COMET
An Open-Ended, Hands-On Project for ChE Sophomores

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*"Georgia Tech was the site of intense competition Monday, but this time it was not Olympic athletes who sought gold. Instead, eleven determined teams made up of chemical engineering majors met in quadrant two of SAC's main gym to embark on a battle of wits. . . . Kamikaze team member Heather Ledbetter explained how her team's COMET operated: "Our COMET stores elastic potential energy by displacing a spring. This potential energy is then converted to work, acting on our projectile—an egg. . . . The peeled egg worked the best."**

Sophomore chemical engineers at Georgia Tech recently built Controlled-Operation Mechanical Energy Transducers (COMETs) as part of a project to introduce them to a number of important engineering concepts that are often not addressed until later in the curriculum, if at all. In the COMET competition, student teams designed, built, and used simple, self-powered devices that independently traveled to a designated location.

While electrical and mechanical engineering students frequently participate in design competitions involving student-built machines,[1] chemical engineering students' hands-on experience is usually limited to prefabricated laboratory experiments during the junior or senior year. To introduce activities other than pencil-and-paper homework assignments earlier in the curriculum, development of hands-on design projects appropriate for beginning chemical engineers has recently received increased attention.[2,3] Motivated by this concern, I developed and offered the COMET competition

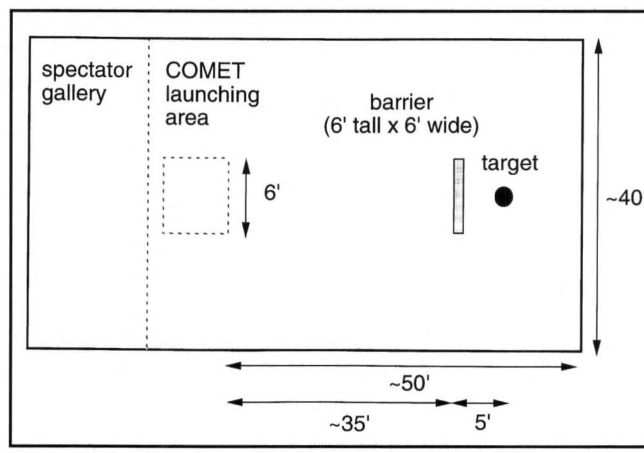

Figure 1. *Schematic of the COMET competition arena located on an indoor basketball court. COMETs traveled by land and/or air from a launching area, around or over a large barrier, and to as close to a target location as possible. The COMETs were designed and built by teams of sophomore chemical engineers.*

in two consecutive sophomore-level classes on energy balances.[4] It was designed to achieve the following goals:

- ***Teamwork*** Students formed teams of two to four members who worked together on all aspects of the projects.
- ***Open-Ended Problem*** Because there were few rules in the competition, many possible designs could accomplish the assignment.
- ***Design*** Given only a spending limit and a final goal, students had to design, build, test, and use their COMET.

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* *Excerpt from a final COMET report written by a team of students.*

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- ***Hands-On Experimentation*** Because a successful COMET design depended largely on empirical physical testing, students needed to get their hands dirty.
- ***Technical Writing*** Each group prepared a final report that described and analyzed the design of their COMET, including written text, figures, and calculations.
- ***Estimation Based on Limited Data*** Quantitative estimates of kinetic and potential energies were required in the final report. Students designed and performed additional experiments to calculate rough estimates of those energies.

THE ASSIGNMENT

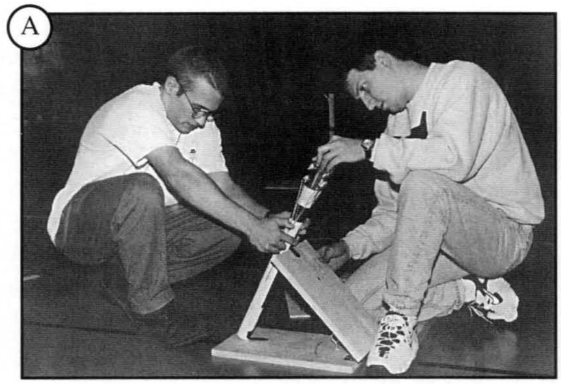
The COMET project had few rules, thereby giving students the opportunity for creative design. In groups of two to four students, each team designed and built a COMET that could be launched from a designated location and, without human intervention after launching, would come to a stop as close as possible to a target location approximately forty feet away (Figure 1). To make the assignment more challenging, a large object was placed five feet in front of the target so that a straight path to the target would be blocked. The COMET had to cost less than \$20, measure less than one foot in all dimensions, have no electrical, chemical, or human power sources, and be safe. The COMET could have a separate launching unit of any size, but the launching unit had to remain behind the starting line.

