Engineering Design Lessons Taught and Learned: The Sandman Project
An Example of the Teaching of the Design Process Methodology

Design = ∫(Art + Eng.)•d(science) + exp(time) ®

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ABSTRACT

This paper presents a brief tutorial of the Design Process Methodology[1] as a means of solving an engineering design problem. The Case Study used for this demonstration of the Design Process Methodology was: How to stop a person from snoring. The problem is not exactly the most mechanically inspiring design topic but was selected in particular for its abstractness from an article written by Ms. Catherine Foster entitled 'Mr. Sandman', published in the Boston Globe magazine on Sept. 5, 1999; coincidentally the first week of Machine Design class. It's selection as a theme for demonstrating the design process was based solely on the expressed intent of the Instructor to select an arbitrary problem which could serve as a spring board for demonstrating to Senior Engineering students the effectiveness and power of a well defined Design Process Methodology to creatively solve even the most undefined engineering problem. It also served as a step by step working example of how the students were to proceed in solving their own design problem; a concurrent design effort to satisfy the Accreditation Board for Engineering and Technology (ABET) Capstone Design Project requirement. The paper proceeds from Problem Statement through a defined Design Process Methodology using contributions from a variety of familiar academic resources. The paper is thus intended to offer a single source (albeit: very brief) of information for Instructors and Students alike, that describes the methodical engineering design process of arriving at a creative solution to engineering design problems while also demonstrating how this process leads to unexpected benefits. Chief among these benefits is the bolstering of the student's resolve and confidence for engineering design; resolve that does not diminish their sight of the goal despite the obstacles that are encountered and personal confidence in their engineering talents that are sharpened with each design success.

[1] A full length Primer is being drafted for future, formal publication.

INTRODUCTION:
Teaching the Design Process has always been a particularly difficult exercise for the engineering teaching profession. In its simplest definition, the Design Process is an integration of Art plus Engineering Science with a little experience that grows with time, thrown into the mix.

-OR- for the 'left brain' readers among us[2]:

$$\textbf{Design} = \int (\textbf{Art} + \textbf{Eng.}) \bullet \textbf{d(science)} \quad + \quad \textbf{exp(time)}$$

Engineering instruction has a long and productive history of teaching the engineering and the science of this equation. But how is the Art factor to be taught? There is consensus as to what constitutes a good Design Process Methodology (DPM) that helps the student to a solution to a well-defined problem (ref.s 1, 2 & 3). The teaching of the 'Art' part of the equation is recognized to be the more difficult because it requires (assumes) that creativity, the essence of Art in any human endeavor, can be taught. While it is arguable whether creativity can be taught, it is certainly less arguable that creativity can at least be demonstrated and even improved upon; honed to a razor edge to solve the most obtuse of engineering (even life's ?) problems. If an engineering solution can be demonstrated for an interesting although (admittedly) whimsical project then, it is hoped, so may the students comfortably deploy the design process to more straightforward and rewarding exercises. It is the purpose of this paper, to support the contention that creativity and art in an engineering problem solution can be demonstrated to the students in a manner that then promotes creativity in the engineering student. Thus, the Design Process Methodology helps to bolster the engineering student's natural abilities and to establish a personalized technique and talent for creative problem solving.

This paper will detail an Instructor's personal Engineering Design Project that was presented to senior engineering students as a 'work in progress' ostensibly to facilitate the completion of their own and more significant Capstone Design Projects. The actual step-by-step engineered solution to the problem at hand was carried out by the Instructor literally in front of the students and in parallel with their Capstone Design projects. In this manner, as a particular step in the design process was taught to the students it was actually also demonstrated to the students in the context of solving the Instructor's Project. This contributes at least two strong benefits to the teaching and the learning of the design process:

1. The design process is actually applied to a project that the instructor has not already solved. The creative design process literally unfolds in front of the student, with all of its unplanned twists and turns; its false starts, its inevitable 'one step backward and two steps forward' pace, but also, hopefully, its sometimes surprising successes that lead to logical conclusions. The students in fact contribute to the creative solution to the Instructor's Project.

[2] Right-brained readers need not panic. This is the only equation that appears in this article. To the left-brainers: DO NOT attempt to solve this equation at home; it does not have a unique, closed form solution. It is also on its way to becoming a bumper sticker for the "in crowd" of engineering enthusiasts!

2. The second and I believe very important benefit in this method of instructing the Design Process is that the Instructor actually solves a problem that he/she has seen only for the first time with the students. Although the unfamiliarity can be very disconcerting and requires considerable course preparation (so what's new!), the immediate effect of having one or more "Eureka" episodes with the student, as an interesting piece of the puzzle actually gets discovered/invented and falls into place, is as exuberating and rewarding for the Instructor as it hopefully is for the student.

PROBLEM SELECTION:
Using the 80/20 Rule, 80 % of the difficulty in solving an engineering problem is selecting the correct problem to solve; at least according to this Instructor. Thus, to select a significant problem one should resort to searching for the needs of a particular Customer or the Public in general. The student was constantly reminded that engineering is one of the most human of endeavors. Abraham Maslow (a founder of the field of study known as humanistic psychology) is renown for having sorted out the basics of human needs. First: shelter, food and security and then: education, introspection and the luxuries that are required to advance a civilized culture. All of these needs require problem-solving people, otherwise known as engineers. And the act of solving problems professionally and ethically is recognized as engineering. Thus the most reasonable area for searching for a problem to solve is among people or by reading of their exploits in the daily newspaper or listening to friends and neighbors who will quickly identify any shortcoming of the present technology.

The Instructor has found a wealth of significant Problems for previous Capstone Design classes by simply listening to people or reading all sources of information and always being receptive to new problems that need solution. For example, previous Capstone Project themes used by the Instructor included:

1. Developing a personalized skier escape mechanism that enables the safe removal of the skier from an avalanche of snow. This need was brought to the attention of any receptive reader after the local newspapers wrote about a recent catastrophe in Switzerland where a party of 14 school children were caught (and some died) in the recent event.
2. When a snow storm caught the driving public by surprise and many Sport Utility Vehicles (SUV's) were found entombed in large snow drifts, local radio announcers gleefully renounced the slick SUV advertisements that promise the SUV owner the ability to "…climb Mt. Everest". From this simple statement was born the clear need for an SUV Snow Removal System.
3. The design and construction of taller and taller sky scrapers anywhere in the world seemed to beg for the development of energy conversion systems that could take advantage of the 1,000+ ft. of skyscraper heights. Example: hydro turbines to recover lavatory drain water from the highest washrooms or how about an energy recovery system for the stress-strain energy produced when the tall buildings sway in the wind.
4. And certainly who would deny that there is considerable latent energy in earthquakes. So what can be done to harness this energy? Why not develop a machine that could capture this potential (soon to be kinetic) energy for the benefit and not the destruction of mankind.

All of these projects may be considered abstract or whimsical by some (all ?) readers yet their solutions are still amenable to Design Process Methodology (DPM). It certainly is true that the tackling any of these problems was an effective means of teaching the DPM to engineering students and that some very creative solutions were demonstrated while the students gained confidence in their abilities.

The subject of this paper is no less enterprising (some would say abstract) an engineering problem found in a whimsical need of a newspaper columnist Ms. Catherine Foster ("Mr. Sandman", Boston Globe Magazine, Sept. 5, 1999). Ms. Foster extrapolates a serious need for "...a sleep attendant...". That is, an attendant who would be paid to stay awake while you and your partner sleep. The attendant would be called upon to nudge, awaken, cajole or, in any manner possible, stop the other offending partner from snoring; thus ruining a perfectly good sleep for the innocent partner. Certainly, the Instructor quickly points out that this need can be solved, not with a human subject (as proposed by Ms. Foster) but rather a suitably designed machine or system. Thus was born a perfect Capstone Project for the Instructor to tackle for the two-semester term. It has all the prerequisite ingredients: an expressed need, an interesting and innovative "not so straightforward machine design problem", which would require some creative solutions for its complete solution and, yes abstract enough to be a good test of the Design Process Methodology, all the while keeping the students interested in the proceedings.

THE ENGINEER'S JOURNAL

One of the most important activities required for effective engineering design is the disciplined maintenance of an Engineering Journal. The Instructor enthusiastically promoted the keeping of an Engineering Journal throughout the class. The Engineer's Journal is a constant and faithful companion[3]; a 'never-leave-home-without-it" accessory, an always, positive receptor for the engineer who may need to perform periodic brain-dumps of any significant, innovative, creative solution to a problem. The Instructor encourages its use not only for the immediate course work but also for any problem that the student/engineer deems to be in need of a solution.

The Instructor also maintained a personal Journal (Avery Denison, No.43-648) during the course instruction not only as an example of the proper and effective use of the Journal but also because it's fun and sometimes even therapeutic: the Journal never agues about the craziness of the ideas expressed by the artist/engineer writing within its pages. The Instructor presented solutions to assigned as well as unassigned problems until, in many instances, the contents of the Journal became more interesting to the Instructor than, I suspect, to the student[4]. Thus, ALL of the engineering design concepts presented in this Paper have their origin in the Instructor's Journal. It is for this reason that some of the figures and tables used in this Paper are hand written or freehand sketched (with the Journal's grid as background) with no attempt to delete original misspellings or even dead-end designs. In effect the

[3] The Instructor's plea to have the journal keep them company even on dates met with only slight amusement before the Instructor was reminded that they were senior engineering students and don't have time for dating.

