THE GREEN SQUARE MANUFACTURING GAME

Demonstrating Environmentally Sound Manufacturing Principles

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The Green Square Manufacturing Game addresses several issues of engineering education. The first is the need to instill future engineers with "environmentally sound" thinking. The concept of pollution prevention should be taught across all disciplines of engineering, and an ideal place to introduce this concept is in the freshman engineering curricula. The Green Square Game is perfectly suited for such an application and can be "played" in a single class period or spread over two class sessions, with a historical perspective of US environmental laws included throughout the game.

Another issue the game addresses concerns hands-on learning versus passive learning. It provides hands-on learning and group design with minimal fuss or preparation time, followed by an open discussion of the results. This approach increases enthusiasm for problem solving, is easy to implement, and uses inexpensive, readily available supplies.

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The Green Square Game can also be easily adapted for use at the secondary-school level as a tool to raise awareness (and the status) of the engineering profession among high school students. In this case, a faculty member or a secondary school teacher can lead the game, providing high school students with a challenging and thought-provoking glimpse of engineering relevance in today's world.

The game is played in two sections. During the first round, students are told that the year is 1953. They are split into different "companies" (of three, four, or five students each) that manufacture green squares. Each of the companies is competing to win YOU (the instructor) as their client. YOU want to purchase green squares of a particular shade and size (5 cm x 5 cm white paper squares painted green on one side). The companies are put to work trying to replicate the sample green square by using powdered blue and yellow tempura paint. No mention is made of environmental impact or waste disposal. Then, during the second round, the year is changed to 1998. Again, YOU are the customer requesting green squares, but this time the constraint of waste minimization is placed on the "companies" and students must try to produce the green square with as little waste generation as possible.

The game is an ideal hands-on classroom project for freshman engineering and high school students; it highlights waste minimization, pollution prevention, and industrial ecology and offers valuable experience in group problem solving. Faculty members at the University of Connecticut and secondary school teachers throughout the state have used the game with great success. Secondary school teachers have been introduced to the game as "participants" during university outreach activities. The game was originally developed by WRITAR[1] as a role-playing exercise to train state regulatory staff.

GOALS AND OBJECTIVES

The purpose of the game is to give students a taste of how waste minimization influences a manufacturing process (the production of green squares). This mock process is also intended to help participants become more aware of sources of waste, options for waste minimization, resistance to change, and the importance of communication and cooperation in waste-reduction efforts.

Underlying objectives of the exercise are to demonstrate the technical challenges (and frustrations) of reducing waste in an industrial setting and to demonstrate the non-technical issues that influence waste reduction efforts, including customer demands and competition.

INSTRUCTIONS

1. Assemble participants into "companies" of three, four, or five students each and seat them around the "production floor" (flip chart paper spread on a table is the best production floor since it lies flat and "waste" is easily seen; a sheet of brown wrapping paper, a cut-open paper grocery bag, or a sheet of newspaper could also be used).
2. Each group is a "company" that manufactures green squares.
3. Tell participants that you are a potential client who would like to purchase green squares that look like the model shown (a prepared sample). You will be distributing the green squares overseas and are looking for a new supplier for a $2-million contract next year. You are asking the "companies" to compete to win your business.
4. Ask the groups to invent their own company name and write the team names on a flip chart, blackboard, or viewgraph.

FIRST ROUND

1. The year is 1953.
2. The criterion for the competition is that the company's product should exactly match the model shown (including dryness) in the allotted amount of time.
3. Companies use the materials provided (powdered blue and yellow tempura paints, paint brushes, mixing cups, water, white paper, etc.) to produce a perfect green square. They are given 10 to 20 minutes (depending on the time available) to complete the project.

At the end of the "production time," instruct the teams to stop. Inspect each team's product and evaluate its efforts using the criteria suggested in Table 1 (or substitute your own criteria). As the customer, you must assign value to criteria as you see fit. If time permits, students may also be given an opportunity to evaluate their own and fellow companies' performances. Rate or rank-order company performance based on the evaluations and instruct the teams to clean up.

Discuss the results of the first round. Discussion questions for it might include:

- Was it quiet while the exercise was going on?
- Was the project time consuming?
- What approaches did groups use to produce the square? Was a lot of planning involved?
- Did students work as a team?
- Was waste a concern?
- How much waste did the groups generate (production floor cleanliness; number of contaminated brushes, cups, and spoons; cleanliness of the back of the green square; left-over green paint; contaminated hands, clothing, etc.)?
- Were raw materials wasted?