The assignment was given to the students two to three weeks before the competition. Immediately before the assignment was given, we held an in-class brainstorming session to help students think broadly about the project. We identified possible paths an object could follow between two points separated by a barrier and considered ways in which an object could be powered to follow some of those paths.

One week before the competition, a preliminary design of the proposed COMET and its expected course was collected to ensure that each group had started work on the project. I provided feedback on these preliminary designs, commenting on approaches that seemed overly complex, unlikely to work, or unsafe. Students also received sample energy balance calculations to guide them in preparing their reports, as described below. Optional practice sessions were held before the competition so that teams could test their COMETs in the competition arena.

THE COMET COMPETITION

The competition consisted of three rounds. During each round, each team in turn launched its COMET toward the target (see Figure 2). The referees (*i.e.,* class TAs) measured the shortest distance between the target and the COMET.



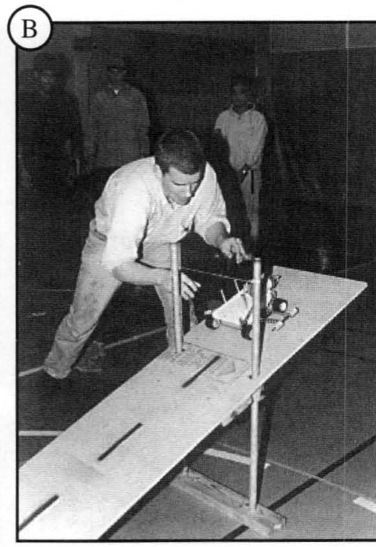


Figure 2. COMETs being launched at the competition.

(A) The "Tomato" team shot a rice-filled balloon from a rubber band-powered cannon.

(B) The "Quadrangular" team COMET drove to the side of the barrier and then made a 90° turn by triggering a second set of wheels.

(C) The "Slingers" launched a putty-based COMET from a slingshot.

(D) The "Spartans" vehicle followed an arced path around the barrier and was powered in part by a rat trap.

After the third round, the teams were ranked by aggregate score from all rounds of play. Members of the winning team each received a small trophy.

The ability of the COMETs to reach their target ranged from reproducibly having no net movement to reproducibly landing and stopping within inches of the target. Most designs were based on potential energy stored in the form of a spring or rubber band that was used to catapult an object through the air. Others used the potential energy of gravity to move the COMET either on the ground, through the air, or a combination of both.

Designs ranged from store-purchased projectiles modified for the competition to home-made vehicles, some with complex and clever mechanisms to control the COMET's direction and speed. While the complex designs were fun to see, they were generally unreliable and yielded only average performance. The winning designs in both of the COMET competitions were either a rocket or an arrow launched from the ground at a predetermined angle with a reproducibly applied force and having a mechanism to prevent rolling or bouncing once the COMET hit the ground.

. . . Controlled-Operation Mechanical Energy Transducers (COMETs) . . . part of a project to introduce [sophomores] to a number of important engineering concepts that are often not addressed until later in the curriculum, if at all. In the COMET competition, student teams designed, built, and used simple, self-powered devices that independently traveled to a designated location.

THE FINAL REPORT

Although the competition was the highlight of the COMET project, grades were determined from each team's final report. The report was due two days after the competition and consisted of four parts:

1. A schematic diagram and description of the COMET
2. A sketch and description of the intended course the COMET would follow
3. Receipts for items used to build the COMET
4. Quantitative energy-balance calculations for each phase of the COMET's travel

Grading was based half on clear, concise, and neat presentation and half on energy balance calculations. Quality of COMET design and construction and the COMET's ability to reach the target did not influence grades as long as each team had made a reasonable effort to do well.

The final reports were generally clear and well written, and they provided reasonable analysis of the energy balances associated with the COMET's travel. The sketches of the COMET design and its intended course were mostly simple, hand-drawn diagrams (see Figure 3) supported by one or two paragraphs of descriptive text. The receipts all totaled under $20, as required in the assignment; some amounted to just a few dollars.