[4] It was therefore somewhat redeeming to have received a perfect grade from the course's Teaching Assistant who was requested to objectively grade all of the student's Journals; one of which was the Instructor's Journal which was suriptiously hid among the pile of the student's Journals using a nom de plume: R. Agostinelli.

Instructor's soul is laid bare here for all to see for the expressed and noble goal of the student's instruction and, perhaps, for a loftier position on Mr. Maslow's self-development pyramid. The author's Journal remains today a work in progress (up to page 79 already!) and a constant repository for ideas; large and small for the Instructor and hopefully, the student.

THE DESIGN PROCESS METHODOLOGY (DPM)-IN BRIEF (or Using PC vernacular: DPM-*lt*)[5]

Creative machine design or the Senior's Capstone Design Project can be imposing courses for an engineering student that has come to expect single answers (to four decimal places) to classical text book problems in Thermodynamics, Calculus and Fluid Dynamics, to name a few. The typical methodology for studying such traditional engineering subjects is to review the concepts, review worked examples presented by the instructor (hopefully these worked examples are derived from real-world engineering applications) and then apply these principals to homework problems of the same ilk. The good (or perhaps a better adjective is: trained) student quickly masters these chapter problems and moves on to the next chapters and their content of engineering principles that must be mastered.

Creative machine design imposes a different study discipline. Creativity, if not teachable can at least be demonstrated and fortified via continuous personal or mentored motivation and application of sound engineering practices. But is there a route that can always be taken to be assured of a successful design once the journey is undertaken? Certainly any such methodical process can not be as universally defined as the natural, physical laws such as Newton's Laws or the Laws of Thermodynamics. A review of many experienced engineers who have documented their 'hard knocks' learned work experiences in textbooks have separately contributed upon a Design Process Methodology which have, at least, visages of commonality. After a review of many such offerings (ref.s 1,2,3) it is suggested that the Design Process Methodology shown in Table 1 is worth considering in its ability to guide the student and engineering professional upon a road to a successful completion of an engineering project.

The process starts logically enough with the identification of a problem in a clearly worded Problem Statement.

PROBLEM STATEMENT

The Instructor's Project Statement was thus born from the need expressed in Ms. Foster's article**:**

To determine a means of stopping a patient from snoring without disturbing the partner.

This simple statement begins the engineering exercise by leaving many questions unanswered. For example: What causes snoring? What are some present, common ways to stop snoring? At what cost and ease may any of these competitive systems be used by the patient? What are the medical establishment guidelines for the treatment of snoring? Is snoring a sign of a more serious health problem? What are the customer's requirements

[5] The full length publication will provide more detail on the Design Process Methodology that is being summarized in this paper. The goal of this article is seen to be the strong suggestion as to how to teach the "creativity" aspect of the subject to the engineering design student.

(the snorer, his partner, etc.)? Can snoring be stopped by medication? What are the relevant engineering specifications and metrics that need to be identified to solve this problem if an innovative solution is to be proposed?

TABLE 1. SUMMARY OF DESIGN PROCESS METHODOLOGY

1. PROBLEM STATEMENT ~~CUSTOMER & ENGINEERING SPEC.S 2. CONCEPTUALIZE SOLNS. 3. FEASIBILITY ANALYSIS 4. PREL. ANALYSIS ~~MRKT. STUDY ~~ENGINEERING ANALYSIS 5. PREL. TECH. PROPOSAL ~~BUSINESS PLAN ~~ENG.G SCHEDULE & ~~BUDGET FOR LABOR/MATL.S	6. DETAIL DESIGN & ANALYIS 7. PROTOTYPE FAB. & TESTING 8. FINALIZE DESIGN, ASSY. And TEST BETA SYSTEM 9. MANUFACTURING SCALE UP ~~BLDINGS, TOOLING, STAFFING, SERVICE ORGANIZATION, SALES & MARKETING 10. PRODUCTION 11. PRODUCT PHASE OUT

The answers to these questions can be found in a focus group analysis or a literature search or queries to friends and family. For this project the student/engineer may need to journey no further than his/her own bed room to research a solution due to the occasion personal experience of elbows in the ribs after a horrendous night of fitful snoring.

The process quickly proceeds to an identification of what the Customer's needs and requirements are. These customer specifications can be simple declarative statements of what the customer expects the machine system to do as well as what it is expected to cost. It must be made clear here that the Customer is not only the tradition customer (i.e. one who actually purchases the system and uses it) but in the broadest sense includes the engineer's other 'customers', some would say Project partners, including the Manufacturing Department, the Marketing Department, the sheet metal or machine shop subcontractor who will need to bid on the individual elements of the machine, the Boss, the Bosses' boss, etc. All who have a need to effect the design of the machine so as to minimize development cost and product expense as well as to be able to utilize if possible existing machining techniques, tooling, materials experienced labor, etc. Once these specifications are identified, in short declarative statements, the Project Specifications are completed by identifying the engineer's specifications or 'metrics'. The metrics of a specification is definitive, quantifiable objectives that the system must meet. A system attribute can only qualify as an engineering specification if it has a physical unit or metric. For example, the system's weight is an engineering metric because it has units of lbf; system size can be identified with length units, ft or meters, etc. A customer may want the size of the systems to be "small" but the engineering metric for this customer requirement is ambiguous unless it is quantified as, for example, 2 ft. x 2ft. x 3ft. in order to qualify as an engineering specification. The entire customer-engineering-competitor specification is part of a formal process called Quality Functional Deployment (QFD This procedure has been adopted by the American engineering community after its successful deployment by the Japanese engineering community circa 1974. The Japanese engineering and business establishment introduced this technique to more formally determine a project's overall specification from a general "customer" viewpoint. That is, everyone who is effected by the project must have their points of view considered during its development from the earliest stages to its completion.

For the Sandman Project the student's and the Instructor participated in a lively discussion and interaction and served the roles of customer, engineer, marketing executive, manufacturing engineering, service engineering and legal authorities.). The result is a single document or Table that contains the Customer's and the Engineer's specifications. This document is often called the House of Quality because of its resemblance to a house that was likely to have been drawn as a child-the budding engineer. The House of Quality (HofQ) for the Sandman Project is shown in Figure 1.

TABLE 2. QUALITY FUNCTION DEPLOYMENT (QFD) CHART

Mr. SANDMAN "SNORE-be-GONE" PROJECT

1=design does not meet req. at all
2=the design meets req. slightly
3=the design meets req. somewhat
4=the design meets the req. mostly
5=the design fulfils req. completely

		WEIGHT FACTOR	CRITERIA SCORE	FINAL DES. SCORE	COST OF SYSTEM	SYSTEM SIZE	MAX. POWER REQ.s	SYSTEM NOISE	INSTALL TIME	SYSTEM WEIGHT		COMPETITIVE SYSTEMS: SURGURY	COMPETITIVE SYSTEMS: NOSE DROPS or APPLIANCE
1	NO DANGER TO USER OR PARTNER	*										5	4,3
5	DOCTOR APPROVED	0.15	10	1.5	9	3	3	9	1	~		5	5,5
3	COMFORTABLE	0.15	8	1.2	3	3	3	9	~	1		4	2,2
4	LOW COST	0.15	7	1.05	9	9	9	3	3	3		2	3,3
7	COMPACT, INSTALLED SIZE	0.15	5	0.75	9	9	9	3	9	9		5	5,5
8	RETROFITTABLE	0.15	4	0.6	9	9	9	~	9	9		1	1,1
12	WARRANTY FOR ONE YEAR	0.05	7	0.35	~	3	3	~	~	3		1	5,5
11	DURABLE	0.04	8	0.32	~	3	3	~	~	3		2	5,3
6	SMALL POWER SUPPLY	0.05	3	0.15	9	9	9	3	3	3		5	5,5
2	EASY TO CONTROL 'ON' or 'OFF'	0.05	2	0.1	9	~	3	~	~	~		1	5,6
9	EASY TO READ INSTRUCTIONS TO USE	0.02	1	0.02	1	~	~	~	3	~		5	3,3
10	Y2K COMPATABLE	0.01	0	0	~	~	~	~	~	~		5	5,5
14	PORTABLE	0.03											
13	NO NEW MATERIALS OR TECHNOLOGY	*											
15	LOW DEVELOPMENT COST	*											
16	LOW DEVELOPMENT RISK	*											
17	LOW DEVELOPMENT TIME	*											
18	LOW PRODUCT LIABILITY RISK	*											
19	LOW MANUFACTURING COST												
	*=asterisk means criteria is essential	100%											
	ENGINEERING UNITS				$	ft^3	Hp.	dB	MIN.s	LBf			LBf
	DESIGN GOALS				.lt. $250	1x1 x3	.lt. 1	40	60 (once)	.lt. 100			.lt. 100
	SURGURY				$10,000	0	0	0	0	0			0
	NOSE DROPS				$15/mo.	1" d. x 3"h	0	0	1 (each appl.)	0.2			0.2
	APPLIANCE				$500	.3 x.3 x.5	0	0	3 (each appl.)	0.1			
					9=strong relationship 3=medium relationship 1=weak relationship 'blank'=no relationship at all								
													11
		N	INDICATES No. OF ZEROS IN THE COLUMN BELOW ENTRY= VALUE OF SPEC. w.r.t. ALL OTHERS										
	BASIS	2	3	4	5	6	7	8	9	10	11	12	FINAL SCORES
2	EASY TO CONTROL 'ON' or 'OFF'	2	X	X	X	X	X	X	X	X	X	X	2
3	COMFORTABLE	1	7	X	X	X	X	X	X	X	X	X	8
4	LOW COST	1	1	5	X	X	X	X	X	X	X	X	7
5	DOCTOR APPROVED	1	1	1	7	X	X	X	X	X	X	X	10
6	SMALL POWER SUPPLY	1	0	0	0	2	X	X	X	X	X	X	3
7	COMPACT, INSTALLED SIZE	1	0	0	0	1	3	X	X	X	X	X	5
8	RETROFITTABLE	1	0	0	0	1	0	2	X	X	X	X	4
9	EASY TO READ INSTRUCTIONS TO USE	0	0	0	0	0	0	0	1	X	X	X	1
10	Y2K COMPATABLE	0	0	0	0	0	0	0	0	0	X	X	0
11	DURABLE	1	0	1	0	1	1	1	1	1	1	X	8
12	WARRANTY FOR ONE YEAR	1	0	1	0	1	1	1	1	1	0		7
		10	9	8	7	6	5	4	3	2	1	55	= (N)x(N-1)/2; N= 11

