MECHANICAL ENGINEEING DIVISION:

TEACHING ENGINEERING ETHICS IN MECHANICAL ENGINEERING DESIGN PROJECTS

Francis A. Di Bella, PE
Assistant Professor, Northeastern University
Boston, MA 02131
(617-373-5240; fdibella@coe.neu.edu)

ABSTRACT

How and when should engineering ethics be taught in a typical four-year engineering curriculum? Should ethics instruction be left to the individual's own morals education after graduation and thus classroom time spent on more tangible subjects? This paper advocates the teaching of engineering ethics in the classroom but also suggests that there is a rational and realistic way of merging the subjects of engineering ethics and engineering design. This paper will describe the manner in which the author has been able to seamlessly insert the instruction of engineering ethics into the Capstone Engineering Design course. The Capstone Design course is required of senior engineering students before they can graduate from an ABET accredited institution. This paper gives examples of how the problem of instructing ethics is forced by the Instructor to literally "sneak up" on the student when perhaps the student least expects it: when the student is in the thralls of solving a difficult problem with no time remaining on his/her schedule and with limited resources to handle the intrusion. In other words, a situation that is the prefect model of what the student will experience after graduation when there are no visible red flags that warn of impending danger.

INTRODUCTION

Teaching the "art' of mechanical design is considered by some to be a very difficult, almost ephemeral exercise. As difficult as it may be, it does not compare by an order of magnitude to trying to teach engineering ethics to the overworked and (typically) the under 21, engineering student. In fact, the instruction on engineering ethics can be and often is encapsulated into its own course within the engineering curriculum. In that event the student is already "standing guard", waiting for the ethical dilemma to be pronounced for which even the most naïve student would be prepared to denounce the unethical maneuver. It is rather like the salesman who makes an appointment to see the busy engineer rather than just pounce on the engineer unannounced. While this is the courteous and professional way for the salesman to present the new products to the engineer it also

Proceedings of the 2002 American Society of Engineering Education Annual Conference & Exposition

suffers the possibility that the engineer will have time to rationalize reasons why the salesman's product is not suitable for purchase.

What then is an appropriate honest and realistic exercise for to test the student's understanding of the wide subject of engineering ethics? There must be a better way to "test' the engineering student in the many faces and the many wiles of the ethical dilemma that the student will likely face in the near future. This author has found some success in catching the student "off guard" by poising an ethical dilemma in the mists of a routine engineering design exercise. In this manner, the student is required to stop and think in order to evaluate a rational and ethical solution to the problem at hand. By surreptitiously presenting the ethical dilemma to the student, the student is exposed to the problem in a way that most closely represents how the ethical dilemma would be presented in the real world of engineering.

Some Ethical Challenges and Examples of Instruction

The author finds some comfort in presenting an ethical dilemma to the student when the student is in the mist of a mind absorbing exercise offered in the Machine Design course. This is particularly effective when the machine design course is combined with the traditional Capstone Design Project Course (typically taken by the senior engineering student). During this course instruction a full range of diverse design topics are discussed. Examples of mechanical design techniques must be given via a variety of design projects whether they are 'real-life' engineering examples or purely conceptualized solutions to a problem. During this instruction there is ample opportunity to poise (some students might say "foist-upon" is the correct phrase) the unexpected, ethical quandary onto the student.

Examples of this method from actual classroom instruction follow.

Example of Ethical Dilemma No. 1: The Vehicle License Plate Lighting System

The author as an instructor for the Capstone Design Project requires that the student keep an engineering journal. The journal is intended as an immediate and omni-present repository for the student's ideas, inventions and solutions to the capstone project that is immediately on the students To Do List. In a way of encouraging the use of the Journal the Instructor also maintains his own engineering journal that is always "a work in progress". Most importantly the journal perfectly suits the requirements of the instructor who is actively involved in professional engineering and thus must professionally maintain the journal. This affords the perfect opportunity for the instructor to demonstrate (too often, if you ask the students being instructed) how and why the journal is important to the education and the developing professionalism of the engineer. With the Instructor's admonition: "Keep the Journal with you at all times in readiness for the whimsical idea or perfect solution to a present or a future[1] problem", the Instructor attempts to set a good example for the students by way of using the journal as intended: to sketch problem solutions for problems that arise at any time.

