World Transactions on Engineering and Technology Education
Vol.4, No.1, 2005

Teaching engineers about technology and policy: a simulation of the decisions involved in exploring Mars

Michael E. Gorman

University of Virginia
Charlottesville, United States of America

ABSTRACT: Engineering students need to learn not only how to form multidisciplinary teams, but also to interact across teams in a variety of organisational contexts, including ones that involve technology policy. In this article, the author describes the design of an interactive, classroom simulation in which students play roles corresponding to companies, research laboratories, newspapers and elected officials, debating whether and how to explore Mars. This simulation was based on the US space programme in its first iteration, then an international component was added in the second.

INTRODUCTION

Engineering education should include information, skills and judgements relevant to specific fields, but it should also include preparation for professional careers [1]. Outcome (d) of EC2000 from the Accreditation Board for Engineering Education (ABET) calls for engineering students to acquire the ability to function on multidisciplinary teams. Outcome (f) calls for an understanding of professional and ethical responsibility, while outcome (h) calls for the broad education necessary to understand the impact of engineering solutions in a global and societal context. In this article, the author outlines an activity that fulfils these three ABET goals (and others as well), not only within, but also across a variety of multidisciplinary teams by putting students into an interactive classroom simulation that encourages them to explore the relationship between technology and policy.

Working within teams is certainly a major challenge for engineering students, but an equally great, if not greater, challenge is negotiating with other teams in a variety of contexts. Multidisciplinary engineering practice, such as the development of the Mars rover, involves trading zones [2-4]. In these trading zones, scientists, engineers and other experts exchange knowledge and resources with other stakeholders – including policy-makers.

In this article, a faculty member (the author) and two undergraduate engineering students describe an activity that they developed in order to help first-year engineering students experience the interaction among, within and across teams that shape technology policy. Ideally, students would experience technology policy trading zones through internships in which they would work with engineers, scientists and policy-makers. The Engineering School at the University of Virginia in Charlottesville, USA, undertakes this with about ten rising juniors and seniors every year. These students have had life-transforming experiences (more information on this programme, conducted jointly with the Massachusetts Institute of Technology, can be found at http://www.sts.virginia.edu/stshome/, then clicking on Washington Internship).

But this kind of valuable internship experience has a high price tag per student, and also works better if students have had prior exposure to the technology-policy process, using simulations and case studies. Success has been realised by utilising case studies of real engineering dilemmas that introduce students to ethical and policy issues in technology [5]. The limitation of case studies is that students react to a set of circumstances, not creating them through extensive interaction with each other.

In this article, the author describes an interactive simulation designed to complement case studies and prepare engineering students to understand and shape policy. These sorts of interactive simulations are often used in sociology and history classes, but not to deal with science and technology issues. Rosenwein and Gorman created *SciSim*, an interactive classroom simulation of the resolution of scientific controversies, in which students would work as members of research laboratories, funding agencies, or as independent scientists [6]. The laboratories began with competing theories concerning the extinction of dinosaurs, and they had to appeal for funding to continue their research. There was a scientific journal, as well as a newsletter, that they could publish in, and they presented research at a final conference, sponsored by the federal funding agency that resembled the National Science Foundation (NSF).

The author ran *SciSim* in a first-year honours course on scientific and technological thinking undertaken by engineering students. The simulation taught students about the social side of science, but not about the development of technological systems. One obvious improvement was to create an exercise that bore a closer resemblance to engineering. Therefore, the author worked with Malow and Ratner to design a simulation that raised significant policy issues in science, engineering and technology. In the initial years, the simulation focused on the USA. At the end of this article, the author discusses an international extension to this.

MarsSim

MarsSim focuses on dilemmas that pertain to the future of space technology, posing questions that include:

- What is the value of space exploration for society? Should projects focus on Earth or other planets, such as Mars?
- Should projects pursue scientific, commercial technology transfer, economic, or exploration objectives?
- Is it better to produce several small *faster, better, cheaper* projects or one large and carefully designed project?
- Should projects attempt to develop highly advanced technologies, such as single-stage-to-orbit launch capability, or use existing technologies, such as expendable launch vehicles, in new ways?
- Should manned or robotic missions be preferred?
- How should government facilities interact with private industry?
- What are the ethical obligations of engineers working collaboratively and competitively with other engineers in a space race?