Figure 1. House of Quality for Quality Function Deployment (QFD)

House of Quality (HofQ) chart, part of the QFD process is broken into five basic parts:

1. The left-hand column identifies the customer requirements or needs.
2. The top row and the last five rows (below the bold horizontal line) identify the engineering specifications or 'metrics' to which the system must be designed.
3. Included in this row of engineering specifications are the values that are known for the Project's nearest competitor system. For example, several alternative methods for preventing snoring has been found to be surgery, nose drops or a mouth appliance. These have been listed in the far right hand columns.
4. The Weight factor and the Criteria Score columns are used to prioritize the importance of the customer specifications. The H of Q chart as shown in this paper is shown with the customer needs (1 through 19) already assigned a priority as determined by comparing every customer need with each other in a logical pair-wise comparison.
5. The body of the H of Q table consisting of entries of: tilda(~), 1, 3 or 9 determines the relative strengths of the engineering specification to the successful, satisfaction of the customer specification.
6. A sixth part of the typical H of Q chart is not shown in this example but is usually identified as the 'peak' of the Quality Functional Deployment house. It is usually placed above the top row (of engineering specifications) and identifies whether there are any

inherent conflicts between the engineering specifications chosen to define the new system that may result as a consequence of attempting to satisfy any of the customer requirements.

Given only this document, the reader should be able to answer the following question: Having reviewed this single document I know now what the Sandman Project customer needs are and how the engineers will accomplish those needs. If the answer is "Yes", then the House of Quality has done its job. If the answer is still "No", then the engineering team has more work to do to complete the Hof Q and better define the Project's objectives.

Brainstorming Techniques for Concept Genesis:

Probably the most interesting and always surprising exercises for the student as well as the Instructor is the generation of innovative, viable, creative ideas that could solve the Problem as stated. The most common form of idea generation is the use of brainstorming and/or morphological techniques. After all, the conceptualizing of brilliant solutions to a problem does not just fall from the sky or flash into consciousness. Or do they? A brainstorming exercise provides the techniques for free and uninhibited thinking which will hopefully lead to a creative and simple solution to the problem at hand. For the more straight-laced, systematic (left-brained, "B" quadrant) types among us, the morphological method is a little more methodical and thus more suitable for them to solve the problem.

There are a variety of brainstorming techniques but all have some commonality. All have a team of engineers (and sometimes non-engineering employees) come together in a closed room (only light refreshments, please, to avoid constant biological breaks and interruptions to the 'flow' as Mr. Csikszentmihalyi, ref. 9 would say) where a moderator simply writes on an easel pad or white/black board the spontaneously generated ideas for solving the problem at hand. The moderator's function is to sometimes light a spark to start the creative juices flowing when there's a lull in the group participation. There should not be any limitation to the suggested ideas. The moderator may (and in this author's serious opinion should) instill a sense of humor into the proceedings. Humor sometimes helps to free the participants from any subconscious taboos and/or preconceived limitations.[6] The source of these ideas is as varied and as imaginative as the participants are diverse. Paramount and literally the equivalent of the Ten Commandments all rolled up into The One Rule for these proceedings is that there is to be no pre-judgment of the ideas that are spilling forth from the group consciousness.

The Author has found that a two and three-dimensional brainstorming technique that was conceived by Leonardo da Vinci (ref. 7) and more recently and humorously promoted by Doug Hall (ref. 5) is particularly effective. The results if this technique for the Sandman Project is shown in Figure 2. The technique places the Problem Statement in the center of a very large black board or paper easel. The brainstorming then proceeds to surround this Problem Statement Island with other Theme Islands that could incite or seed the imagination with possible solutions to the Problem at hand. As the 2-dimensional brainstorming continues the satellite theme island ideas seem to beg that they be connected in some manner with pathways that could lead to viable solution(s). The Leonardo technique adds a measure of artistic

[6] The author will go as far as to declare that humor generally helps to accomplish the most difficult of engineering tasks, including writing ASEE papers as hopefully the reader will attest.

flourish to the contents of the islands. Where a normal, albeit talented engineer, might identify a solution as having a mechanical gear content to it, the Leonardo artist/engineer would draw a gear set (with perfectly meshing, pins for teeth-cycloidal profile gears were yet to be invented) to embellish the 2-dimensional construction[7]. It has long been acknowledged that pictures and not just words are more effective in stimulating the brain for more and better associations that can be linked to an ultimate solution to the problem.

The 3-dimensional aspect comes into play when the pathways to a successful solution become so congested (to maximize the association of these ideas) that you literally must use the third dimension, i.e. above and below the paper to connect even subtlety the ideas that heretofore seemed to have no relative association. The ideal way to affect this three dimensional effect is for the moderator to attach a strip of construction paper or stiff, colored ribbon to the idea islands until all of the reasonable pathways have been connected. The strips must be wide enough to be able to hold a single sentence for reference purposes.

Ribbons of different color can be used to easily discern the alternative 'reasonable pathways' that have been found. This technique also helps to discern reasonable paths that may share many of the same Theme Islands except for a crucial one or two; which may make all the difference in producing a creative solution option.

[7] The Codex Leicester, for example, contains many examples of the small sketches that are appropriate for a L. da Vinci brainstorming session.

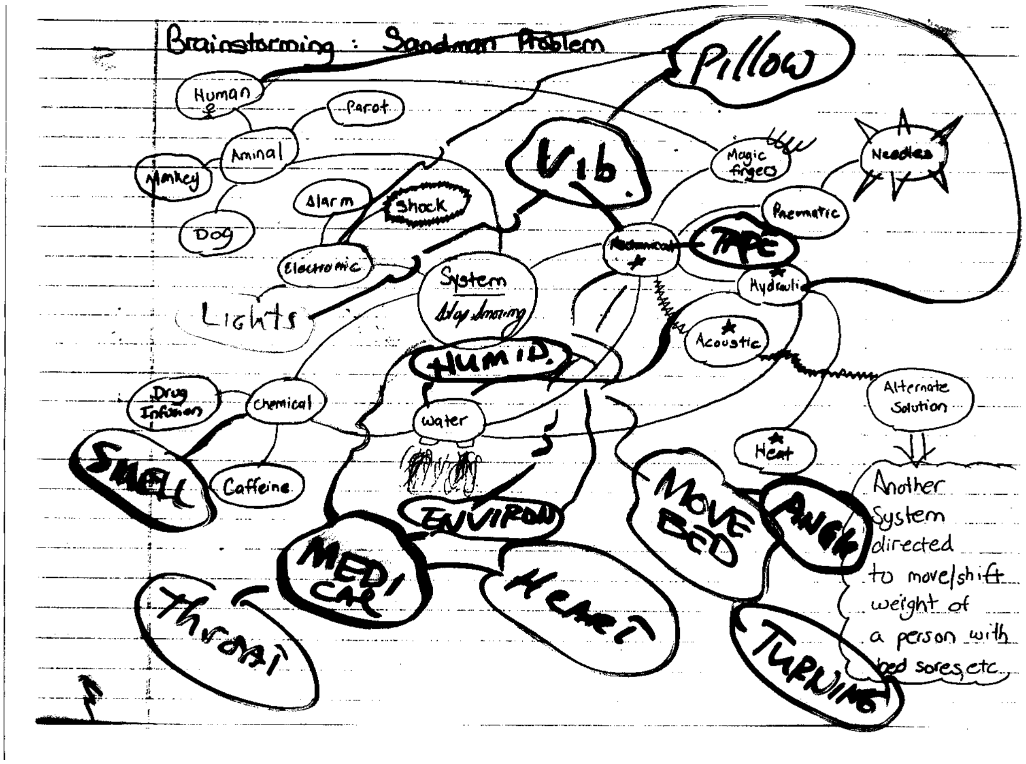

Figure 2. 2-Dimensional Brainstorming Technique

The author's recognition of a 4th-dimensional aspect of this brainstorming technique is interesting to note here although its utility is usually not immediate when conducting a brainstorming session. The fourth dimension is time. Time is an attribute to this brainstorming (or any) technique. Like wine, the utility of ideas is known to improve with time. Thus, sometimes the unused brainstormed solutions are found to be the perfect solution to problems that arise in the future. It's conceivable that every brainstorm-generated idea, particularly the wildest and craziest solutions, take hold in the engineer's subconscious and materialize, seemingly from nowhere, when needed in the future. This deja vu experience lends the alternate name given by the author to this 4th-dimensional phenomenon: Deja Vu Design (DvD).