[1] Indeed a journal entry can provide a solution to a future problem in a phenomenon that the author calls the DvD or Déjà vu Design attribute of the journal entry. This phenomenon identifies a solution that is made in the journal for a present engineering problem but one that does not ultimately gain acceptance as the immediate solution. But then, as if by plan, the solution is found to be perfect for a problem that arises sometimes years later.

As an example of this journal application, the instructor identified a perfect solution to a very straightforward problem that had occurred during a recent trip on the Massachusetts Turnpike. The problem stems from traffic backing up at the tollbooths on the Turnpike exits. While the majority of drivers sit in traffic waiting to pay their toll with cash, other motorists (in the minority) are quickly paying their toll without even stopping by using the latest and greatest in electronic instruments: the transponder. The transponder is mounted to the vehicle on the drivers side of the dash board and debits a toll charge as the motorist motors through the toll at 15 mph.

While expressing the often repeated mantra: "I've got to get one of those" the instructor enters a sketch in the journal depicting a vehicle license plate that can be flooded with white light in such as manner that a vehicle without a transducer can pass (at 15 mph) through he tolls WITHOUT being debited the charge for the toll and without being detected by the cameras that are installed at the tools to photograph the transgressors. The white light that floods the license plate serves to obscure the plate so that the vehicle cannot be identified. The instructor finishes up the sketch with labels and a Problem Statement and Solutions and presents the results to the class at their next meeting. Fig. 1 is a copy of this journal entry. The solution is presented to the students as a perfect example of how the journal should be used to capture a spur of the moment solution to a problem at hand. It is after all an engineering solution to a rather expensive and time-consuming chore: waiting at the tollbooth to pay a dollar or more for the privilege of using the turnpike.

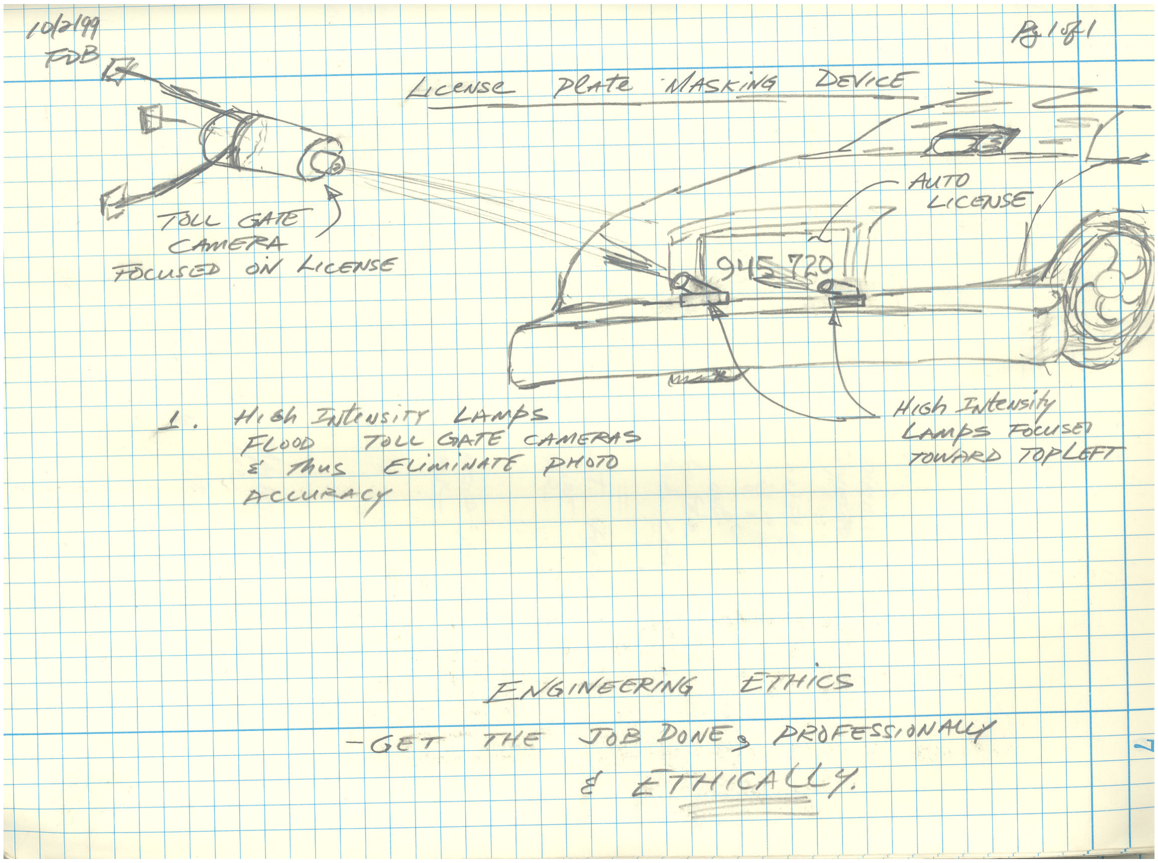
What could be simpler to design: a mini-light powered by the car battery and turned on by the driver whenever needed; even if the "whenever needed" seems to always coincide with the need to drive through the tollbooth without paying.

