Evaluation and Refinement of a Restructured Introduction to Engineering Design Course Using Student Surveys and MBTI Data

Daniel D. Jensen
Department of Engineering Mechanics, United States Air Force Academy

Capt. Michael D. Murphy
Department of Engineering Mechanics, United States Air Force Academy

Kristen L. Wood
Distinguished Visiting Professor, United States Air Force Academy, and
June and Gene Gillis Endowed Faculty Fellow in Manufacturing,
Department of Mechanical Engineering, University of Texas, Austin

ABSTRACT

A major restructuring of the Sophomore level "Introduction to Design Theory" course at the United States Air Force Academy has recently been completed. The most significant aspect of this restructuring is the addition of a redesign component to the course. In order to gauge the effectiveness of this restructuring, a questionnaire was developed to determine student rating of the course content lecture by lecture. Student responses are compared from before and after the restructuring. In addition, Myers/Briggs Types Indicator (MBTI) data are correlated with responses from specific lectures to determine if portions of the restructured course can be further improved. Results indicate that the course restructuring has been viewed positively by the students. Also, MBTI data indicate that, with additional effort towards providing "hands-on" experiences as well as increasing the amount of abstract content, the content can be better directed to the span of MBTI types. In addition, increased ties to student's design projects and other relevant examples will further improve the present course.

INTRODUCTION

During the Fall semester of 1997, a restructuring of the first design course at the United States Air Force Academy was accomplished. Historically, this first design course has been based on learning a design process followed by one original design project at the end of the course. Specifically, the course consisted of an introduction to the design process (following Ullman's process only) [Ullman] and incorporated a mass vs. lean design case study [Womack] throughout the course. An original design project was then completed which typically consisted of a past or present ASME design competition.

Beginning in the Fall semester of 1997, the restructured course included an introduction to the design process using Ullman as a guide, but also incorporated a redesign/reverse engineering process using the work of Otto and Wood [Wood]. Specifically, the first half of the course taught design tools by means of redesigning a simple child's toy, thus providing a "hand's-on"

aspect to which the tools could be immediately applied. Upon completion of the redesign project, an original design was embarked upon, again, using an ASME competition. The original design is then the student's second time going through the design process. The restructured course then provides an avenue to learn and apply the subject matter intuitively with sensory inputs from a hands-on article directly in front of them rather than learning a theory to be applied much later in the course.

In order to evaluate the effectiveness of the restructuring, from the student's perspective, the students were provided with a brief daily survey requesting their feedback on that lecture. The results from these surveys were used to provide course feedback in two different ways. First, the current (restructured) format for the course was compared with the previous format by viewing survey results from before and after the restructuring. The purpose of this feedback is to determine if the restructuring of the course is perceived to be positive or negative by the students. Details of this part of the investigation are given below.

For the second method of obtaining feedback, ratings for each individual lecture are separated based on whether the student had a sensing (S) verses intuitive (N) MBTI preference. These data points were then examined to determine if there was a correlation between the S-type or N-type student's rating and the specific content of that lecture. The four categories of lecture content used were 1) amount of "hands-on" , 2) quantity of relevant examples (relevant either to the student's design project or to an industrial example), 3) level of abstractness, and 4) amount that lecture presents a step-by-step process. Results from the MBTI portion of this work will allow a refinement of the course depending on the MBTI makeup of future classes. In addition, the MBTI work will provide possible explanations for results which appear to be unique to the student body at the United States Air Force Academy (USAFA). The specific methods for obtaining, manipulating and postulating conclusions regarding the MBTI data are provided below.

