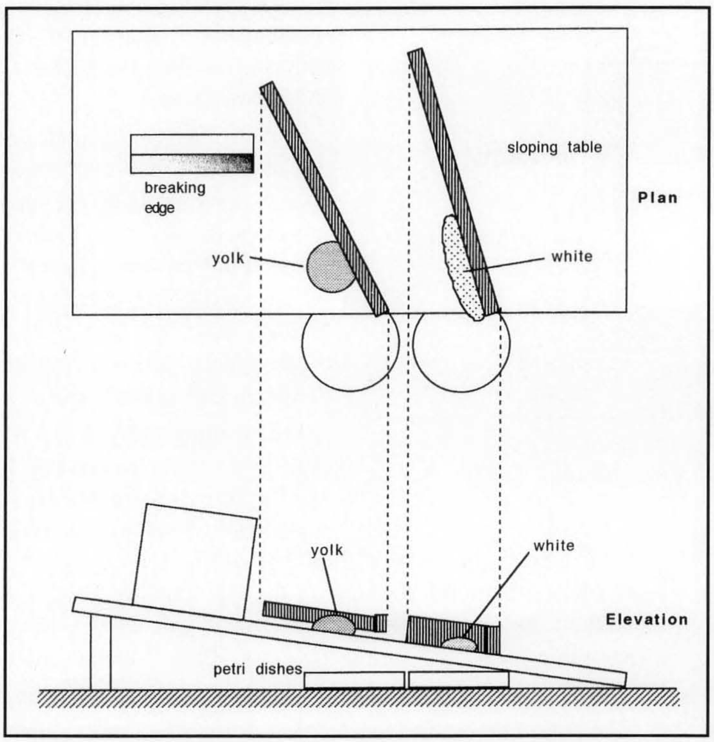


Figure 2. *Schematic diagram of the winning entry in the Separate the Egg Competition of 1988.*

There was a clear winner, however, who surpassed all expectations. It satisfied the design conditions in every detail and exploited the properties of the materials beautifully. In this design (see Figure 2), the egg was dropped via a chute onto a metal breaking edge pointing upward. Contact broke the egg, which then flowed down the sides of the edge onto a sloping table. Two barriers were positioned on the sloping table such that the flow of yolk and egg would continue by gravity. The first barrier was an underflowing weir that held back the yolk while the white flowed underneath, while the second barrier captured the white. Both barriers allowed the yolk and white to continue their flow to the edge of the sloping table where they were collected into separate petri dishes. When tested in front of an enthusiastic audience, the final plop of the yolk into its dish was greeted with thunderous applause.

The Bead Elevator (1991)

Planning, timing, and teamwork were especially required in this competition. The aim was to design a mechanical means of conveying foam beads from a ground-level feed bin to a receiver bin located on a platform 2 m above the ground. The fastest time to convey more than 95% of the beads, or failing this, the greatest quantity of beads moved in a 30-second period would be the winner. Students would need to understand the nature of pneumatic transport as well as to optimize the efficiency and operation of their design.

Many designs based on vacuum cleaners appeared on the day of competition, but none was as well calculated to succeed as the eventual winner. In most entries, an operator applied suction to the receiver bin via a hose inserted into a removable lid. Another hose was let down to the feed bin where the other operators could manipulate it. Ideally, the resultant air movement was supposed to suck up the beads and deposit them into the receiver bin. Several problems emerged with these designs, however. Frequently the hoses, being fairly narrow, clogged up with beads. In some cases the vacuum applied to the receiver bin was too great and

Figure 3. *"They should have won!" Students face defeat graciously in the Bead Transport Competition (1991).*

collapsed it by sucking it in. Hoses would fall out of their intended mountings, or the weight of the hose would pull the receiver bin over and spill the beads. Some entrants found that the beads did not remain in the receiver bin but continued on into the vacuum cleaner. This did no good for the flow of air, especially if the cleaner's dust bag had been removed. The most valiant attempt that did not work was based on an industrial blower. In it, the feed bin was pressurized and a large-bore hose conveyed beads to the receiver. Unfortunately, the pressure applied was too great for the flimsy plastic bin and its lid blew off in a white blizzard (see Figure 3). The entrants, who showed great courage in the face of defeat, received the Encouragement Award.