The topic of space exploration was an effective choice for three reasons. First, it was broad enough to encompass all fields of engineering. Second, there is no consensus on a strategy for space exploration. Students have to present and defend policy objectives in addition to considering how to meet these objectives. Third, during the life of the simulation, actual current events, including the space shuttle Columbia accident, European and American Mars exploration missions, Chinese space projects, and the Bush Administration's lunar and Martian exploration goals, provided valuable teaching opportunities. But one design objective for the simulation was to make it adaptable to other issues, such as nanotechnology or environmental policy.

The simulation required students to design a scientifically and financially feasible mission while reacting to changes in support from key government agencies and constituents at the same time. Students took on roles in the simulation corresponding to the following:

- Members of House Science and Appropriations Committees responsible in the simulation for appropriating funds for mission facilities and public laboratories;
- Public laboratory/industrial facilities simulating centres of the National Aeronautics and Space Administration (NASA) like JPL and Goddard;
- Private laboratory/industrial facilities reflecting major aerospace corporations, such as Lockheed-Martin, Inc. and the Boeing Company;
- A group representing a newspaper, such as the *Washington Post*, that published a paper issue every class and issued electronic updates of important events and interviews during class sessions.

Students assigned to each group set their own objectives for their group's success and developed strategies within the simulation rules to meet these objectives. Student activities included the following:

- Building prerequisite infrastructure, such as research laboratories and launch facilities;
- Developing a research strategy that involves basic and applied research projects, progressive levels of scientific discovery, and different areas of academic focus;
- Tracking the progress of these research projects and applying their products to make aspects of mission design more affordable or effective;
- Designing both manned and unmanned missions with practical engineering concerns, such as launch mass, engine thrust, scientific payload and orbital trajectory;
- Securing intellectual property rights for completed technology research through a patent application and review process;
- Negotiating the rental and trade of resources, such as research laboratories and launch vehicles;
- Reporting to Congress and addressing Congressional funding priorities;
- Responding to media inquiries from the newspaper group.

The open-ended nature of the simulation allows either students or the instructor to introduce events. Examples include:

- Hearings by Congress to investigate budget issues;
- News events that suddenly shift Congressional funding priorities, such as evidence of life on Mars, or a new international security threat;
- Litigation between laboratories and private companies over intellectual property (the litigation, in the simulation, is not handled by an actual court trial, but by the instructor and teaching-assistants).

Special effort has been made in the simulation to address ethical issues, including preserving the intellectual property rights of other groups.

Scaffolding for *MarsSim*

The goal of the software backbone for *MarsSim* was to free the instructor and the teaching assistants (TAs) to interact with students, instead of processing paper proposals for research, patents, launches, etc. Further, it would keep a complete record of all activities in the simulation. Student groups accessed a database-driven PHP application that provided budget information, project options, status information on current projects, an archive of completed projects and transactions, intellectual property information, and proposal forms for facility construction, missions, research projects and patents.

Groups could select research from a wide range of possible topics; if a group had enough money in its budget, had met the research prerequisites and no one else had researched this aspect of science or technology, the group got credit for the advance. When designing a mission, students accessed an interactive spreadsheet that presented design options and performed engineering calculations in real-time so that students could see the cost and expected outcome of these design decisions. The design spreadsheets did not directly test students' computational capabilities, but challenged them to think analytically about engineering design decisions and their relationship to project outcomes and the group's strategy. Plans, agreements, and financial transactions were recorded in the simulation using a system of forms and interactive design spreadsheets. Instructors interested in using this digital scaffolding should contact the author (meg3c@virginia.edu); a rough version is available on CD.

However, the scaffolding was not perfect, and still left a lot of work for the instructor and the TAs, especially in a recent version of the class where there were 43 students. There was a blizzard of patent and research proposals that demanded human evaluation. It was the online system that facilitated the blizzard – there were no delays imposed by the paper forms. The digital scaffolding makes the simulation more active, which is the right problem for instructors and TAs to have!

Example of *MarsSim* in Action

There is no typical experience in *MarsSim*, but the steps a laboratory had to go through will illustrate how the simulation worked. At the beginning, laboratory members could see a list of requirements for missions, as well as a technology tree similar to those in computer games like *Civilization II*. The laboratory members would then have to decide on a research direction.