OVERVIEW OF THE COURSE RESTUCTURING
As previously mentioned, before the Fall semester of 1997, this course followed the mechanical design process as described by Ullman. While the general course material and design competition usually received high ratings, students evaluated the design methods with mixed reviews. Typical responses stated that the material was taught at a very high level and in a compartmentalized fashion. There did not appear to be clear relevance and hands-on experiences to deal with abstract topics, such as functional modeling and quality function deployment.
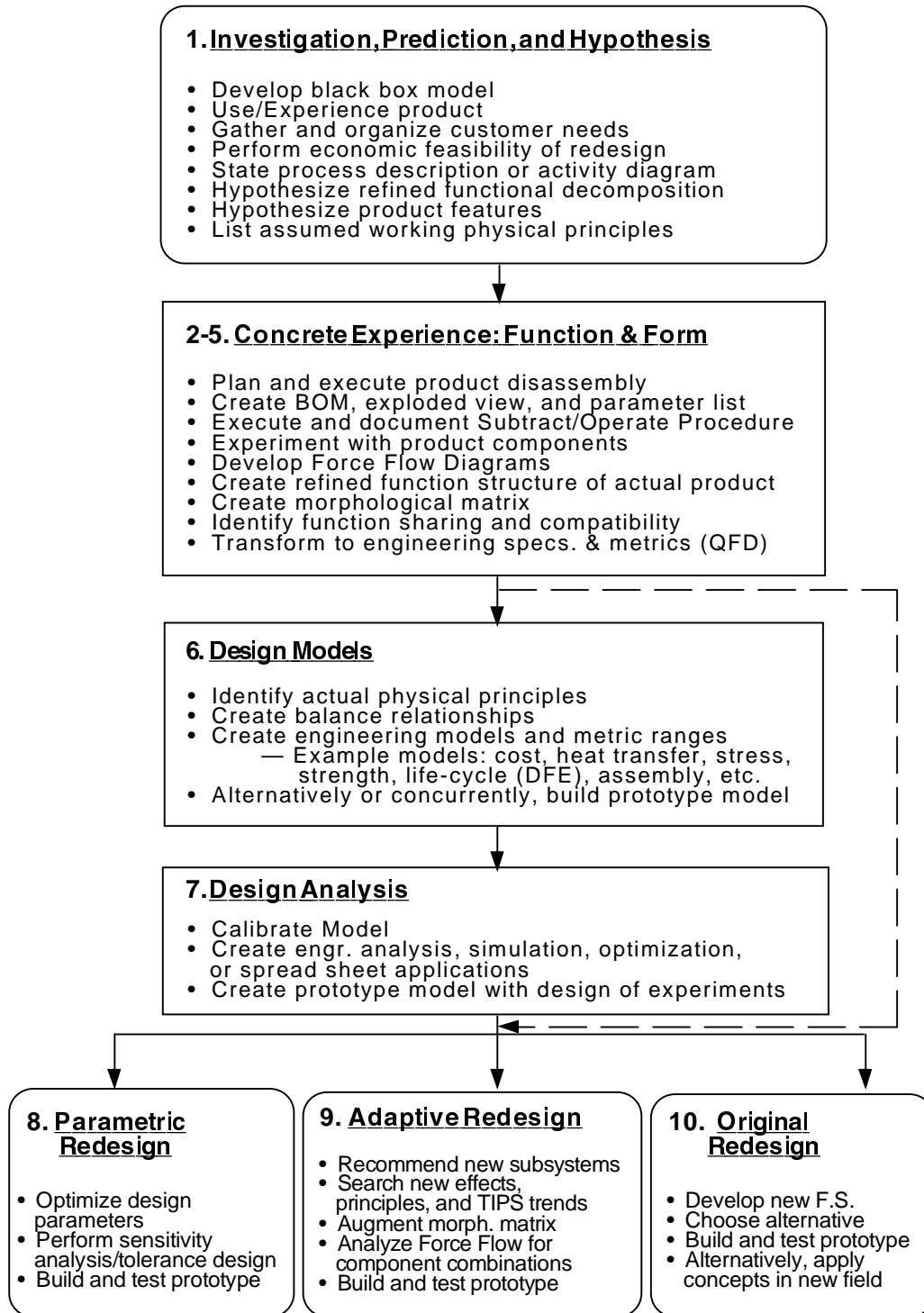
To address these issues, the restructuring involved adding a significant redesign component to the course and adding significantly more hands-on content than was previously included in the course. Reverse engineering of household products provided the foundation for redesign and the new hands-on emphasis [Otto and Wood]. For the first half of the course, students applied the course material directly to products chosen for redesign (such as mechanical and electro-mechanical toys, power tools, kitchen appliances, etc.). They also learned novel techniques for disassembling and evolving product architectures [Lefever and Wood, Otto and Wood]. By so doing, the students often had a physical object in their hands to test their understanding of the course materials. Hands-on products, in this sense, provided a forum to dissect, to measure, to experiment, to visualize, and to evolve their ideas into wonderful new creations.