SECOND ROUND

1. The year is 1998.
2. Again, the goal is to manufacture green squares—but with an additional constraint. In addition to product quality and time, companies must consider environmental impact.
3. Explain that any surface or object that becomes contaminated with paint (of any color) becomes "hazardous." This includes all materials, hands, clothing, table surface, and floor. Explain that teams will be evaluated on their ability to paint the square green while generating the least amount of "hazardous" waste.
4. Let the teams begin production. Again, allow 10 to 20 minutes to complete the exercise.

TABLE 1
Evaluation Criteria

First-Round Evaluation Criteria
- Color and size match model
- Color consistency
- Dryness of sample
- Cleanliness of back of sample

Second-Round Evaluation Criteria
- Color and size match model
- Color consistency
- Dryness of sample
- Cleanliness of back of sample
- Amount of raw material used
- Production floor cleanliness
- Number of contaminated brushes
- Number of contaminated cups
- Number of contaminated spoons
- Left-over paint
- Contaminated hands, clothing, etc.

At the end of the "production time," instruct the teams to stop. Again, inspect each team's product and evaluate its efforts. Table 1 contains a list of possible evaluation criteria for this round. It is easiest to give each criteria equal weight. Rate or rank-order company performance based on the round-two criteria and instruct teams to clean up.

As an alternative to this scheme, more "realism" can be injected into the project by assigning dollar values (based on product quality) and costs to the items listed in Table 1. Company performance can then be judged by profits (*i.e.,* value less cost).

For example, values of $1, $0.50, and $0.00 can be given for perfect color match, acceptable color match, and unacceptable color match, respectively. Equal valuations can be assigned for color match, consistency, dryness, and cleanliness (a perfect sample would be worth $4.00). Similarly, costs can be assigned to raw materials (paint), equipment (brushes, cups), labor, and environmental decontamination ($/area of contamination?). Time permitting, different "value and cost" schemes can be used in judging performance to illustrate the interactions between environmental concerns and engineering design.

Second-round discussion could include:

- Was it quiet while the exercise was going on? Which production round was more time consuming?
- Did the second round require more planning? Did the students work more as a team?
- How did the focus change?
- What techniques were used to minimize waste generation? Which ones were the most successful?
- How much waste minimization was accomplished? How is it quantified? Is zero discharge possible?
- How was the product quality affected during the second round?
- Solicit ideas on how to dispose of waste generated by each company.
- If incineration is recommended, what might happen to the hazardous material? Solicit ideas on how to dispose of toxic ash and air pollution.
- If landfill is recommended, again ask what possible environmental impact may result. Solicit ideas on how to clean up contaminated water and soil, and on what should be done with the hazardous remains.
- Is there a compromise between product quality, cost (time), and environmental concerns?
- Where does the garbage that the students generate at home go?
- Encourage students to research industries in their own communities that generate air, water, and soil pollution and where that waste is disposed.

ADVICE TO INSTRUCTORS

Materials (for each round)

- Small paper cups (about 3-ounce size), two for the powdered paints, one for water, and three for mixing
- 1 tablespoon of powdered blue tempura paint in a paper cup is provided to each company
- 1 tablespoon of powdered yellow tempura paint in a paper cup is provided to each company
- Plastic spoons (popsicle sticks or plastic spatulas)
- Inexpensive watercolor brushes
- White construction paper
- Scissors
- "Production Floor" (a sheet of brown wrapping paper, a cut-open paper grocery bag, or a sheet of newspaper spread on a flat table).

Short Version (less than 50 minutes)

To play the game in a short time period, it is best for the instructor to pre-cut the squares and to have two production floors for each company set up (one for each round) before the students arrive. The students should be pre-assigned to a company and the company name should be selected in advance of the class period. Restrict the production runs of each round to 10 minutes and have prepared score sheets available for judging performance. The first- and second-round discussions can be combined if necessary, and any issues not discussed in class can be given as homework.

Long Version (less than 120 minutes)

To play the game in a longer period, a lecture (Historical Perspective: U.S. Industry and the Environment) is given so the students are brought from 1850 up to 1953 before round one is played. Then the lecture is continued from 1960 up to today before round two is played. A brief description of this historical perspective is given below. It is focused on industrial pollution, but keep in mind that a large percentage of waste was (and still is) generated by non-industrial sources. Historical information can be found in references 2 through 6.