Having presented this result, the Instructor waits for a response and/or comments form the students. The instructor is not disappointed.

Without exception and to the credit of the students this example of how the journal should be used usually provokes more than one student to scream-out the ethical dilemma of the instructor's solution. "But...but Sir, isn't the use of engineering to solve this sort of problem unethical if it is to be used to escape from paying a toll? "

The point thus made, the Instructor uncovers the only part of the viewgraph that had been hidden from the students' view indicating, indeed that the proffered engineering suggestion is indeed unethical.[2]

[2] National Society of Professional Engineers Code of Ethics, Part III, Section 1: Engineers shall be guidedin all their professional relations by the highest standards of integrity, Section 3. Engineers shall avoid all conduct or practice, which is likely to discredit the profession or deceive the public.



Discussion can now be focussed upon similar but more significant ethical dilemmas that may face the student. What about radar detection monitors for citizen automobiles? What about designing an automobile to go over 120 mph when most (all) states have speed limits that do mot exceed 75 mph? What about building an automobile like the Ford Pinto compact that was designed to meet the 2000 by 2000 indict of the CEO. (i.e.: 2,000 lbf of automobile for $2,000 (in 1973 dollars)). Why not design gas tanks with collapsible bags that can not only survive a rear end collision but also reduce the amount of volatile gas compounds from leaving the vehicle upon each refueling at the gas station.

These and many more questions come forward when the ethics topic is brought to the attention of the student in this rather round about way.

But perhaps the instructor's guise was transparent after all. Another example of this method of ethics instruction follows.

Example of Ethical Dilemma No. 2: Feasibility Analysis of Energy Generation Opportunities in Skyscrapers

For the sole purpose (it would seem to the students) of instructing Capstone Design students in the fine art of preparing a Feasibility Analysis and Technical Report, a virtual client is invented who desires to have an analysis performed on the most effective method for generating power in skyscraper buildings. The virtual engineering company that is chosen to do this study consists of the Instructor (General Manager for the Virtual

Company and Project Manager for the proposed project) and the students who are to represent the full array of engineering talent: mechanical, electrical, control, computer, manufacturing, etc. The problem is to be solved using the Design Process Methodology that is the principal purpose of the course. A Problem Statement is generated, the customer requirements are clearly determined via interviews with the virtual client (the instructor plays this role as well) and a brainstorming session is conducted during which time many concepts for generating power using the height of the building is identified. Once the concepts are identified a small feasibility analysis is conducted on each to determine their relative merits. This entire process unfolds in front of the students in approximately six classes, during 2 full calendar weeks. The students are completely focused on the use of the Design Process Methodology and not at anytime are there the prospect that there is an ethics lesson hidden within the course content. And this is where we pick up the instruction in a little more detail.

The Instructor (a.k.a. Project Manager and General Manager of the company) survey the various concepts that have been generated by the engineers (students). Wind turbines, solar energy, hydro electric power generation using rain water stored on the roof, hydro power generated by free fall of water drained from the lavatories on each floor, air stream power recovery from the elevator shafts that generate wind from the stack effect and finally, the announced favorite of the General Manager (Instructor), the stress-strain energy stored in the building's superstructure as the building strains against the forces of the wind.

The later is a favorite of the General Manager of the virtual company because it has never been done before and this is an opportunity to utilize ingenious stress-strain energy to electric power device that was invented by the General Manager for much smaller applications. This is the perfect opportunity for the invention to be demonstrated to its full potential- and it certainly doesn't hurt that the patent was recently awarded to the General Manager.