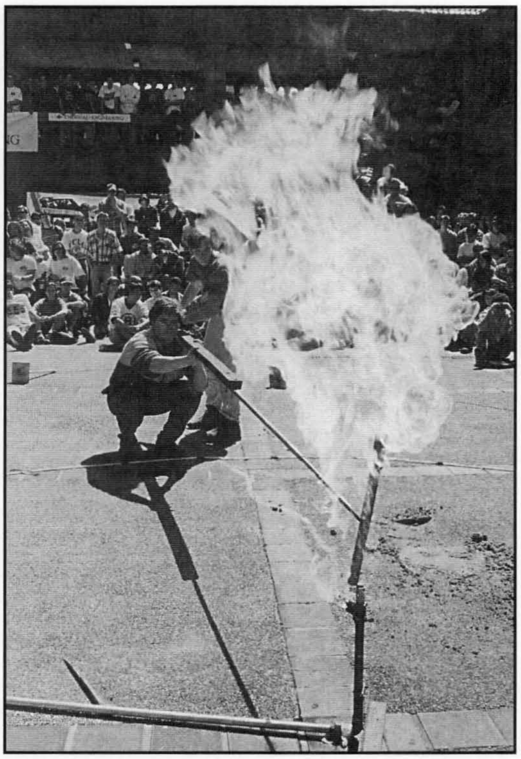


Figure 4. *Encouragement Prize winners of the Extinguish the Gas Flame Competition (1994) brave the heat with the elegant nozzle-extension-on-a-pole.*

The winners had a different approach altogether. Their design was based on a rotary-motor mower in which a lightweight fan was substituted for the normal blade. A cardboard ducting system was attached beneath the mower so that the beads could be neatly sucked up. The outlet of the mower (where the grass is normally ejected into the catcher) was fitted with a duct that led to a lid fitted over the receiver bin (which was firmly held down by an operator). This lid was fitted with a gauze mesh to allow air out of the bin while retaining beads within. After starting the mower, the whole operation was over in eighteen seconds, and the recovery of beads was nearly perfect. This winning entry demonstrated the advantage of establishing clear design parameters and good teamwork, as well as thorough planning and testing.

A joke entry came in the form of a firework that was placed in the feed bin. The resulting explosion blew beads out of the bin and in a total duration of twelve seconds, half a handful was transported to the receiver bin. This entry did not come in last.

Extinguish the Gas Flame (1994)

This was possibly the most entertaining spectacle of all. The aim was to extinguish a luminous flame of LPG emerging from a 25-mm nozzle at full cylinder pressure. This competition was advertised as providing "a serious flame" later estimated at about 40 kwatts of heat. Competitors were allowed within a minimum radius of 3.5 m of the flame and were given thirty seconds. The fastest time to extinguish the flame would be the winner.

Many entrants tried to smother the flame with a variety of devices held by poles over the nozzle. Many devices caught fire, and others did not succeed when the flame found a way around them and ignited elsewhere. Some attempted to pour water down the nozzle, but the gas pressure simply blew it back out. An ingenious entry (winner of the Encouragement Award) used a piece of pipe that fitted neatly over the nozzle and extended it some 400 mm (see Figure 4). Manipulating this pipe attached to the end of a pole, the entrants placed it over the nozzle, causing the flame to jump to the end of the extension. The entrants then quickly jerked the extension upward

Figure 5. *Winners of the same competition show their style with baby stroller and gas bottle. The flame was put out in under five seconds.*

and off the nozzle, lifting the flame away from the gas source. The flame went out accompanied by loud acclamation from the audience. Unfortunately, the unwieldy apparatus was difficult to manipulate at the distance invoved and the entrants took too much time.

The winning team carried out their task with insouciant ease. Their entry consisted of a bottle of carbon dioxide gas resting in a baby stroller that could be pushed by a long pole (see Figure 5). One member opened the valve, allowing the gas to flow, while the other poled the stroller out to the flame. In less than five seconds the flame was out. Although the crowd was greatly impressed, there was some resentment from the other contestants since the competition conditions stipulated that no commercial fire extinguishers were to be used. Indeed, this entry used a commercial principle, but it was not itself a commercial extinguisher—so it won.

Antigravity Water Transfer (1995)

The Competition for 1995 was based on moving water from one vessel to another using a pump. Normally, this is a routine task, but there was a catch. Entrants could not put any external power to the pump, so all of the energy for pumping the water had to be derived from the head of water itself. Water was supplied in an 800-liter tank, filled to the brim about 1.6 m above ground level. A receiver was arranged so that its entry point was at the same height as the water in the tank. Obviously, siphons would not work.