LITERATURE SEARCH:

A very important part of any design process is the Literature Search. This is particularly important if the engineer has little or no experience in solving the problem. Although this might beg the question: Is it ethical for an engineer to take on a project for which he is not trained and/or knowledgeable? I believe the fair answer from a professional engineer, with a flair for the entrepreneurial might be: "I'm an engineer trained in the art and science of the design process, willing to explore new projects and gather more experiences, I'll take on the new project, learn what needs to be known to accomplish the job at hand, speak with experts or consultants, read the state-of-the-art literature and "get the job done, professionally and ethically"; presenting viable solutions that are well grounded in engineering art and science.

But after performing due diligence if I am still not sufficiently knowledgeable to solve the problem I will recluse myself from offering a solution."

By its very origin the Instructor's "Sandman Project" fits into this category as the Instructor nor the class had much in the way of medical or state-of-the- art information on techniques that can stop snoring.

The literature search has never been so easy for the student or engineer to conduct given the omnipresent World Wide Web. The literature search by the Instructor revealed sleepless societies, professional sleep institutes with sleep experts conducting sleep experiments in sleep labs as well as a gaggle of amateur Yankee-type inventors with home businesses that offer snoring sleep aids via the mail. Several of the more significant results of the Mr. Sandman Project literature research are given in the full length, Primer version of this article.

A patent search using www.uspto.gov , www.spo.eds.com/patent.html or www.sunsite.unc.edu/patents/intropat.html is also worthwhile in order to avoid 'reinventing the wheel'. For this Project with its clear association with possible medical complications, the engineer is well advised to review the Medical literature and/or conducting phone interviews with medical authorities. In fact it would be considered unethical for the engineer not to consult medical authorities for this project where the safety of the user is paramount to the implementation of any design.

Thus, an ethical cautionary note was issued to the student. The literature search conducted for the Sandman Project revealed that snoring may in fact be a symptom of a more serious sleep apnea problem that the patient is not yet aware. Thus, an ethical solution to the Problem at hand must also include some research that will avoid designing an electrical/ mechanical system that could possibly mask the sleep apnea (real) problem while only solving the snoring (noisy) problem. This would likely require seeking the latest medical advice but also extensive prototype and beta testing after the system was designed with any of the concepts that follow. The medical dictum of "primum non nocere" (above all do no harm) in fact is also appropriate for prudent engineering design!

The Technical Basis for *The Sandman Project* Concept Solutions

The literature and focus group research conducted by the Instructor indicated that a strong basis for solving a snore's problem lies in having the snorer change his sleeping position (ref. Appendix C). Snoring is likely to occur when the patient is sleeping on his back and/or when the air is relatively warm and dry. Some research also indicated that moistening the snorer's throat also helps reduce the occurrence by reducing throat membrane swelling. Thus, the technical basis for the following solutions is to safely and quietly induce the patient to move, on his own, to a new position PLUS adding an option of delivering either a medicated air stream or a moist (humid) air stream to the snore's environment.

WHAT'S IN A NAME?

The intense, focused concentration of thought that continues to grow during the Project is often the most appropriate stimulation to derive the first suitable phrase that immediately identifies the Project and its objective. For the Sandman Project the class and Instructor evolved the product name: 'Snore-*be* ***Gone***' with an emphasis on the design of the letters that constitute the name as shown here.

Certainly, if the Instructor or the students can decide upon an appropriate trademark for the Project at hand, then there exists the perfect opportunity to segue into a discussion about the ability to copyright© or register trademarks™ using the United States Patent and Trademark Office (USPTO).

The choice of an appropriate name or phrase for the Project is not the highest priority during the engineering design process. However, it must be emphasized to the students that the proper choice of a trademark name could mean the difference between a second glance from the customer (translate customer here to be Banker or supporter for the Project) and maybe the 'sale', ie. the acceptance of the Project.

Still not convinced that a good tradename™ or phrase is important to attract positive attention? Then the reader should ask him/herself which caught the reader's eye more: this paper's title or the equation that appeared below the title?

For the remainder of the course the "Snore-*be* ***Gone***" trademark was prominent in the Instructor's presentation.

FEASIBILITY ASSESSMENT

The solid lines shown in Fig. 2 can exhibit the reasonable paths to a solution for the Instructor's Snore-*be* ***Gone*** Project. These pathways were added only after the 2-dim. Brainstorming activity was exhausted. The time duration for these results from the 2-dim. Brainstorm was approx. 45 minutes or about 1/2 of the class period.

A listing of the "Reasonable Pathways' that were found from the brainstorming session for the Snore-be Gone project is given here.

#1: MECHANICAL-PNEUMATIC-NEEDLES (PRONGS)
#2: ELECTRONIC/ELECTRIC-VIBRATION-PILLOW
#3: MECHANICAL+CHEMICAL-HYDRAULIC-WATER PULSING IN TUBES IMBEDDED IN MATTRESS (FIRST TIER); WATER SPRAY (SECOND TIER); HUMIDITY CONTROL (THIRD TIER)
#4: CHEMICAL-SMELL
#5: ELECTRONIC-LIGHTS (FIRST TIER)-VIBRATING PILLOW (SECOND TIER)-ALARM (THIRD TIER)
#6: ANIMAL-MONKEY (FIRST TIER); HUMAN(SECOND TIER)
#7: MEDICAL ATTENTION-CHEMICAL/DRUG(FIRST TIER);SURGERY(SECOND TIER)

It can be observed from this list that specific, details of the design solution are not yet readily discernible from just this list. Creative, intuitive, experienced, educated, biomimic-ed (i.e. duplicating or following Nature's lead for producing viable systems) and/or synergistic engineering design is still needed to transform these reasonable pathways into a viable mechanism(s). This list simply focuses the attention of the engineer to conceptualize on a design that, for example, utilizes mechanical, pneumatic needle (item #1 above) in its solution to the problem or on a design that utilizes mechanical and chemical systems that can constitute an hydraulic system of tubes (filled with water) and a means of producing a pulsing of the fluid within the tube (item No. 3, above). Certainly, item No. 7 is straightforward as a possible solution: seek medical attention in the form of prescribed drugs or surgical intervention. It is also possible that the final path to the most viable solution is a combination of these seven pathways. The sorting of all of these possibilities into a final solution is the essence of intelligent and experienced engineering design.

As may be observed from all of the above, the designs for these 'reasonable pathways' are still very obtuse and non-descript. Given all of the above, perhaps the most definitive statement that can be made at this point in the Design Process is that after only a relatively brief brainstorming exercise a myriad of "reasonable Pathways" to an abstract problem has been produced in a brief period of time. Starting from almost nothing but a Problem Statement, the Engineer now has something to focus his/her attention while conducting the first "weeding-out" process: the Feasibility Analysis to determine the viability of these ideas. More of this in the Feasibility Analysis section of this Paper.

Morphological Technique for Concept(s) Genesis

Another technique for generating reasonable paths to a solution is the morphological method. The morphological method is described in several texts but most succinctly by Koberg, James Adams and Ullman (ref.s 1, 2, 7 and 8, resp.). The morphological technique is based upon the piecing together of somewhat unrelated themes, related only in their individual relation to the Problem Statement. An example of the morphological technique applied to the Snore-be-Gone Project is shown in Fig. 3 as excerpted from Page 34 of the Instructor's Engineering Journal.

The morphological technique starts with identifying the Functions or "The Whats" of a problem statement and the Forms or the "Hows" of the problem solution. In this application, 'the What's" of the solution are: The Snoring Patient', 'Sleeping Soundly', 'A Safe Procedure' and "The Sleeping Partner' ; all of which can be easily found to be the nouns or pronouns used in the Problem Statement. The 'Hows' of the problem's solution for each of the 'Whats' are shown listed under each in Table 2. The morphological process finds 'reasonable paths' that combines the 'Whats' with the 'Hows'. Several combinations are shown on the bottom of Fig. 3. These results are remarkably similar to the results gained from the 2-dimensional brainstorm technique. No doubt the same group performing both techniques may have subconsciously influenced this result. Allowing for this possible influence, the morphological results for the Snore-be-Gone application are still impressive and could lead to feasible solutions to the Problem.