As an example, let the focus shift to a laboratory that took on a role similar to JPL and decided to launch a robotic mission to search for life below the Martian surface. To prepare, the group focused on biology research to improve the sensors they would use to detect life, then realised that they had to research materials in structural engineering in order to reduce the mass of the components in the launch system. In order to improve their propulsion system, they had to gain access to computer and particle physics research. If this work were produced by another publicly-funded laboratory, then it was in the public domain. If produced by a private company, then this JPL-like laboratory would have to license the rights or work out some kind of sharing arrangement.

To obtain continued funding, the laboratory would have to present its plans to Congress, another group in the simulation, and show evidence of the results gathered to date. Congress would sometimes have its budget cut, or would change priorities, and the laboratory would have to negotiate its role and funding in this changed environment.

By the third or fourth day of the simulation, the group might be ready to assemble its mission. They had to choose a payload, balancing mass, cost, energy utilisation and what experiments the mission would carry.

For power, for example, one actual *MarsSim* group simulating a JPL-like facility picked fuel cells, which weighed less but also generated less power. From a list of possibilities, this same group selected the rover with the longest surface range and added a drill, microscopic imager, camera and X-ray spectrometer. They also had to pick engines from the Earth to lower orbit stage, then the transfer to geocentric orbit, then a third stage to move to a Martian orbit, then a fourth stage to get onto the Martian surface. The group had to balance the cost of the components, including fuel, the efficiency of the engine relative to its mass (thrust-to-weight ratio) and the reliability of the engine, using a spreadsheet built into the simulation that allowed them to explore whether different configurations in each stage met their design objectives.

After they had made their choices, the group submitted their launch online. The teaching assistants assigned it a launch time, accounting for construction time. The teaching assistants assessed the reliability of the components and utilised a probability model to assess whether the mission failed or not. Here is one of the areas where the teaching team could manipulate the direction of the simulation: by providing surprising results. In this case, the teaching team decided that the laboratory found evidence of bacterial life. The group made a public statement that was disseminated by the newspaper. This result encouraged further missions to Mars.

Two other *MarsSim* groups launched unmanned missions looking for life (in the pre-Mars-rover days). One combined both atmospheric testing and drilling, and obtained positive results at the end of the fifth day. Another did a deep subsurface mission using an advanced drill with rock abrasion tools, and they also succeeded in finding evidence for life. Based on the positive results, groups across the simulation elected to combine in order to complete a manned mission, and were encouraged by Congress and by the TAs, who represented the Administration's priorities. The manned mission was successful.

Going Global with *MarsSim*

In the latest iteration of *MarsSim*, groups representing China and the European Space Agency (ESA) were added. These groups were put in adjacent rooms in a separate building from the regular classroom, so that travel was required to reach them – literally and figuratively. Both groups kept track of the classroom via the *MarsSim* newspaper and cell phones. A newspaper reporter sat with the international groups to relay stories back to the main room, where they were posted on a projector and were also available to students online.

China and the ESA were not told much about their roles; they were allowed to evolve them. Interestingly, the Chinese group started out competing with the US early, and even figured out how to steal some money from one of the US laboratories, sparking sanctions that slowed China's technology advance and raised prices for technology in the USA. A US corporation, in collaboration with one of the national laboratories, entered into fake negotiations with China to further delay them. Had it not been for the sanctions and delays, China would have launched its own mission.

The ESA broke up at one point, with two members who decided to play the role of Italy, choosing to move to China's room and collaborate. But the theft of US technology and the anti-US attitude of the Chinese made them quit that collaboration and open one with the US – giving access to China's technology in the process. So those who stole were robbed in turn!

The end result was the resolve by all US partners to come together and launch a Mars mission to beat the Chinese.

An important follow-up is to remind students that, while unethical conduct was encouraged to be explored in *MarsSim*, it is not appropriate outside of the simulation. *MarsSim* is studded with teaching moments, where the instructor could explain how things would work in the real world, especially with respect to ethics. Even within the simulation, unethical behaviour had negative consequences. Another example was a Senator who tried to bribe constituents to vote for him. He was censured by the Senate and removed from his seat.

Students were able to test ethical, as well as social and technological, limits in *MarsSim*, and see the consequences in a safe situation where no real harm is done. The instructor must use these situations as teaching moments to relate *MarsSim* incidents to professional conduct. In the end, most students concluded that, while competition can stimulate missions, it requires cooperation to complete them. As one student noted, *as a result of a combination of competition and cooperation, the simulation succeeded*.

