CONSUMER PRODUCT ENGINEERING: A CASE STUDY OF AN ELECTRIC TOOTHBRUSH AND TOOTHPASTE

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Abstract - The hallmark of the newly configured Rowan College of Engineering undergraduate program is the interdisciplinary, project oriented clinic sequence that spans 8 semesters. This sequence is taken by all engineering students. In this paper, we specifically describe the innovative efforts in the second semester of Freshman Clinic that is devoted to competitive assessment through reverse engineering. Specifically, experiments on a low cost consumer appliance (electric toothbrush) and an important associated consumer product (toothpaste) are described. This will enable the freshman students to determine how scientific principles, material properties, manufacturing techniques, cost, safety requirements, environmental considerations and intellectual property rights impact the design of a product. Also, the students actively participate in a meaningful design effort by evaluating the performance of a consumer appliance.

Introduction

The College of Engineering at Rowan University is composed of four departments, namely, Chemical, Civil, Electrical and Mechanical Engineering. In each year, there are between 25 to 30 students in each department. This results in 100 to 120 students in the entire college. The size of the college has been chosen to provide specialization in small departments and permit the creation of a multidisciplinary curriculum in which laboratory/design courses are offered to all engineering students. The hallmark of the Rowan program is the interdisciplinary, project oriented clinic sequence. This 8 semester long sequence is taken by all engineering students.

The Engineering clinic is based on the medical school model and involves side by side interaction among students and faculty for performing laboratory experiments, design projects and research. Multidisciplinary design projects and laboratory experiments at the freshman and sophomore levels stress teamwork, implementation of engineering principles into practice, oral communication, and written communication [1][2]. In the freshman year, the theme of the fall semester is measurements [3] while the theme of the spring semester is competitive assessment (what this paper is about). Comprehensive one semester and two semester projects at the junior and senior levels (more discipline specific) give the students exposure to the nature of scientific research and provide the initial maturity to appreciate how research is carried out. Although many schools have recognized the need to integrate design into the freshman year [4][5], most traditional programs offer only a senior capstone design course and ignore the freshman, sophomore and junior years in terms of design and research activities. Therefore, at most institutions, undergraduate students will not be provided with the necessary skills to conduct independent research until well into the senior year.

The focus of this paper is on the second semester Freshman Clinic course known as Freshman Clinic II. In this course, the theme is competitive assessment through reverse engineering. The term competitive assessment has been coined by manufacturers to describe the process of ethically acquiring, inspecting, analyzing, instrumenting and testing the product lines of other manufacturers. Reverse engineering is the process of developing sufficient information about a product to allow replication with or without enhancement in original or current technologies, materials and manufacturing processes. The objective of competitive assessment through reverse engineering is to understand and outdo the competition. In the Competitive Assessment Laboratory at Rowan University, multidisciplinary teams of freshman engineering students from each of the four engineering disciplines perform competitive assessment on a consumer appliance (in this case, an electric toothbrush).

The objectives of the Competitive Assessment Laboratory are as follows:

1. Provide the launching pad for an innovative, four year design curriculum by introducing freshmen to the science and art of design by evaluating the work of practicing engineers.
2. Introduce multidisciplinary groups of engineering students to unifying engineering principles.
3. Enable students to determine how scientific principles, material properties, manufacturing techniques, cost, safety requirements, environmental considerations and intellectual property rights impact the design of a product.
4. Allow freshman students to actively participate in a meaningful design effort by evaluating the performance of a consumer appliance.

A general block diagram of reverse engineering and competitive assessment is given in Figure 1.