Lecture

1850-1900 • *U.S. industrial waste regulation between 1850 and 1900 was minimal. Industrial expansion and population growth resulted in severe pollution in urban areas. The major industrial chemicals manufactured during the period from 1850 to 1900 were caustic soda (NaOH), chlorine (Cl_2), soda ash (Na_2CO_3), fertilizers, ammonia, acids (H_2SO_4, HCl, HNO_3), refined petroleum products, soaps, steel and refined metals, paint, pulp and paper, and coal gas. Typical waste streams from these activities included heavy metals (including mercury and lead), polycyclic aromatic compounds, waste acids, pulp and paper liquors, solvents from petroleum and wood distillation, and aquatic nutrients such as nitrates and phosphates. Waste treatment techniques were rarely used during this period except for the recovery of valuable by-products, and waste streams were disposed of in the most convenient manner available. The first environmental law enacted in the U.S. was the Refuse Act of 1899 for the purpose of preventing impediments to navigation!*

1900-1930 • *From 1900 to 1930, industry focused on maximizing production. Factories became centralized in locations best suited for the particular type of product being made (e.g., Pittsburgh became the "Steel City"). Emerging technologies during this period included synthetic rubber, polymers and plastics, and metal finishing (electroplating). Typical waste streams from these new endeavors included aqueous heavy metals and metallic sludge, cyanide compounds, "off-spec" materials and products, and petrochemical by-products. Waste "treatment" during this period consisted of dumping solid waste into landfills and liquid waste into on-site ponds or lagoons. Urban population and pollution continued to grow at exponential rates, primarily due to spectacular increases in immigration and rural-to-urban migration. Pollution problems were regarded as nuisances, but no comprehensive environmental reforms were made concerning industrial discharge.*

1930-1950 • *The period from 1930 to 1950 saw many advances in chemical technology. Rapid-growth industries included pharmaceuticals, synthetic organic petrochemicals (pesticides, chlorinated compounds, polymers), detergents, cosmetics, and coatings. Breakthroughs in one area often provided abundant and inexpensive raw-material feedstock for many other operations. For these reasons, the variety, volumes, and toxicity of industrial waste streams were rapidly on the rise. Disposal was preferred to treatment because of economics and a lack of federal regulations. Disposal methods included the use of sludge ponds, dilution ("the solution to pollution"), deep-well injection, and ocean dumping. Most government regulations at the time were concerned with product quality and safety rather than environmental issues (Federal Food, Drug and Cosmetic Act of 1938, Federal Insecticide, Fungicide, and Rodenticide Act (FIFRA) of 1947).*

The first federal law dealing with conventional forms of water pollution (the Federal Water Pollution Control Act) was passed in 1948. It authorized funding for municipal sewage treatment plants and established broad authority to regulate industrial and municipal discharges through the National Pollution Discharge Elimination System (NPDES). States were given the job of issuing permits and enforcing compliance of this law, which dealt mainly with blatant and acutely toxic industrial discharges.

In the 1950s, an exponential increase in manufacturing occurred as a result of the healthy economy, a rapidly growing population, and product-hungry consumers. During this time, the prevailing government attitude was "If it's good for business, it's good for America," the prevailing industrial attitude was "Profits are high, regulations are few, and life is good!", and the prevailing consumer attitude was "Buy it, use it once, throw it away."

TABLE 2
Current Environmental Laws Affecting U.S. Industry

- Toxic Substances Control Act
- Clean Water Act
- Hazardous Materials Transportation Act
- Emergency Planning and Community Right-To-Know Act
- Federal Food, Drug, and Cosmetic Act
- Pollution Prevention Act
- Poison Prevention Packaging Act
- Marine Protection, Research, and Sanctuaries Act
- Clean Air Act
- Resource Conservation and Recovery Act
- Comprehensive Environmental Response, Compensation, and Liabilities Act
- Federal Insecticide, Fungicide, and Rodenticide Act
- Consumer Product Safety Act
- Federal Hazardous Substances Act
- Ports and Waterways Safety Act

1950-Present • *In the 1960s, U.S. industry continued to grow and prosper. Crude oil was practically free, so Americans were combusting it and polymerizing it as fast as they could. Environmental laws were few, and most discharges were unregulated. But the effect of pollution on the environment was becoming obvious—major rivers were catching fire, smog was causing significant health problems in many urban areas, fish were floating instead of swimming, and wildlife was disappearing.*

These and other problems resulted in public outrage and the demand for far-reaching environmental legislation. The United States Environmental Protection Agency (USEPA) was created by presidential order in 1970. It became the lead agency for the control of pollution of the nation's air, water, and land resources (a job previously relegated to the U.S. Department of Health Services and the Federal Water Pollution Control Administration). The USEPA was given authority to regulate the industrial community.