Students performed energy balance calculations for each phase of the COMET's travel. A representative example follows, taken from the "Bernoulli Bunch" group's analysis of a COMET that was shot into the air from a rubber-band sling shot, landed on the ground, and finally bounced and rolled to a stop. First, these students estimated the elastic potential energy of the rubber band by shooting an object of known weight straight up into the air. They measured the maximum height of the object and, assuming no friction with the air, set the elastic potential energy lost by the rubber band equal to the gravitational potential energy gained by the object. They determined this energy to be 1.4 J. They then calculated the COMET's velocity to be 11 m/s upon leaving the rubber-band launcher by setting the COMET's kinetic energy equal to the potential energy lost by the rubber band. Using energy balances applied when the COMET reached its maximum height, first hit the ground, and finally stopped, they determined at each point the COMET's kinetic and potential energy, as well as its position and velocity.

ASSESSMENT OF THE PROJECT

From the instructor's perspective, the COMET project accomplished the six goals for which it was designed. Students responded well to the teamwork environment and seemed to share group responsibilities. They also approached this open-ended design project with an open-minded attitude, as demonstrated by the many different types of COMETs built, most of which worked well. Students spent a lot of time building and testing their COMETs, which indicated they enjoyed the opportunity for hands-on learning. The final reports contained adequate technical writing and data analysis, topics that are addressed more thoroughly in later classes.

To assess student opinion of the project, a brief, anonymous survey[5,6] was given a week after the assignment. It revealed that students generally found the COMET project to be educational, enjoyable, and worth repeating. Figure 4 shows student responses to the three specific questions asked. Students also provided written comments, which are summarized below.

The average scores shown in Figure 4 indicate generally favorable responses by the students, but not enthusiastic endorsement of the project. This observation should be tempered in two ways. First, a large standard deviation is associated with each average, largely due to a few students who

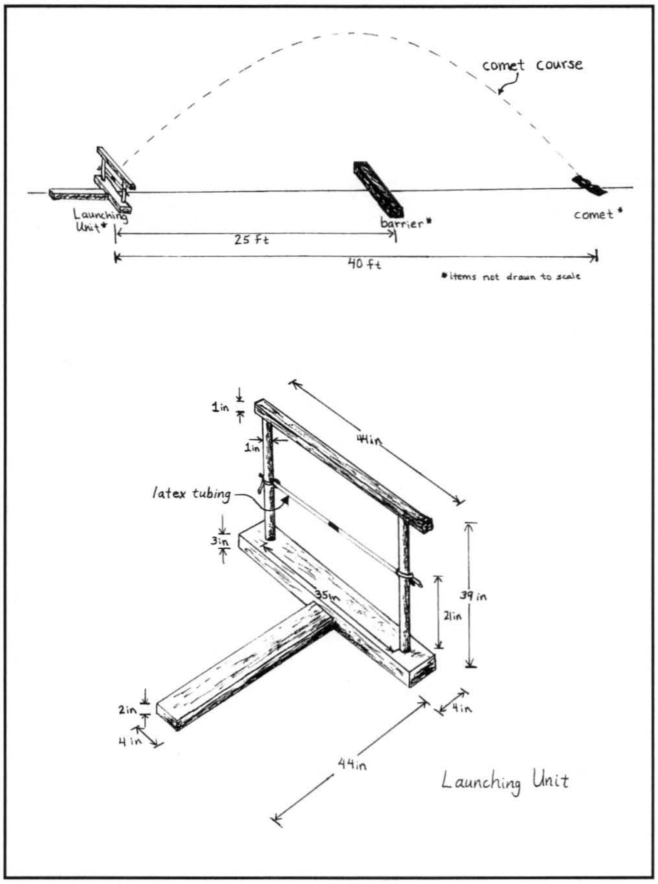


Figure 3. *A sample student sketch of the intended course the COMET would follow to the target (above) and a schematic diagram of the COMET launching unit (below) from the "COMET Busters" team final report.*

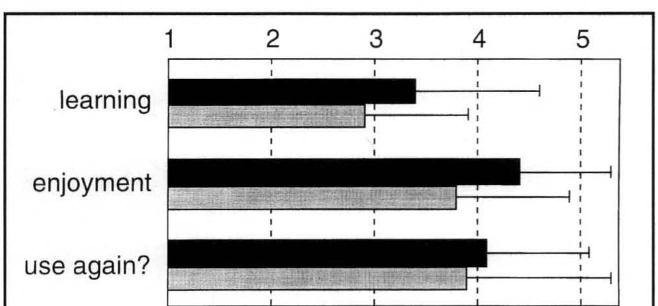


Figure 4. *Student assessment of the COMET project. Based on anonymous responses from 28 students (solid bar) and 34 students (grey bar) in two different classes, averages and standard deviations are shown for responses to the following: Rate your learning from the COMET project (1 "waste of time" to 5 "very valuable"); Rate your enjoyment of the COMET project (1 "dull" to 5 "lots of fun"); Give your recommendation on using the COMET project again (1 "absolutely not" to 5 "absolutely yes"). Overall, students found the COMET project to be educational, enjoyable, and worth repeating (see text).*