The feasibility analysis performed by the company engineers has clearly identified the relative magnitudes of the power (kW) and the energy (kWh) that is recoverable from each of these power generation opportunities. This summary is reproduced in Table 1. The order of priority is to be given in the engineer's Report to the virtual client along with the engineer's recommendations. The engineers (i.e.: the students) must give the client their professional opinion as to the value of each of these energy generation solutions and also professionally recommend a course of action. The strain energy solution is, unfortunately for the General Manager, the lowest power recovery opportunity on the list. However, the General Manager is adamant that all of the data be given to the client with a recommendation that Report not completely eliminate the possibility of the stress-stain solution. The General Manager's instruction to the engineering team is made clear: "Let the client decide which solution is best. Let's also include a ready-made drawing of the stress-strain power system that could be scaled up to provide a workable system if the client wants to pursue that option"

TABLE 1. SKYSCRAPER POWER GENERATION OPTIONS						
INPUTS:	COMBINED POWER	WIND POWER GEN.	SOLAR POWER GEN.	WASTE WATER POWER	PNEU. COLM PWR.RECOV.	STRESS STRAIN ENERGY
HEIGHT ,ft =	1,000	100	1,000	1,000	1,000	1,000
STORY HEIGHT, ft.=	13	13	13	13	13	13
ROOF-to- BASE AREA=	0.30	0.30	0.30	0.30	0.30	0.30
OCCUPANTS per FT^2.=	100	100	100	100	100	100
WATER USE (gal./per.)=	2.5			2.5		
WIND TUR. SPACING, ft.=	6	6				
ELEV. USE FOR *PCPR*=	25%				25%	
WIND TUR. VERT. HT., ft.=	26	26				
PINNACLE TURB. Ht.,ft.=	0	0				
TURBINE MECH. EFF.=	30%	30%		30%	30%	
WIND. DAILY UTILIZATION=	75%	75%			100%	
MECH. -to- ELEC. CONV.=	80%	80%		80%	80%	
TUR. DIA. -to- SPACING=	75%	75%				
SOLAR INPUT,Btu/Hr./ft^2=	300		300			
SOLAR DAILY UTILIZATION=	65%		65%			
SOLAR PNL. ROOF FRAC.=	75%		75%			
SOLAR PANEL CONV.EFF.=	15%		15%			
DC -to- AC CONVERSION=	99%	99%	99%	99%	99%	99%
SOLAR FACADE HT.,ft.=	26		26			
PNEU. PPRC, VEL., ft/s=	66				66	
ELEV.SHAFT AREA,ft^2=	144	144	144	144	144	144
PEAK WATER FLOW, Hr.s=	1.0			1.0		
BUILDING ELEC. DEMAND, W/ft.^2	2.5	2.5	2.5	2.5	2.50	2.5
OUTPUTS (Part 1):						
EFFEC. FLOOR UTIL.=	73%	80%	73%	73%	73%	73%
AREA OF BOTTOM FLOOR.,FT^2 =	36,000	1,000	36,000	36,000	36,000	36,000
WIDTH OF BLDG. @ BASE, ft=	190	32	190	190	190	190
WIDTH OF BLDG. @ TOP, ft.=	104	17	104	104	104	104
EFFEC. FLR. AREA, Ft^2=	1,400,000	10,000	1,400,000	1,400,000	1,400,000	1,400,000
No. OF OCCUPANTS=	14,000	1,000	14,000	14,000	14,000	14,000
SPEED of ELEVATOR, fpm =	880	-704	880	880	880	880
No. of ELEV.s in BLDG. =	18	0	18	18	18	18
No. of ELEV. Used w/ PCPR=	4				4	
Vwind @ BLDG. TOP, ft/s=	32	22		32		32
No. of TURBINES INSTALL.=	52	8				
TOTAL Gals./Day OF WATER	35,000			35,000		
PEAK WATERFLOW,gpm=	156			156		
PNEU. POWER REC. Dp,psi	0.52				0.52	
NET WIND LOAD ON BLDING, LBf=	266,787					266,787
NON-STORMING BUILDING SWAY, ft.	0.097					0.097
STRESS-STRAIN CONV. EFF.=	75%					75%
OUTPUTS (Part 2):						
POWER & ENERGY RESULTS:						
TOTAL WIND POWER, Kw=	103	5				
WIND ENERGY/DAY,KwH	1,846	98				
ROOF SOLAR POWER, Kwe	106		106			
ROOF SOLAR KwH/Day	825		825			
FACADE SOLAR POWER,Kwe	26		26			
FACADE SOLAR, KwH/Day	206		206			
TOTAL HYDRO,KwH/Day	16			16		
PEAK HYDRO POWER,Kwe	4			4		
PEAK PNEU.(PCPR) PWR,Kwe=	2425				2425	
PNEU.(PCPR) ENERGY,KwH=	48497				48497	
STRAIN ENERGY (KWH)	0.004					0.004
BLDING DAILY AVG. PWR., Kwe	4773	31	4773	4773	4773	4773