Many entrants designed variations of the hydraulic ram. This well-established invention inspired by the phenomenon of "water hammer"[1] converts the momentum of a falling water column into pressure energy when the flow is suddenly stopped by a valve. The increase in pressure then elevates a fraction of the water to a higher level. Because the hydraulic ram is readily found in textbooks, the organizers expected most entries would be based on this principle, and, in fact, the winner was. One of the delights of the Competition, however, is being amazed by the unexpected and, as hoped for, several entries exploited entirely different principles.

One entry (which won second place) caused falling water to pressurize the air in a vessel of about 20-liter capacity situated at ground level. This increased air pressure was transmitted via a tube to a second vessel at a higher level that had been previously filled with water from the tank. The air pressure then pushed water out of the second vessel into the receiver. Other less successful but amusing entries included a flimsy cardboard-and-rubber-band turbine that turned half a dozen times, got waterlogged, and stopped, meanwhile giving the operators a bath (see Figure 6), a great slow-working piston pump, reminiscent of a Boulton and Watt steam engine, which did not even fill up in the thirty seconds, and an unofficial entry by graduate students that used solid carbon dioxide pellets and a lid on the tank to pressurize the water, forcing it directly to the receiver (shown in Figure 7). Al-

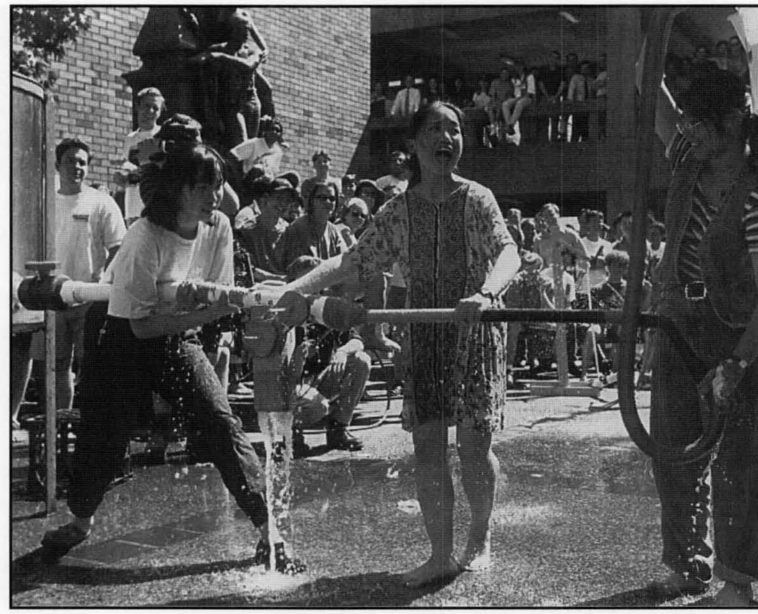
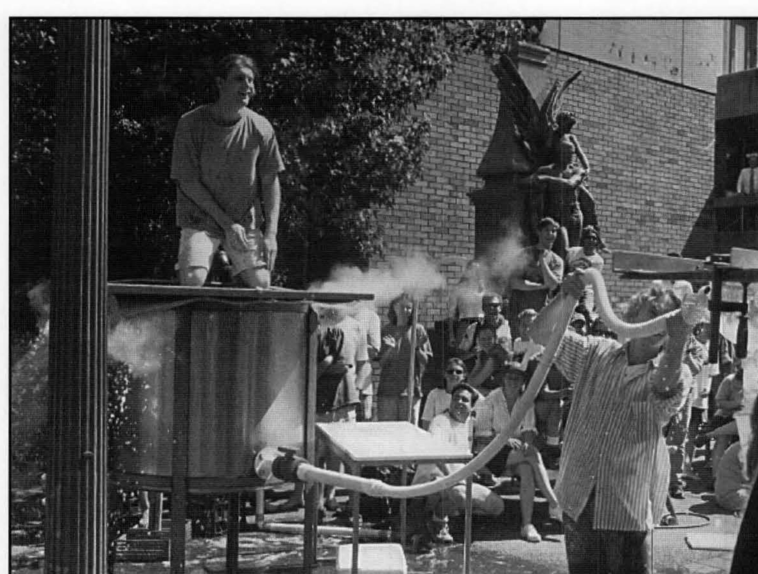


Figure 6. *Typical of the more whimsical entries in this cardboard and rubber-band turbine pump seen in the Water Transport Competition (1995). Despite the team's well-drilled display, no water entered the receiver.*

Figure 7. *Unofficial entries often appear with the intention of getting around the rules. In the same competition and amid clouds of CO_2 vapor, graduate students successfully put a lid on the tank and transport 8 liters of water in 30 seconds.*



though the resultant flow was spectacular, using the heat energy of the water was a too-clever interpretation of the rules and it was disqualified.