were unhappy with the project and rated it with a 1 or 2. The vast majority of students gave ratings of 3 and higher on all three questions. If the averages were recalculated without the two or three dissatisfied students in each class, all three questions would have average values above 4. Second, the scores from the first class were consistently higher than scores from the second class. Based on student comments, this difference is largely due to greater time pressure: the second class received only two weeks to work on the project, while the first class received three weeks.

Some representative student comments are provided below, followed by a discussion of what these comments say about the successes and shortcomings of the COMET project.

Enjoyable Project

"This is the only project I have had at Tech that was enjoyable. I didn't even feel like I was doing a project for a grade."

"Fun project, but still learned a lot."

Many students enjoyed the project. They were surprised to find that something educational could also be fun. Making the connection between academic values (*i.e.,* learning) and personal values (*i.e.,* fun) may be the most important lesson of the project. Student-perceived relevance of course material is known to be important for effective learning.[7,8]

Hands-On Learning

"It was nice to do something in ChE away from paper and theory."

"Home Depot is very fond of Georgia Tech students."

A number of students commented on the hands-on nature of the project and appreciated it as a refreshing change from conventional problem sets. The opportunity to exercise "right-brain" thinking through an active process that yields concrete results appeals to students with learning styles not easily accommodated in conventional "left-brain" classroom lectures.[9]

Weak Connection with Course Material

"I don't think I really learned anything from the project that pertained to the course."

"I'd suggest allowing chemical energy sources. After all, this is a Chem E class."

Some students were concerned that the project was not closely related to the rest of the course material. I partially share this concern. While the quantitative energy balance calculations required in the final report relate directly to material presented in lectures, the design, construction, and testing of COMETs are not as closely linked to the rest of the course. Nevertheless, I believe it is important to expose engineering students to concepts like teamwork, open-ended design problems, and hands-on experimentation, and I think the COMET competition provided an exciting framework

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drophilic and very mobile in the environment. The solute and bulk organic liquid that comprised the red NAPL, on the other hand, were very hydrophobic and relatively immobile in an aquifer system.

From a pedagogical standpoint, providing students with an active learning experience and very visual observation of these phenomena effectively improved their overall understanding of the fate and transport of organic contaminants in an environmental system. In terms of Bloom's hierarchy of learning,[4] the first laboratory increased the students' *comprehension,* while the second laboratory addressed the *application* of these ideas in engineering calculations. Both comprehension and application are critical steps for the students to achieve prior to advancing to the more challenging tasks of analysis and synthesis. Thus, by completing these laboratories early in the semester, students were better prepared for tackling more complex issues associated with formulating engineering decisions with respect to the potential for environmental contamination.

ACKNOWLEDGMENTS

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COMET Project

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for introducing these topics.

As the instructor, I should have made more clear to the students the connections between the project and the course material. I also should have explained why the project is of value to a beginning engineer. Clearly stated instructional objectives are known to facilitate student learning.[10] The project might have been more closely linked to the main course content if, for example, it had permitted chemical energy sources and involved more energy balance calculations in the COMET design. But this would have been difficult since the project had to be safe and relatively short and simple for sophomore students. The COMET project is therefore a compromise that achieves the primary goal of introducing ideas not found in traditional pencil-and-paper projects, but does so in a non-chemical engineering-specific format.

Logistical Improvements

> *"I think this project would have been better at the beginning of the quarter."*
>
> *"Give the groups an extra week or so to think about the project."*
>
> *"Make the project worth more than 5%."*

A number of students would have preferred different logistical arrangements for the project. Because it involved a lot of work, students wanted the project assigned earlier in the quarter when it would not conflict with midterms, wanted more time to work on the project, and wanted it to be worth a larger fraction of their grade. All of these changes can be easily made and will be implemented next time.

CONCLUSIONS

The COMET project provided a relatively simple assignment that introduced sophomore chemical engineers to a number of important engineering concepts that are often not addressed until later in the curriculum: teamwork, open-ended problems, design, hands-on experimentation, technical writing, and estimation based on limited data. Most students enjoyed the project and recommended its use in future classes.

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