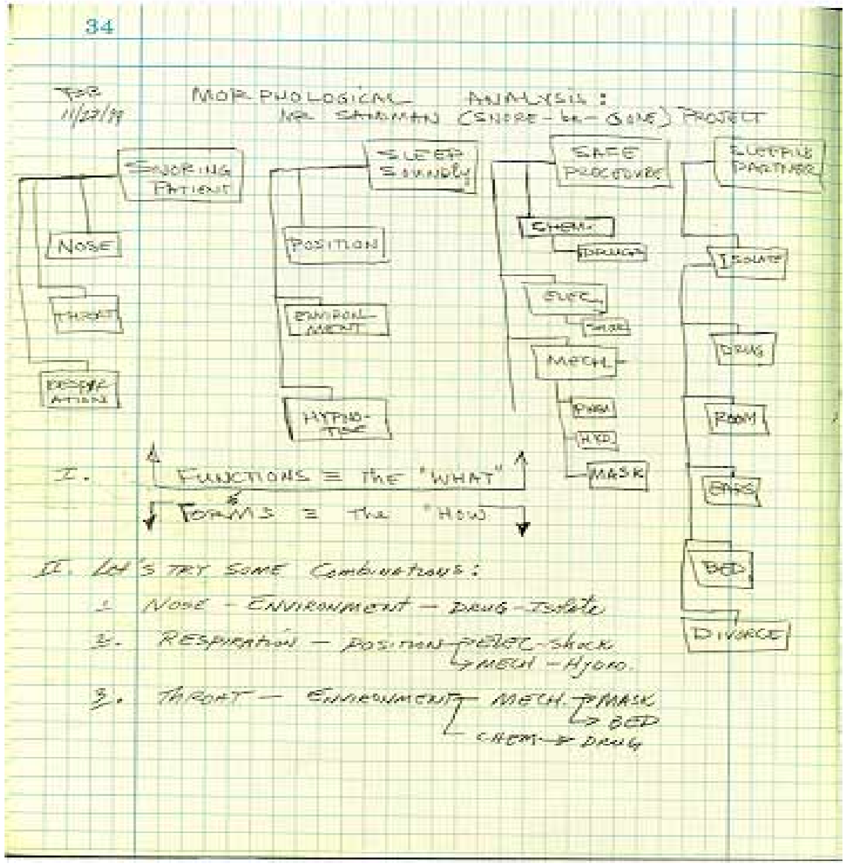

Fig. 3. Page 34 from Instructor's Journal Showing a Morphological Solution to the "Sandman Project"

FEASIBILITY ANALYSIS:

The student/engineer has been educated in the application of the natural laws so as to make the engineering analysis be relatively straightforward to complete; at least to a point where decisions can be made. In many instances the student's rapidly improving, engineering judgment comes into play in order to make reasonable assumptions and approximations in order to be able to complete the analysis. Some basic questions that your engineering analysis should answer are the following: 1. what is the process's overall efficiency (1^{st} law and/or 2^{nd} law) or overall effectiveness in 'getting the job done' ?, 2. Can the product/project be accomplished with available materials of construction or must a new material be invented during the project with state-of-the-art controls and instrument technology? 3. How much power/energy will be needed-is it .05, .5, 5., 50 or 500 kW and what is the energy source-solar, elec., battery, nuclear? 4. What is the size of the final product that needs to be built to accomplish the customer's specification- is it 'bigger than a shoe box, a bread box, a refrigerator AND does this size fit the application and the user's scale- a spare tire, for example, must FIT into the trunk, the glove compartment must fit gloves (but is it suppose to fit a baseball glove or winter gloves?), 5. Can the product be assembled with state-of-the-art 'off-the-shelf' components, 6. Can the project be completed with the funds at hand and with the qualified, professional personnel available to the project, within the available development time 7? What are the precise engineering specifications for the product based on engineering as well as customer needs and does Engineering need to work closer with the 'Customer' to better match their needs with the compromises that may have been brought to the surface based on all of the feasibility analysis described above?

Regarding the economic part of the feasibility analysis, the student should be able to conduct a first-order market analysis for the product/project or at least determine the cost-benefit of the system under consideration. That is: given the customer's requirements and the engineering specifications, how much will the final product cost the user if it were to be produced in mass production? Does this cost make sense when compared to the product's true, contributed value to the user or society, in general? How does this cost compare with the closest competitor's product or even your engineering associate's alternative concept solution?

The analysis can be as simple as what may be called the "barber shop" feasibility test example. The "Barber Shoppe" test is a 'back of the envelope, economics calculation that answers the straightforward question: Is it profitable to open a barbershop with 3 chairs in this locale? The income derived from this enterprise can be quickly calculated and a profit or loss determined with some very basic assumptions that are quickly discerned. For example, given that all three chairs are in operation for 80% of the business hours (10 hours per day, 5 days/wk.) AND that it takes 20 minutes for each haircut AND that the SHOPPE is located in Newbury Street (Boston, Ma.) AND that the rent is 2,000 month AND that the only barbers I can find in a 4% unemployment want $35,000/yr AND all fringe benefits that total twice this salary: How much do I need to charge per haircut for the profit to be $20,000 /year and how does this compare with a barber shoppe on Boyleston St., in Boston, MA.? Calculating time to get an answer that can be used in a Business Plan: 15 minutes… TOPS! A spreadsheet solution is best in order to be able to quickly change any of these assumptions and see their effect on the answer.

The "Barber shop test" is the first "back-of-the-envelope" that the engineer can quickly apply to test the validity of the Problem Statement and then later to the concepts developed to solve the Problem Statement.

Informational sources for customer trends and statistics are wide spread, particularly with the advent and prevalence of the internet. Government Statistical Data on USA businesses, census, energy usage, gross national production of goods, etc. are readily available from the Federal Office building(s) in each State's capital city. The reader is well advised to make a field trip to the Federal Building and visit their Government Publications bookstore. Reports are also available from the hundreds of various 'Product Associations' that exist across the country. These references are a wealth of very specific information: from boating to home appliances.

A way of improving your guestimate for the percent of snorers parameter is to research the competitive system manufacturers. If they are a public company, then annual reports will be publicly available. These reports will identify the gross sales of the company, sometimes by product and may boast of the percentage of the market for which they are providing systems.

A little arithmetic (no equations here, remember my promise on page 1!) can improve the guestimate made earlier.

If annual reports are not available, then considerable marketing information may be available from the competitor's product brochures or from canvassing the retail outlet stores where the product is sold.

Given all of the above, the student is advised that the most effective and demonstrable way to answer all of these questions is to prepare an engineering (computer or mathematical) and economic model of the system and then to conduct a parametric analysis to determine the optimum efficiency, size, cost, weight, loading, marketability of the system under consideration. The Ernas and Jones textbook (ref. 2), for example, has numerous examples of such models.

If you need a more sure-fire test of economic viability (a **GO/NO GO** decision) in the event that you still can't decide on the system's merits in the market place, ask yourself whether YOU would put up the development money to continue the project past this feasibility stage. If the answer to either of these questions is "no", then it's better for the engineer's time to be spent elsewhere.

Once the priority for the engineer's attention has been determined, the 'Viable Paths to a solution' must be ferreted out from the 'Reasonable Paths to a solution'. This requires that an Engineering Feasibility Analysis be performed on these possible solutions.

Suggested Snore-*be-Gone* Concept Solutions

Concept No. 1 - A Mechanical-Pneumatic-Needles/Prongs

Page 27 of the Instructor's Engineering Journal contained several ideas that utilize a mechanical, pneumatic and needle (prong) solution to induce the patient to move when snoring is initiated. Thus, as the Journal sketches indicate, an array of air actuated needles or prongs are installed in the mattress and will poke the patient when snoring begins. The discomfort caused by these needle/prong pokes induces the snorer to change his sleeping position.

A detail of the design of one of these air-actuated needles is shown below the main sketch. This detail quickly reveals the complexity of the solution envisaged (including: spring actuated prongs, embedded in the mattress, actuated with air generated by an air compressor!) and hence prompted the Instructor to consider an alternative mechanical-pneumatic solution, shown in the bottom left hand corner of the Journal page.

Concept No. 2: A Mechanical-Pneumatic- Air Piston Solution

In this rendition of the mechanical solution and air actuated piston is used to lift a corner or the entire side of the bed. The lift is just enough to disturb the snoring patient and forces the patient to literally role to a new sleeping position. The lifting is done by a sandwich board-type flapper mechanism that is opened by an air piston. This design is much simpler than the first concept although perhaps not yet the 'best' solution.

Concept No. 3: Hydraulic or Pneumatic Tubing
The entry on Page 29 of the Engineer's Journal illustrates a concept of using hydraulic and pneumatic tubing to 'induce' patient movement during the onslaught of a snoring episode. The concept is to generate pneumatic or hydraulic pulses to disturb the patient enough to cause her movement to a new sleeping position. The sketches indicate that a variety of hydraulic circuits can be configured that can randomly direct the hydraulic pulses so that the patient does not get accustomed to any pattern of pulses. The design concept shown suggests that the pulsing pattern can be altered via computer controls (not shown) that open or close an array of electrically operated solenoid valves. These valves will direct the pneumatic or hydraulic flow in a variety of directions; directions that are preprogrammed by the engineer on the computer-based (PC or industrial Programmable Logic Controller, PLC).

Also shown on this page of the Journal, next to the appropriate sketch, is a first effort to determine the feasibility of the concept. For example, if the hydraulic circuit design is to be a viable pathway to a solution to the Problem Statement, then the size of the tubing must be determined so that the velocity of the pulse is high without causes excessive pressure drops and a requirement for a high pumping power. To determine a reasonable tubing size and length and water flow a straightforward feasibility analysis is performed. As may be seen in the bottom right hand corner of the Journal page, it was found that a small pump power of 0.05 hp would suffice to pump water in a 1/4" dia. tubing with a length as much as 240 ft.