Indeed, quantitative evaluations of *MarsSim* have also supported its value. In one recent class, nearly two thirds of the students gave grades of As, and over 90% a grade of at least B when asked to rate how interesting it was. One student stated:

> *I had a lot of fun with* MarsSim*, and I did a lot of work for it, except I didn't mind all the extra time I was spending out of class for it. The essay also came very easily to me because of my enjoyment with the project. I would definitely recommend using it again.*

Adapting *MarsSim* to Other Problems

The simulation is designed to be adaptable to topics other than space exploration. The software is set up so that groups could be created around themes like nanotechnology research, biotechnology research, or other technologies that are greatly impacted by national policy. In each case, the simulation provides an opportunity for students to learn more about a particular area of research while enhancing communication and teamwork, as well as engineering design and analysis skills.

Consider, for example, an environment in which students explore the government funding of nanoscience and nanotechnology. Groups could emulate the Office of Science and Technology Policy at the White House, the House Committee on Science, the National Science Foundation, non-governmental organisations like the ETC group that call for a moratorium on nanotechnology, companies that would be hurt by such a moratorium, newspapers like *The Wall Street Journal* and nanotechnology newsletters like *Small Times*, plus other countries like Japan that are making significant investments in nanotechnology.

MarsSim could, therefore, become *NanoSim* – or even combine multiple initiatives, forcing students to choose between funding space exploration or nanotechnology, or the environment, or poverty. Such a wider simulation could involve multiple universities that could be connected online.

CONCLUSIONS

In its present version, *MarsSim* takes about six hour-long classes and works best when there are several undergraduate TAs to help run the simulation. The author recruits his TAs from previous classes, so that students running *MarsSim* have been through it. Therefore, *MarsSim*, even when complemented by the software designed to keep track of research and budgets, represents a considerable investment in time. However, this investment is justified, it is felt, by the objectives it allows to be attained. Students learn about the following:

- Working within multidisciplinary teams;
- Coordinating activities across teams – sometimes cooperatively, sometimes competitively;
- Writing concise reports and memos, as well as preparing brief and accurate budgets;
- The excitement (and frustrations) of shaping technology policy.

After the simulation is over, one representative from each of the *MarsSim* roles is placed into a large group where students are given the opportunity to explain their simulation roles to each other and discuss the simulation. After this discussion, students write a paper about *MarsSim* in which they describe their own role groups' activities, relate it to what they heard about other roles in *MarsSim*, and talk about what they think they learned. This gives the instructor a chance to reinforce lessons about technology, policy and professional conduct. Two student comments include:

- *MarsSim* helped *provide insight into the way technology is handled in industry, government, and media*;
- *I was able to learn much about how scientific goals can be distorted to a political end, and how difficult it can be to achieve a goal so closely in reach because of monetary and economic constraints.*

This kind of activity could be introduced into existing courses at a variety of stages in the engineering curriculum. However, it is felt that it has an especially important role to play in the first year, because it allows students to experience some of the excitement – and frustration – that comes from the interaction between technology and policy on the cutting-edge. Simulations of this sort, coupled with other experiences like internships, have the potential to attract future leaders to engineering.

REFERENCES

1. Gorman, M.E., Turning students into professionals: types of knowledge and ABET engineering criteria. *J. of Engng. Educ*., 91, **3**, 339-344 (2002).
2. Lambert, M.H. and Shaw, B., *Transactive Memory and Exception Handling in High-Performance Project Teams*. Palo Alto: Stanford University (2002).
3. Gorman, M.E., Levels of expertise and trading zones: A framework for multidisciplinary collaboration. *Social Studies of Science*, 32, **5**, 933-938 (2002).
4. Gorman, M.E., *Expanding the Trading Zones for Convergent Technologies.* In: Roco, M.C. and Bainbridge, W.S. (Eds), Converging Technologies for Improving Human Performance: Nanotechnology, Biotechnology, Information Technology and Cognitive Science. Kluwer: Dordrecht, 424-428 (2003).
5. Gorman, M.E., Mehalik, M.M. and Werhane, P.H., *Ethical and Environmental Challenges to Engineering*. Englewood Cliffs: Prentice-Hall (2000).
6. Gorman, M. and Rosenwein, R., Simulating social epistemology. *Social Epistemology*, 9, **1**, 71-79 (1995).