The reports are worked on by the students and submitted for his review. Many of the reports submitted give the stress-strain energy, power generation option a favorable and/or less then a denigrating review. Several recommend that the strain energy method for power generation be considered for further work if it the virtual client options to so after reading the report. Only a few completely disregard the strain energy as a viable generation option except to list it in a summary table (Table 1) where it's deficiency can be judged by the customer, assuming that the customer can glean the engineering data from the Table. Fewer still suggest that the virtual client should be told out-right that the stress-strain method is not recommended for further consideration.

Abandoning the role of General Manager, the Instructor now ‘returns’ to the classroom to assume the Instructor’s roll again. This roll that is most suitable for instructing these students in engineering ethics, particularly the unsuspecting type- the kind that creeps up to you and surprises even the professional engineer when its least expected.

The reports are technically graded and then graded for ethical considerations; the later grade not expected by the students.

The students are then given a review of their reports for their technical content (generally very good) and for their ethical status. Here the judgement is more severe if also very opinionated. Witness the paraphrased Questions and Answers by the Instructor and the students, respectively.

QUES.: Why was the strain energy concept given more weight then the technical results could justify?
ANS: Because the General Manager wanted the stress-strain energy solution to be highlighted in the report to the customer.

QUES.: Why does the technical results not over ride the business judgement of the Gen. Manager and why did not some of the engineers simply state the inferiority of the strain energy solution to the Gen. manager if not to the client?
ANS.: Because the General Manager knows the results and understands it and still wanted the results to be given to the client as a possible solution. It is the Manager’s responsibility…it’s his call. What harm does the Report do the client... its not life or death?

The engineer always has the responsibility of instructing the client (who pays the bills) in what is the correct action to take based on the best professional engineering opinion that the engineer has to offer[3]. The General Manager is certainly deserving of a complete explanation of how the results were obtained to be sure that no error was committed or that the engineers who performed the analysis did not misunderstand the client’s requirements. However, the General Manager does not deserve unconditional obedience from the professional engineer when that obedience requires falsifying or even obscuring analysis to the detriment of the customer or the public regardless of the benefit to the company and./or to the manager.

Hopefully the students have learned a strong lesson about engineering ethics using this “bait and switch” format. It certainly focussed the attention of those students who

[3] NSPE Code of Ethics. Fundamental Canons. Engineers in the fulfillment of their duties, shall No. 4 Act in professional matters for each employer or client as faithful agents or trustees and No. 5 Avoid deceptive acts in the solicitation of professional employment.

received a poor “ethics” grade when least expecting it; a small price to pay for a valuable lesson learned.