It was the Instructor's intention that the students see this example of a feasibility analysis as very straightforward. The feasibility analysis needs to be only sophisticated enough to answer the simple question: Are there any physical or economic laws that are violated by the proposed concept and are the results reasonable for the scope of the problem. For this concept, if the solution of the pumping power were found to be 5 hp instead of 0.05 hp or if the tubing diameter needed to be 1" instead of 1/4" then the answer to this question would be quickly judged to be "Yes" and the engineer knows enough to "move on" to other design options. At this stage of the Design Process, it is not yet time for a detailed stress-strain analysis using ANSYS or for a finite element model of the heat or mass transfer involved with the design.

The previous design Concept No. 2 has a limitation that only the corners or a small width of one side of the bed is lifted when snoring begins and the Snore-be-Gone system is activated. The pneumatic/hydraulic system in Concept No. 3 has a limitation that water or air tubing must be used, which must be integrated into the mattress making retrofitting of the design difficult.

Concept No. 4: Wave Roller
Another concept for inducing the snorer to change sleep position is shown on Page 35 of the Instructor's Journal. The concept is for a roller to create a 'wave' under the sleeping patient that will move the patient away from what ever position the snorer finds herself in at the time the snoring begins. It's the 3-dimension, contemporary version of "The Princess and the

Pea"[8]. Two methods of driving a roller forward, under the entire mattress, is shown from the Journal entry. The first design used a cogged wheel that will not slip on the top fabric of bed box spring. But this design requires an upright that produces the 'moving pea' that is felt by the sleeping snorer. Another design shown on the right has a roller within a roller. The internal roller is actually drives the outer roller. In this design the roller need only be guided so that its forward motion remains parallel to the edge of the bed as it progress across the mattress.

This design lends itself to a little more difficulty while calculating its feasibility. First: where can a roller with a built-in motor be found? And what power is required to propel the roller with a speed, V? How much of a ripple should be produced? These answers were researched and it was found that a roller with a built in motor is commercially available and with a power rating that is sufficient to move the roller forward at a "disturbing" speed. The manufacturer's 'cut-sheet' (or standard specifications) for a commercially available, motorized roller are reproduced in the Appendix. Thus, a major feasibility question is answered: an internal motor-driven roller is commercially available and need not be designed specifically for this concept to be reasonable in its execution for the problem at hand.

At the same time that this information was being conveyed to the students, a student questioned, correctly, the reason for having put the rollers BELOW the main mattress rather than putting it on top of the mattress, under a thinner mattress pad. This would certainly reduce the power requirements and increase the size of the ripple disturbance that the patient could be exposed to with the same forward motion. The thin mattress pad would save the patient from being pinched rather than just rolled-under as the roller proceeds. An excellent suggestion and dramatic evidence that even these simple drawings do impart information quickly and that there's always a simpler way of doing something that even the Instructor may have trouble seeing immediately. In other words: Progress!

But, even with the student's design improvement, there must be a simpler design! Using rollers to create a moving wave that will disturb the sleeper and induce his movement seems, intuitively at least, a very complicated 'means' to a rather simple 'end'. Although this design is feasible, i.e. it doesn't violate any natural or physical laws; it is rather complicated in its implementation. In other words it violates the K.I.S.S. or K.I.S.M rule: **Keep It Simple, Sir or Keep It Simple, Madam**[9]. Although it has been stressed in this paper as it was throughout the course that there are many ways of solving a given design problem, it is also true in design that there is a simplest solution that eventually can surface depending entirely upon the creativity of the engineer(s) involved with the solution to the problem.

Finally, one more feasible solution.

Concept No. 5: Air Spray with an Optional Medicated Water Ingredient (to increase humidity) with an Optional Temperature Conditioning and Scenting

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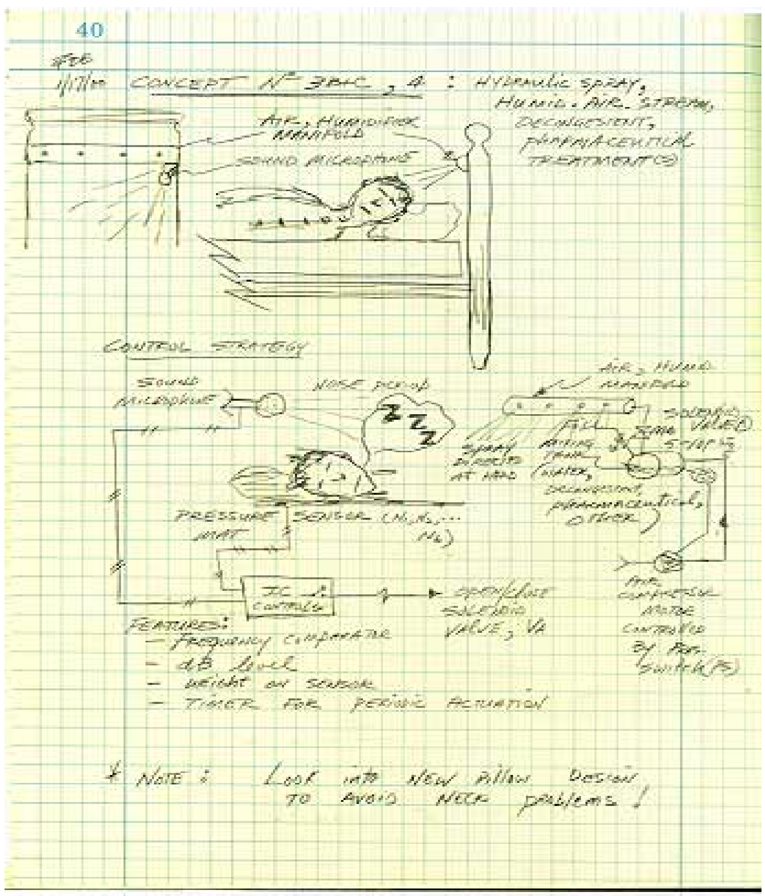
[8] Or, perhaps to be more politically correct, one should write: "The Prince/Princess and the Pea"

[9] The rest of the engineering world knows this rule as Keep It Simple, Stupid but I always prefer the non-derogatory approach! Thus, the Author has replaced the idiom with more contemporary anagrams.

A final design solution (at least for the Instructor's purpose) to the Snore-be-Gone Design Problem is illustrated in a reproduction of Pages 39 and 40 from the Engineer's Journal and shown here in Fig. 4. This concept is based on the technological premises stated earlier in this Paper namely that a movement induced on the snorer will stop snoring (perhaps at least temporarily) and that medicated air that is also humidified will help open throat air passages and ease breathing. This design concept also introduces a (snoring) noise actuation system, which could be used in any of the other concepts to trigger the Snore-be-Gone system. The noise actuation system initiates the sequence of events that includes the spraying of a high velocity air jet onto the face of the snoring subject. The air stream can be medicated and/or humidified and even temperature controlled to improve the air quality around the patient. The air jet velocity can be adjusted using a needle valve or adjustable nozzles. The nozzles are installed in a manifold that is either retrofitted onto the bed's headboard or industrially designed into a new, factory installed headboard.

Figure 4. Entry from Instructor's Journal Showing Initial Sketches of the Preferred Solution to the Sandman Project



The nozzles can either all be actuated simultaneously with a single switch closer (triggered by the noise actuation system) or can be individually by a PC or PLC-based control system. If individual nozzles are to be used then a means of identifying which of the nozzles to be triggered must be determined. For this purpose, one solution proposed here is the use of a pressure pad that locates where on the bed the patient is sleeping. The pressure sensitive sensors located in this pad send a digital signal to the controller which in turn uses an algorithm to determine which air nozzles are closest to the patient's face to trigger only those air valves. The snoring patient's face is then awash with air jets that gently nudge (or perhaps the better emotion invoked is annoy) the patient to move out of its way. A very preliminary control schematic and piping and instrument diagram is also shown in Fig. 4 and summarizes this control strategy.

The result: the patient awakens alert with a great night's sleep AND a partner who is not only no longer threatening divorce but has benefited from the conditioned and treated air that envelopes the bed- at least in theory, anyway! To paraphrase Shakespeare: The proof is in the tasting.

Feasibility Analysis Results:
A Feasibility Analysis (F.A.) on the above concepts provides a means of quantifying whether any one of these concepts violates any of the physical laws or whether, after applying these physical laws, any of the designed parameters can't pass the 'reasonable test". A comparison of the results from a feasibility analysis applied to each concept also provides a means of comparing the positive and negative attributes of each design. At this stage of the Design Process, the F.A. need not be very detailed or use extensive computer analysis (such as Finite Element Analysis, Computational Fluid Dynamics or Finite Differences, etc.). The objective of the F.A. is more to eliminate obviously poor design options rather than to pick the optimum design. Optimum design analysis is left for the Detail Analyis phase of the project. An example of a Feasibility Analysis for the 5 concepts presented here is, once again, taken from the Engineering Journal and is presented in Table 2. It is also recommended that a simple computer program or spreadsheet be written that enables the engineer to perform very straightforward parametric calculations. This parametric analysis can quickly help identify the proper size of pump for a given flowrate in a particular size diameter tubing of a certain length, for example. All of these previous parameters can be changed (the proper name for the process is: parameter iteration) until the 'right' combination is found. The spreadsheet display also lends itself to immediate use in a written or oral progress report.