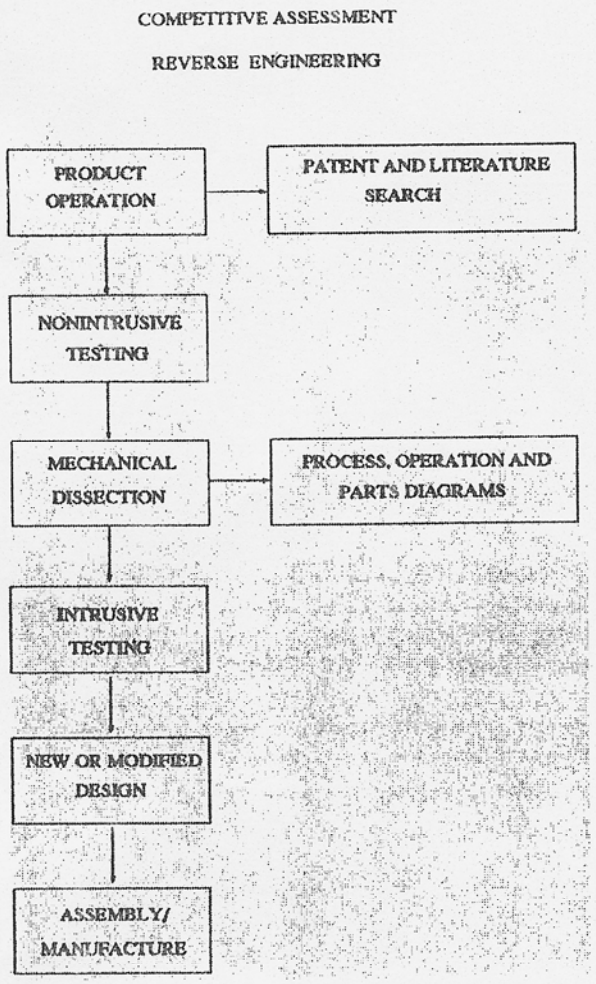

Figure 1 Block diagram of competitive assessment through reverse engineering

In the course, both nonintrusive and intrusive testing was done. The focus of this paper is on the nonitrusive testing of the electric toothbrush and the work on the toothpaste.

Nonintrusive Testing

Figure 2 shows the electric toothbrush that was used. For the nonitrusive testing, students were asked to:

1. Record all external features, observe safety features and identify potential hazards.
2. Comment on the ergonomics and aesthetics of the design.
3. Record external dimensions, make a list of parts and understand the function of the various parts.
4. Do AUTOCAD drawings of the entire toothbrush and the various parts with proper labelling and dimensioning.
5. Note all intellectual property rights (like trademark, patent numbers and registration).
6. Do a patent search of related patents on the Web.
7. Estimate cost of the product.
8. Check environmental feasibility in terms of recyclability and packaging.
9. Understand the operating instructions and operate the product.
10. Devise and perform an experiment to see how the electric toothbrush compares with a manual toothbrush in removing stains. Is the cost of the electric toothbrush justified in terms of its cleaning capability?
11. Recommend any improvements in terms of cost, manufacturing, aesthetics, safety and environmental issues.
12. Do a literature survey of electric toothbrushes available in the market.

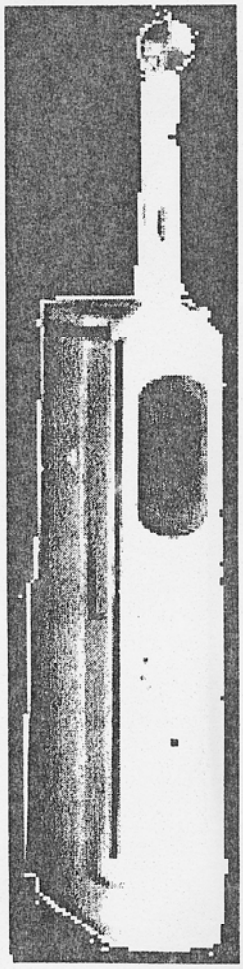

Figure 2 The electric toothbrush

Some of the observations and results of the above exercises are now given. Note that these results have been obtained by students working in teams under the direction of the faculty instructor.

1. External features:
   (a) Automatic shut off after 2 minutes of operation.
   (b) No metallic connection from toothbrush to charging surface.
   (c) Removable brush head.
   (d) Wall mounting capability.
   (e) Toothbrush will not switch on while charging.
2. Safety features:
   (a) O-ring seals and lubricant to prevent electrical hazard.
   (b) Hard and durable plastic casing to prevent shock during charging and when in contact with water.
   (c) Lack of orifices into the actual workings of the device to again prevent hazards.
3. Ergonomic and aesthetic properties:
   (a) Casing is shaped to fit the hand and hence, allow for easy grip.
   (b) Rubber on/off switch easy and comfortable to operate.
   (c) Convenient rectangular wall mount.
4. Environmental aspects:
   (a) Recyclable: Nickel cadmium battery, external packaging and operating instructions on paper.
   (b) Not recyclable: Brush heads, charger and body of toothbrush
5. Recommendations for improvement:
   (a) Operational tip is a puncturing hazard especially for small children. Protective covering is needed during routine changing of the brush head.
   (b) Base of handle can easily tip over if a small amount of pressure is applied. There is a need for greater stability.
   (c) Other components should be made recyclable.

The experiment to compare the electric toothbrush versus the manual toothbrush is very significant in determining whether the increased cost of the electric toothbrush is justified in terms of cleaning performance. Five teams determined the cleaning time for removing a tomato sauce stain on an enamel bowl. Statistics of the cleaning time were taken and are given in Table 1. The results indicate that the higher cost of the electric toothbrush is not justified. However, this is only a preliminary experiment that can lead to errors, particularly since the force applied to the manual toothbrush varies from person to person. Further investigation into this important issue is needed and more sophisticated experiments is a subject of further work. A literature search into how the company Braun compared the manual and electric toothbrushes will be done. The experiments done by Braun will be replicated by the students.