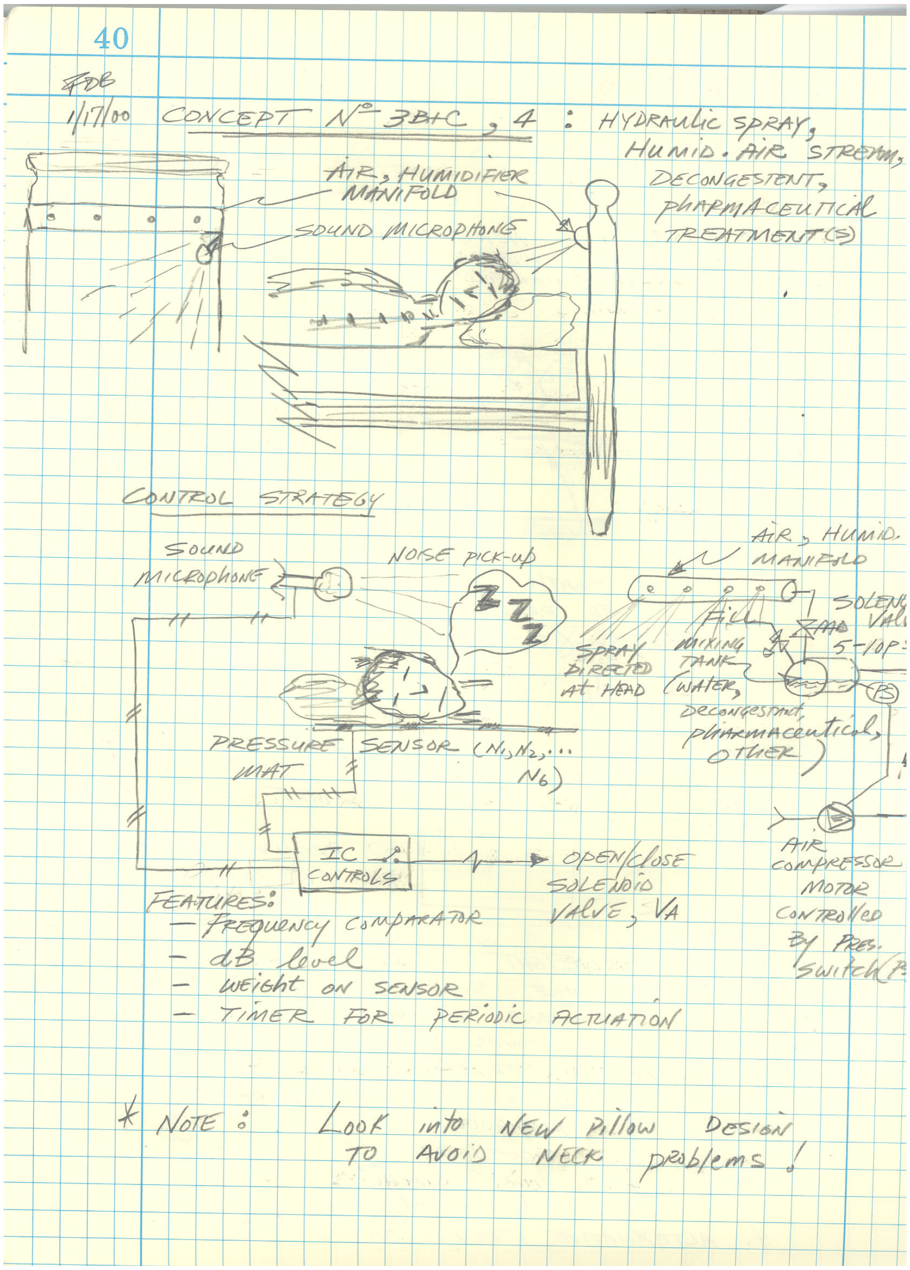
A final example of the suggested technique for administrating an engineering ethics lesson within the context of engineering design instruction.

Example of Ethical Dilemma No. 3: The “Sandman” Design Project
An actual, but very much tongue-in-cheek, article by a local magazine editor suggested to her reading audience that it would be very prudent to pay a sleep attendant (much like one pays for a live-in maid or nanny) to administer gentle but persuasive nudges to a sleeping partner who has begun to snore uncontrollably. The snoring is otherwise likely to effect the sleep of the innocent partner if it is not curtailed. The consequence of this article for the Instructor was another project theme with which to teach engineering students the Design Process Methodology (DPM). After all, or so it is reasoned by the Instructor, if the Design Process Methodology could be applied to this problem, then it can be applied to any problem that the student may be exposed to in their engineering careers. Certainly, the human sleep attendant solution offered by the magazine writer could be replaced by some electrical-chemical-mechanical device in order to have some reasonable attempt to demonstrate the strengths of the Design Process Methodology to a mechanical system.

Once again, after suitable time is spent in determining a precise Problem Statement, determining the customer and engineering specifications, conducting a brainstorming exercise and several feasibility analysis on those concepts, the student is ready to focus on a single concept (after conducting a suitable Pugh analysis) to pursue toward a preliminary design. The strongest solution derived from all of the proceeding efforts (conducted over a 3 to 4 week period) consists of an electro-mechanical system that has sound sensors that can detect when snoring has begun and upon recognizing the raspy noise of a typical snore, the instruments trigger the administration of a *medicated* (emphasis by the author is intentional here but the word was not emphasized during class time instruction) air spray from the head board of the snorer’s bed which has been specially designed as a sleep aid. Figure 2 (a reproduction of the Instructor’s journal entry) diagrams this solution concept and was directly copied from the engineer’s journal. The Instructor also assigned the trade name: **Snore-*be Gone*** for future marketing purposes.