TABLE 2. SUMMARY OF FEASIBILITY ANALYSIS OF CONCEPT SOLUTIONS

	CONCEPT No. 1	**CONCEPT No. 2**	**CONCEPT No. 3**	**CONCEPT No. 4**	**CONCEPT No. 5**
DESIGN FACTORS	***PNEU. PRONGS***	***RAISED CORNERS***	***HYD. TUBING***	***WAVE ROLLER***	***MEDIC. AIR SPRAY***
UTILITIES REQ.d	AIR, ELEC.	AIR, ELEC.	WATER, ELEC.	ELEC.	AIR,MEDIC., ELEC.
POWER	< .1	< .2	< .1	< .25	< .1

REQ.s (Kwe)					
OVERALL STANDARD COST ($)	750	500	800	550	300 to 900
No. OF MAJOR COMPONENTS	<70	<15	<20	<10	<10
SYSTEM WEIGHT (LBf)	125	50	70	60	50
ASSESSMENT of COMPLEXITY	HIGH	LOW/MOD.	MOD./HIGH	HIGH	MOD.
PROBABILITY of MEETING SPEC.S	<50%	<75%	<25%	<25%	<75%
CONTROLS REQ.S	HARD WIRED	HARDWIRED	PLC	HARD WIRED	PLC or HARDWIRED
PATENTABILITY	YES	YES	YES	YES	YES
NEW TECHNOLOGY REQ.d	NO	NO	NO	NO	NO

Certainly more engineering metrics could be used to compare these concepts but those shown in Table 2 are sufficient for the purpose of revealing that Concept 5 (The Medicated Air Spray) is slightly better than the others and is thus worth further detail design consideration.

Demonstrating Deja Vu Designing Opportunities for the Students

The last design suggestion (Concept No. 5) is perhaps also not the simplest means to stop snoring. After all, that honor probably belongs to one of the mouth appliances that are commercially available either via the Internet or over the counter (see Appendix). Assuming that the advertised user testimonies are accurate, these appliances are inexpensive, completely mobile, easy to use and WORK! Can the above designs, one or all or in some combination there of, be competitive? The simple and frank answer is: probably not.

Then, has all this design engineering been wasted? Also, probably not! For example, look what has been achieved from these ‘crazy’ ideas that stemmed form a short brainstorming session that was initiated by the compelling article written by Ms. Foster: An air conditioning and treatment system, including: heated or cooled, medicated and/or humidified and even scented[10] (concept No. 5) that can be installed onto a patient's bed who may also be able to take advantage of the pneumatic or hydraulic system (Concept 3) to provide a constant massage that is required to prevent bed sores- a constant threat to patients who are constrained to their bed. The pressure pad can also be used to sense and time how long a patient is resting on the same spot and then direct via the computer controller where the pneumatic or hydraulic pulses should be routed. This is an answer to a completely new problem, one that has not even been asked for a solution until, with a little imagination and entrepreneurial spirit, the engineer gives birth to a new product! This is also a benefit and a very effective use of the engineering journal. The Instructor has labeled this Deja Vu Design Opportunities because inevitably an Engineering Journal that is jammed packed with 'bad' or 'not so good designs' or 'not the simplest' design attempts for a variety of problems becomes the store house for 'great' designs and 'just the right thing' for an as yet undefined problem. The simple lesson here then becomes: Do not use the eraser or dispose of any Journal entries and always, always, Date and Sign the pages.

Not convinced? Then let's look further at Concept No. 2: The raised Bed Corners. How much of a leap in imagination is needed to see that the basis for this design is a perfect solution for a retrofitable device that can transform a regular bed into an adjustable bed; one that enables the head or the food of the mattress to be raised or lowered to make the user more comfortable.

How about Concept No. 1? The pneumatically actuated needles/prongs design can readily be transformed into a localized, mechanical pressure measurement device, similar in function to the electrical pressure sensing pad used in Concept No. 5. Or perhaps a means of distributing a variable point loaded pressure to an object.

Finally let's look at Concept No. 4: The Wave Roller Design - a perfect, single roller pizza dough spreader for the home market- assuming that there is a need for a perfect pizza dough spreader for use at home! Yes, a stretch perhaps, probably not the best alternative application for this design BUT there is no doubt that this design will be found to be the perfect solution for a problem that still lies in the future. The Journal page is Dated, Signed and very patient, awaiting an expressed 'need'-in other words: ready for DvD!

THE PUGH ANALYSIS

There are now technically five concepts that have passed the Feasibility test if not the K.I.S.S./K.I.S.M. test. The engineer's time and other valuable resources must be directed to solving the Problem Statement using the most viable design concepts. How can the five design solutions be prioritized to identify the design that should be given the most attention? The Pugh Analysis is formulated for this purpose. Named after Stuart Pugh, an practicing engineer and engineering educator, it is one of several recognized methods for rationally comparing many viable concepts with the hopes of identifying one that is clearly and objectively the most likely to succeed in solving the problem.

[10] The use of scents to improve mood and health has been used for thousands of years and has recently been employed as a means of relaxing the user after a particularly stressful day.

The Pugh Method starts by choosing a reference or Datum to which all of the other concept ideas will be compared. In Table 3 the reference is concept idea No. 5. A competitor's design is often chosen as the reference. The analysis proceeds by continually repeating the following mantra for each test:

'Does the attribute (1 through 11 in this example) present more or less risk, more or less cost, more or less power consumption, occupy more or less space, effect better permanence of stop snoring, cause more or less wastes, etc. than the reference idea?'

If the attribute under consideration presents a better solution for a concept idea then the reference then it is given a plus (+). A negative (-) is given to the comparison if the attribute for the concept idea under consideration is worse for the idea when compared to the reference. If the comparison is judged not to be better for either, then a 'N' for Neutral or an 'S' for Same is entered. At the conclusion of the analysis all of the Plus and Minus and Neutral signs are added for each concept idea and the results compared.
Table 3 provides the results of the final (not the first) Pugh Analysis. It should be observed from this table that the Customer specifications from the QFD have been added to attributes used in the previous Pugh Analysis (not shown in this paper) as well as the Feasibility Analysis. For this Pugh Analysis, the Datum or Reference system was selected to be Concept No. 5.

The results indicate that Concept No. 5 has a better opportunity to solve the Problem Statement than any of the other Concepts. The Summed results shown in the Concept No. 5 column is shown to be: 10 'Pluses', 3 'Minuses' and 15 Neutrals". These Sums are based on the calculations shown in the rows and are uniquely used in this Paper for quantifying the Datum. The Reference normally does not have its performance tallied in this manner but rather remains simply the reference around which all other concepts are judged against. The author has contributed the calculation for the Reference Sums shown in the Table results, enables the reference to also be quantified.

Thus it would appear from this second Pugh Analysis as well as from the previous discussions that Concept No. 5 is worth pursuing.

TABLE 3. FINAL PUGH ANALYSIS FOR 'SNORE-be-GONE PROJECT

DESIGN FACTORS	**CONCEPT No. 1** ***PNEU. PRONGS***	**CONCEPT No. 2** ***RAISED CORNERS***	**CONCEPT No. 3** ***HYD. TUBING***	**CONCEPT No. 4** ***WAVE ROLLER***	**CONCEPT No. 5** ***MEDIC. AIR SPRAY***
UTILITIES REQ.d	-	-	-	-	**D**
POWER REQ.s (Kwe)	N	-	N	-	

OVERALL STANDARD COST ($)	-	-	-	-	**A**
No. OF MAJOR COMPONENTS	-	-	-	N	
SYSTEM WEIGHT (LBf)	-	N	-	-	**T**
ASSESSMENT of COMPLEXITY	-	+	-	-	
PROBABILITY of MEETING SPEC.S	-	N	-	-	**U**
CONTROLS REQ.S	N	N	N	N	
PATENTABILITY	N	N	N	N	**M**
NEW TECHNOLOGY REQ.d	N	N	N	N	
DEVELOPMENT COSTS $	-	+	-	-	**D**
PRODUCT COST, $					
POWER CONSUMPTION					**A**
SHORT TERM USER SAFETY	N	N	+	N	
LONG (PHSYCO.) USER SAFETY	N	+	+	N	**T**
INSTALL. SPACE DIMENSIONS	-	N	-	-	
RETROFIT MOD.S COMPLEX	-	N	-	-	**U**
EFFECT. TO TEMP. STOP SNORING	N	N	N	N	
PERMANENCE TO STOP SNORING	N	N	N	N	**M**
USE OF UTILITIES					
WASTES TO CLEAN UP	+	+	N	N	
NO DANGER TO USER OR PARTNER	**N**	**-**	**N**	**N**	**D**
DOCTOR APPROVED	**N**	**N**	**N**	**N**	
COMFORTABLE	**N**	**N**	**N**	**-**	**A**