Toothbrush Test Class Statistics (Cleaning Time in seconds)		
Quantity	Manual	Electric
Number of teams	5	5
Mean	43.20	47.80
Standard Deviation	12.30	8.58
Minimum	31.00	41.00
Maximum	61.00	62.00

Table 1 Comparison of manual and electric toothbrushes

Toothpaste Experiments

Since a toothbrush is normally used with a dentifrice, various properties of commercial toothpastes were explored. Students were first given a one hour lecture on the chemical aspects of toothpaste and how it is manufactured. Then, students were asked to study and compare four types of toothpaste: cavity protection, gum care, tartar protection and sensitivity protection by doing the following:

1. Compare ingredients of the four types of toothpaste. Understand the terms active ingredient, vehicle, humectant, abrasive, sudser, buffer and binder.
   - Active ingredient: Ingredient that gives the toothpaste its drug and efficacy value and which distinguishes it from being a cosmetic.
   - Vehicle: The base ingredient in a toothpaste.
   - Humectant: Ingredient that retains mositure when the toothpaste is exposed to air thus retaining the glossy appearance.
   - Abrasive: Ingredient that removes debris and stains from teeth.
   - Sudser: Ingredient that loosens surface deposits.
   - Buffer: Ingredient used to maintain pH balance.
   - Binder: Enables the solid and liquid in the paste to stay together.
2. Measure pH, sagging behavior and specific gravity of the toothpaste and do a statistical analysis of the results in terms of mean and variance computation.
3. Devise experiments to do a taste test and appearance evaluation that involves the entire class since both aspects are very important for marketability. Do a statistical analysis of the results and see if any one type of toothpaste is better than the rest.

Table 2 gives a comparison of toothpaste varieties.

Toothpaste	Cavity Protection	Gum Care	Tartar Control	Sensitivity Protection
Active Ingredient	Sodium Fluoride	Stannous Fluoride	Sodium Fluoride	Potassium Nitrate, Sodium Fluoride
Vehicle	Distilled Water	Distilled Water	Distilled Water	Distilled Water
Humectant	Sorbitol	Sorbitol	Sorbitol, Glycerin	Sorbitol, Glycerin
Sweetner	Saccharin	Saccharin	Saccharin	Saccharin
Abrasive	Hydrated Silica	Hydrated Silica	Hydrated Silica	Hydrated Silica
Sudser	Sodium Laryl Sulfate	Sodium Laryl Sulfate	Sodium Laryl Sulfate	Sodium Laryl Sulfate
Buffer	Trisodium Phosphate	Sodium Gluconate	Tetrasodium Pyrophosphate	Trisodium Phosphate
Binder	Xanthan Gum	Hydroxethyl Cellulose	Xanthan Gum	Xanthan Gum, Cellulose Gum
Color	Blue	Titanium Dioxide (opaque)	Blue	Titanium Dioxide (opaque)
Feature(s)	To fight cavities	To reduce gingivitis; cavity prevention	Tartar prevention; cavity prevention	Sensitive teeth pain prevention; cavity prevention

Table 2 Comparison of toothpaste varieties

Type \ Statistic	Cavity Protection	Gum Care	Tartar Protection	Sensitivity
Mean Score	4.0	1.9	3.9	2.1
Median Score	4.0	2.0	4.0	2.0

Table 3 Appearance scores of toothpaste varieties

Type \ Statistic	Cavity Protection	Gum Care	Tartar Protection	Sensitivity
Mean Score	3.3	1.4	4.4	3.3
Median Score	3.0	1.0	5.0	3.0

Table 4 Taste scores of toothpaste varieties

To do the appearance and taste tests, each student evaluated the appearance and taste of the toothpaste varieties on a scale of 1 to 5. The 1 indicated the lowest score while the 5 indicated the highest score. Over the entire class, the mean and median scores were computed. Tables 3 and 4 show the results. By doing the statistical analysis and observing that the mean and median are close in value for the appearance tests, students concluded that there were no outliers in the experimental data. However, for the taste test, there are possible outliers which were identified by the students. Therefore, students not only calculated two important statistical quantities, but also understood the concept of statistical outliers. Students also learned how to interpret Tables 3 and 4 and concluded that the toothpastes for gum care and sensitivity protection need to be improved for appearance and taste.

Summary

The clinic course gives the freshman students:

1. Hands-on exposure to the electric toothbrush and toothpaste.
2. Computer skills in terms of using AUTOCAD and the Web.
3. An understanding of safety, aesthetics, cost, environmental issues and efficacy of a product.
4. Some exposure to entrepreneurship in terms of comprehending about intellectual property and patents.
5. An opportunity to devise their own experiments.
6. The ability to do a statistical analysis.
7. Training in effective oral and written communication. Students are asked to do Microsoft Powerpoint presentations of their work. Also, formal reports were written that included a cover sheet, table of contents, executive summary, narrative describing and analyzing all the work, list of references and appendices (includes a glossary and one page resume).

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