The operating principle of the solution is based on the (documented) premise that snoring is sometimes caused by dry air that has dried the snorer’s air passage membranes so that breathing has become constricted. The medication was added to the spray based on the research by the instructor who found that there are medications that can relieve snoring symptoms. The application of the spray also provides a subtle touching of the patient’s face (via the jet spray) so that the patient is sufficiently irritated, even while asleep, to try to move out of the way of the administered spray. That forced, albeit involuntary, movement itself helps to stop the snoring; as any awakened sleeping partner that nudges the offending party is willing to testify.

Proceedings of the 2002 American Society of Engineering Education Annual Conference & Exposition



Voila… problem solved! The patient has stopped snoring; at least according to the theory, properly referenced in the available literature, as applied by the students and the helpful instructor.

So where is the ethical violation or concern?

None to be found actually…except:

Ques. from the Instructor: Which one of you (students) has the medical degree and hence can prescribe medicine?[4] Which of you students has some understanding of the medicine that has been listed in the Bill of Materials for the **Snore-*be Gone*** system. Who among you has the technical experience or educational background to recommend that the medicated spray be administered in lieu of the patient seeing a medical doctor (as opposed to a Ph.D. degreed engineer!) to be sure that the snoring is not symptomatic of a more ire malady not yet diagnosed by the engineering students. Which students have affixed a warning label to the Operator's manual that states the user should first check with his/her doctor before using the **Snore-*be Gone*** system to eliminate the snoring problem. Which of the students has, during the literature search or when determining the customer and engineering specifications, called a doctor or nurse for recommendations for administrating the drug in the dosage prescribed and how is that dosage monitored to insure that the dosage is correct upon each triggering and for each snoring patient, young or old?

Once the ethics lessons have been provided by the Instructor, the most disheartening aspect of the instruction to the student is the realization that their short sightedness in not considering the ethics of the design will compromise all of the work (3-4 weeks) up to this point. They must now research another design solution to the snoring problem.

The Instructor's lament: "Let's begin again, from the top!" is perhaps the final (the best?) lesson taught and learned in the entire exchange or, in the words of Winston Churchill: **Never Give Up! Never Give Up! Never Give Up!**

Conclusion

The answers to questions in engineering ethics are not obvious sometimes simply because the professional is caught off-guard by them. The question of ethics in these true-to-life design studies were never directly brought to the attention of the students just as they will never be a forewarning of imminent ethical dangers in real-life engineering practice. The need for constant vigilance for the potential violation of engineering ethics must be identified to the student as their responsibility. They must assume the roll of a wary attendant as well as the competent engineer once they join the engineering profession. It is suggested that weaving ethics instruction within the 'normal' engineering course work can be an effective means of accomplishing this task. It also has an added benefit: the Instructor is constantly reminded of his/her ethical responsibilities while trying to instill some ethical conscience in the students.

Biography:

Francis A. Di Bella, PE is an Assistant Professor, Northeastern University, Boston, MA.; College of Engineering , School of Engineering Technology. Mr. Di Bella's professional engineering research interests involve the practical, engineering applications of Thermo-fluid and Machine Design sciences within the Mechanical Engineering discipline.

---

[4] NSPE Code of Ethics, Fundamental Canons Section I: Engineers, in the fulfillment of their professional duties, shall: No.1 Hold paramount the safety, health and welfare of the public in the performance of their professional duties, and No. 2: Perform services only in areas of their competence.

Specific areas of interest include all aspects of energy systems including generation, storage, conservation and a variety of innovative applications of wind, solar and hydropower. Such systems and their application include gas and steam engines (reciprocating, gas and steam turbines) with steam generation and steam turbine cogeneration of ancillary power. Engine power augmentation including turbo compounding, micro-turbine power generation using turbo-charger machinery for stationary electric power generation and use. Interest extends to the thermodynamic modeling of cogeneration systems and their size vs. cost optimization. This interest is exhibited in course instruction in heat transfer, thermodynamics, fluid dynamics.

Prof. Di Bella is also involved in all aspects of creative product concept genesis, design and product development. Product development extends the gamut from systems to prevent Road Rage to emergency repair of ruptured natural gas pipelines. University application of this interest includes instruction in the following courses: Machine Design, Statics and Dynamics, Intro. to Design and Intro. to Product Design as well as student Capstone Design Projects. He is also the Faculty Advisor for the Student's Mini-Baja vehicle competition.