LOW COST					
COMPACT, INSTALLED SIZE					T
RETROFITT ABLE					
WARRANTY FOR ONE YEAR	N	N	N	N	U
DURABLE	N	N	N	N	
SMALL POWER SUPPLY					M
EASY TO CONTROL ’ON’ or ’OFF’	N	N	N	N	
EASY TO READ INSTRUC.	N	N	N	N	
Y2K COMPATAB LE					
PORTABLE					
NO NEW MATERIALS OR TECHNOLOGY					
LOW DEVELOPMENT COST					
LOW DEVELOPMENT RISK					
LOW DEVELOPMENT TIME	-	+	-	-	
LOW PRODUCT LIABILITY RISK	N	N	N	N	
LOW MANUFACTURING COST	-	+	-	-	
SUM OF ALL PLUSES (+)	1	6	2	0	(11+6+11+12)/ 4=10
SUM OF ALL MINUSES (-)	11	6	11	12	28-10-15=3
SUM OF ALL NEUTRALS	16	16	15	16	(16+16+11+16) /4=15

PRELIMINARY ANALYSIS

This methodical process toward an engineered solution to the Problem Statement continues with a Preliminary Design and Analysis of the preferred concept. A Preliminary Design and

Analysis of a concept begins the process of formalizing the embodiments of a solution that, until now, may have only been hand sketched or rendered with only approximate dimensioning or with little concerns about optimizing the design. The Preliminary Design should be able to identify the entire major and most of the minor parts of the system. The major parts are certainly: pumps, fans, clutches, gears, special bearings, motors, structural elements, controls, instruments that are necessary for control- and in general: any component or sub-system that costs more than 10% of the total cost of the system. Minor components are: fasteners (nuts and bolts), small bushings or bearings (off-the-shelf), tubing for low pressure fluids, electrical wiring, switches, data acquisition instruments, small valving. A successful Preliminary Design should enable the Project's first Bill of Materials (B.O.M.) to be constructed. A B.O.M. lists all of the known components which helps to identify whether the components are commercially available (and thus prices are known) or whether 'extreme' measures may be needed to design an important component (which may be costly in engineering labor as well as materials). The Preliminary Design begins to focus the Group's attention on the appearance and function of the final design and usually involves drafted or CAD drawings of the Assembly in lieu of hand sketches. It's important to note that detailed dimensioned, individual component drawings, suitable for construction, are produced later during the Detail Design Phase of the Project.

A good Preliminary Design also enables a more accurate Economic and Marketing Analysis to be performed. The Marketing Analysis will determine the size of the customer market; assuming that a commercial product is the ultimate goal of the project. Even if the project is not to develop a commercial product but rather a custom solution to a Customer's unique problem, the Preliminary Design will help to estimate the final cost of the system AND identify the engineering disciplines that need to be involved, their work effort (labor hours), the cost of prototype materials and testing equipment and, in general, the total expense that will be expended in order to complete the project. Certainly, the labor and materials expenses and the time duration of the Project would be of interest to any potential backers of the project as well as, together with the Marketing Analysis, a means of determining the Return On Investment (ROI) for the Company and/or Client if the Project were to proceed.

A successful Preliminary Design first, strengthens the engineer's confidence and judgment that the chosen design will solve the problem and that the design can be built for a profitable cost and still have a willing buyer. But then, it must convince the 'Customer' (i.e. your Boss, the Boss' Marketing Dept., the Marketing Dept.'s demographics –OR- the Boss's Client and the Client's Money Manager) that there is a reasonable expectation of success if the Project were allowed to continue to the Detail Design, Prototyping and Testing Phases of the project.

DETAILED ANALYSIS

Assuming that the decision is made to proceed, the next step is to prepare a Detail Analysis and Design from which a Prototype component/system can be built and tested. Everyone (student and professional engineer alike) would agree that it is only logical that a Prototype system cannot be built without first completing a substantive Detail Design and Analysis.[11]

[11] The following excerpted from Course notes prepared by the Author and Prof. Mort Isaacson (Boston Univ., AERO/MECH. Dept) for the 1999-2000Machine Design Courses I & II.

The Detail Analysis and Design, in a real sense, can be considered “more of the same” with respect to the Preliminary Analysis and Design effort that the student has already performed. The emphasis however must be on the word “more”. The completion of a successful Detail Design effort must facilitate the next step in the design process: the actual building of a viable and representative prototype. The Detail Analysis and Design should provide the Project with all of the necessary engineering calculations required to size, design, select the material of construction, determine product life, specify and/or select any component that is to be used to construct, operate and/or control the Prototype.

A very critical requirement for a successful Detail Design, therefore, is the need to optimize the design of each component of the system. Optimization involves determining, for example:

1. the minimum size a material can have while still providing sufficient fatigue strength to support the applied load,
2. the minimum weight and cost of a part while still providing an adequate Safety Factor for the design,
3. the design of the assembly that uses a minimum of individual parts so as to minimize manufacturing labor time (and hence cost) to assemble and later, to service the system,
4. the design of each component so that it utilizes the least expensive manufacturing tooling (i.e. forgings or stampings vs. casting vs. molding vs. weldments vs. CNC machining vs. manual machining, etc)
5. more than just the functional engineering aspects of the design and consider the need for the aesthetics of the final assembly in order to improve marketability or customer acceptance.

The well-engineered project will ultimately proceed to the fabrication and testing of a Prototype, its redesign based on the test results, the finalized (refined) design of a beta system and its testing by representative customers of the product. Product manufacturing and service, product manuals and, if appropriate, the product phase out once the design components, particularly the electrical control elements, become obsolete.

CONCLUSION

In an ideal world it would be possible to stop the or at least increase the page limit for reasonably sized ASEE papers! It certainly enters the mind of the engineering student who has struggled through 2 courses of Machine Design only to have it culminate in the Capstone Design Project which is infamous in its requirement for a working prototype to be completed.

More time would have enabled the Instructor to actually complete a Detail Design (ie. accurate, dimensioned and toleranced drawings, a complete Bill of Materials, a working prototype and a series of tests with a group of volunteer snorers. The higher priority demands of assisting the students in their more significant and real Capstone Project Designs required that the completion of the Instructor’s Mr. Sandman Project be postponed.

If a further rationalization is needed to justify the curtailment, then consider the observation that the amount of Design Process Methodology that has been reviewed in this Paper represents most of the innovative and creative aspects of the design process as it may be applied to engineering design. If forced to quantify the amount covered, the author will fall back on the 80-20 Rule once again and indicate that 80% of the Design Process Methodology has been reviewed in this Part I[12] of the Mr. Sandman (a.k.a. Snore-be-Gone) project. In other words: "it's all down hill from here".

This is not to imply that all of the important work is completed. Rather, only that the remaining 20% involves the more mechanical tasks of Detail Design, including detailed analysis, prototype fabrication and laboratory testing, customer beta testing, manufacturing scale up and product launch. Certainly these are a very significant part of the design process BUT the student/engineer is trained "by-the-book" to undertake these activities. The Detail Design and Analysis consists of the basic application of all of the engineering science that the student/engineer has struggled to learn within 4 or 6 (if graduate work is considered) short years at an accredited engineering College. Testing and, if necessary, prototype modification and then, very likely, retesting and then, hopefully, manufacturing continues the engineering development of the final product. But again, the accomplishment of these tasks can be learned in the more traditional manner of hands-on attention to detail, through mentoring with an experienced engineer, through technical papers, handbooks and one or two unscheduled courses in the 'school of hard-knocks'- all necessary activities to achieve success in solving the engineering problem.

Hopefully, the review of 80% of the design process provided in this Paper was successful in assisting the reader in what is considered the most difficult part of the process to teach or to learn: the application of a methodology to assist in the determination of creative design concept solutions to the problem at hand.

ACKNOWLEDGMENTS:
Anyone who has attempted to solve an engineering design problem very quickly realizes that the best design solutions cannot be obtained in a vacuum or by diligently pursuing the art and science of a solution from a self-imposed lofty ivory tower or deserted island. The constant stimulus available from the engineer's environment is a necessary spark to ignite the engineer's latent creative powers. The Sandman Project presented in this paper was born from the Instructor's need to provide an interesting theme to present to the senior (Class of 2000) Mechanical Engineering students of Machine Design I and II (Boston University) but was nurtured and spiritedly matured by the active involvement of these students. The Instructor thus taught but also learned from this interchange. Thus, gratitude is expressed (and not in any particular order of appearance or per centage of class attendance!) to the Class of 2000 for their attention, courtesy and involvement: Giovanni De Santi, Ferry Widjaja, Sergey Grigoryants, Claudio Rios, Mark Klein, Sean Leheny, Manna Lima, Jonathan Derosier, Artyom Makagon, Edward Notosoehardjo, Toby Varghese, Norhal El Halwagy, David Tasto, Tara Golba, Juliet Sonkoly, Michael Wier, Rebecca Young, Jason DeGray, Elizabeth Faria,

[12] Lest the Instructor's students begin to be alarmed over the prospects of a Part II of this treatise, please have no fear, for (to paraphrase Andrea del Sarto) your reach from the University will far exceed my grasp by the time Part II is written, OR what's a Graduation for?

Patrick Shores, Mary Jaggers, Emma Brianne Jaggers-Herkal (the youngest but not the sleepiest student; who also had the best excuse this Instructor's ever heard to take the course out of sequence), Andrew Roberts, Deborah Turner, Euijin Kim, Kevin Smith, Koichi Tsuji and Mark Wallace.

Thanks certainly to Prof. Mort Isaacson, Assoc. Prof. AERO/MECH. Dept., Boston University, for his constant participation, interest and late night contributions to the shared development of the Capstone Design Project course work and who always seeks and expects only the best from his students.

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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.

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.