The winning entry, based on the hydraulic ram principle, was a well-researched and well-designed device that transported 2.6 liters of water in thirty seconds. The winners had consulted an engineer (actually, one of the team's parents), and having gotten the general idea, made their entry from PVC pipe and fittings, a 2-liter plastic soft-drink bottle, a squash ball, a marble, and a piece of garden hose. Unlike many of the others, this team hardly got wet at all.

A COMPETITION FOR VISITORS

A related competition is held from time to time for visitors to the department on University Open Days. This competition requires a more spontaneous approach, and because there is no time for the contestants to design and prepare an entry, construction materials are provided and the assigned task is simple.

Our favorite example involves a hot-air balloon for which contestants must design and build a burner of greatest efficiency. This burner contains a small quantity (say, 25 ml) of fuel, such as ethanol. The burner is attached by metal wires to the inside of the hot-air balloon and the fuel is ignited. The longest duration aloft wins. The balloon, made from plastic foil, is only 2 m tall and slides up and down a taut wire inside an atrium within the building. Typical materials provided are aluminum foil, wire, cotton wool, scissors, pliers, etc. Obviously, the lighter the burner, the less is the effort required to lift it, but the more flimsy it is. The shape of the burner is important in determining the time aloft. An initial burst of heat is generally required, and heat should then taper off for maximum duration. Several minutes aloft is not uncommon.

Typically, the response to this competition overwhelms the organizers. On our first attempt, there was a line of contestants waiting for thirty or more minutes to have a go at it. In subsequent years we had four balloons going at once and still had no time to relax. Entries were widely variable and imaginative, but typically the simplest designs did best.

DISCUSSION

Students take the challenge seriously, using imagination and intuition together with some formal engineering to devise a wonderful range of exotic devices. The Competition not only broadens their scope but also gives them an excellent excuse to have some fun. It also performs a service in socializing students. For most, this is their first time in a public exhibition in front of their peers. Although there may be some degree of humiliation in defeat, this soon passes as the rewards, as ever, are in participating.

Other Competitions not described in this paper have been based on various examples of process unit operations. They have included optimizing a distillation rig for producing drinking water (1987), operation of a precision soap-cutting device (1989), transporting beer using only the pressure in the can (1990), and optimizing a simple heat exchanger (1993).

Originally, most Competitions involved a means of transporting matter or energy by some method that could be optimized. More recently, two of the Competitions have been based on the area of risk in the process industries (*e.g.*, the Bursting Disk and Extinguish the LPG Flame). There is an obvious extra level of excitement in this type of competition and we will continue to include them, mindful always of the necessary safety precautions.

Despite the general levity of the occasion, there is usually some scholarly relevance. In the bursting disk competition of 1992, the solvent can that exploded and rocketed was noted to have relevance to a major industrial fire in which a solvent storage tank ruptured at its base, similarly exploding and rocketing.[2] The 1994 Competition to extinguish the LPG flame had relevance to the oil fires in Kuwait after the Gulf War. Interestingly, the winning entry used a similar principle to extinguish the fire that was used by the team of experts on the real thing.

One lesson might be, "Do your research carefully, especially if deception is the aim." One of the entries in the soap-cutting Competition of 1989, a mysteriously modified cardboard box produced two perfect halves from a whole cake of soap in record time and looked like winning. But it was not to be. A spirited audience observed, and the judges confirmed, that the cake inserted into the device was pale pink while the two halves that emerged were white!

The Competition's real message is, I like to think, that Experience is the best teacher. Until they reach the university, nearly all of the students' academic experiences have been theoretical. The concept of actual catastrophe never seems to emerge. In the real world, however, catastrophe is always ready to exploit the unready. Perhaps most students do not realize the Competition's lessons at the time, but some will in the future—we hope, to their benefit.

ACKNOWLEDGMENTS

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REFERENCES

1. Smith, B.E., "Building a Model Hydraulic Ram," *Modeltec,* pg. 8, April (1995)
2. Thomas, F., "Coode Island: Vapour Recovery to Blame?" *The Chemical Engineer,* **506**, pg. 17, October (1991) ❐