During the late 60s and throughout the 70s, many new environmental laws were enacted, including the Clean Air Act, Clean Water Act, Toxic Substances Control Act, and Resource Conservation and Recovery Act. Significant national policy changes such as removing lead from gasoline, removing phosphates from detergents, and banning a number of dangerous pesticides were also made during this time. Current laws affecting U.S. Industry are listed in Table 2.

In 1980, a major piece of legislation, called the "Comprehensive Environmental Response, Compensation, and

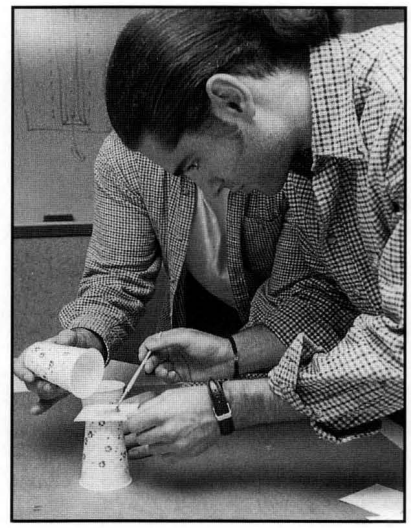
Liabilities Act," was passed. It authorized the federal government to respond to spills and other releases of hazardous substances, established a fund for cleanup, and established industrial cost liability.

Additional environmental issues that reached public awareness in the 80s include airborne acids, heavy metals, oxidants, acid rain, stratospheric ozone depletion, global warming, the disappearance of municipal and hazardous waste land fills, ocean dumping, and other illegally dumped hazardous waste.

As a result of these and other problems, industries found themselves faced with lawsuits, protests, opposition to new plant sites, disputes over product approval, and more environmental laws.

Today, every aspect of doing business is affected by environmental concerns. Industrial expenses associated with environmental protection include the purchase and transport of regulated materials, consulting fees, air and water discharge permit fees, and administrative costs for permitting, reporting, monitoring, sampling, manifesting, and labeling. Additional costs to industry are incurred in the purchase of pollution-control equipment, taxes and insurance, penalties and fines, lawsuits, off-site transportation, treatment and disposal, on-site treatment and control, contaminated site cleanup, customer dissatisfaction with poor environmental policy, and long-term liability for waste disposal.

Students at work during round one.



Students during round two.

During the "long version" it is still best to have two production floors for each company (one for each round) set up before the students arrive. There is sufficient time to let the companies cut their own squares. The production runs of each round are now limited to 15 to 20 minutes.

Examples of Green Square "Innovations"

Typically in round one, the companies will mix paints in the extra cups provided, paint several squares, and paint the production floor while painting the edges of the square. Often, the production floor is used as a mixing area. Some groups may assign functions and work as teams, while others may produce squares as individuals.

In round two, expect more up-front discussion and more teamwork. Most of the innovation occurs in round two. Mixing typically occurs directly on the square, and the paintbrush may be the only tool. Holding the square so the edges can be painted without contaminating other surfaces or hands presents a challenge. Curiosity as to how the other companies manufacture their squares is also greater in round two ("industrial espionage").

Often the students will use other pieces of equipment. The fan on the viewgraph projector has been used to dry the green squares. Small containers such as lipstick lids have been used for mixing, and tissues are often used to wipe hands and spills. Occasionally these "outside" items have been used and then hidden from the instructor (illegally dumped hazardous waste!").

CONCLUSIONS

The Green Squares Manufacturing game is an excellent hands-on way to introduce the concept of pollution prevention to undergraduate engineering and secondary school students. The game demonstrates both technical and non-technical challenges of reducing waste in an industrial setting and makes participants more aware of sources of waste, options for waste minimization, resistance to change, and the importance of communication and cooperation in waste-reduction efforts.

REFERENCES

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