After learning and applying design techniques to the reverse engineering projects, the second half of the course focused on an original-design problem. Design competitions were again the focus, but the students carried with them a grounding of the techniques from reverse engineering. They could now apply techniques, such as specification generation, customer needs analysis, and functional analysis, to a more general and abstract problem. In so doing, they could build on their concrete experience with an actual product, without having to simultaneously learn the mechanics of the techniques.

As stated above, the restructuring efforts focused on implementing reverse engineering projects during the first half of the course. These efforts centered around a new reverse-engineering and redesign methodology, depicted in Figure 1 and detailed in [Otto and Wood, Lefever and Wood] Three phases compose the overall structure of the methodology: reverse-engineering, modeling and analysis, and redesign. The first stage of reverse-engineering begins with investigation, prediction, and hypothesis of a product being redesigned. Through this approach, the product is treated, figuratively and literally, as a black box to avoid bias and psychological inertia. Product disassembly and experimentation completes the reverse engineering phase, wherein the product under study is dissected to understand its function and form. Design modeling and analysis follows reverse engineering. The intent in this phase is to fully understand the physical principles and design parameters for the product. Redesign completes the methodology with a choice of three avenues for product improvement: parametric, adaptive, and original.

The execution of this process in the present course begins by giving the students a household product to reverse engineer and redesign. The students are initially asked to predict how they think the product should work and gather customer requirements for later use in a QFD matrix (House-of-Quality). They then conceptualize both black box and more refined models of the predicted product's functionality and possible physical solutions (without taking the product apart). Only after this predictive phase is completed do they actually disassemble the product. They document the steps of disassembly in a disassembly plan (in order to aid in reassembling the product) and also develop a bill of materials which lists all of the parts contained within the product. An exploded view and subtract-and-operate procedure are required to make the students consider assemblability issues and to truly understand how their product fits together. Actual product function is documented and compared to the prediction. A morphological matrix is constructed using the parts and their corresponding functions, and function sharing throughout the device is investigated. Once the students fully understand the physical nature of their product and its functionality, they are asked to develop complete QFD matrices for the product, including benchmarking, technical difficulty, etc. They are then expected to use the QFD results, and other data collected, to propose design changes that should be made in the product.

FIGURE 1: REVERSE ENGINEERING AND REDESIGN METHODOLOGY.

1. Investigation, Prediction, and Hypothesis

- Develop black box model
- Use/Experience product
- Gather and organize customer needs
- Perform economic feasibility of redesign
- State process description or activity diagram
- Hypothesize refined functional decomposition
- Hypothesize product features
- List assumed working physical principles

2-5. Concrete Experience: Function & Form

- Plan and execute product disassembly
- Create BOM, exploded view, and parameter list
- Execute and document Subtract/Operate Procedure
- Experiment with product components
- Develop Force Flow Diagrams
- Create refined function structure of actual product
- Create morphological matrix
- Identify function sharing and compatibility
- Transform to engineering specs. & metrics (QFD)

6. Design Models

- Identify actual physical principles
- Create balance relationships
- Create engineering models and metric ranges
    — Example models: cost, heat transfer, stress, strength, life-cycle (DFE), assembly, etc.
- Alternatively or concurrently, build prototype model

7. Design Analysis

- Calibrate Model
- Create engr. analysis, simulation, optimization, or spread sheet applications
- Create prototype model with design of experiments

8. Parametric Redesign

- Optimize design parameters
- Perform sensitivity analysis/tolerance design
- Build and test prototype

9. Adaptive Redesign

- Recommend new subsystems
- Search new effects, principles, and TIPS trends
- Augment morph. matrix
- Analyze Force Flow for component combinations
- Build and test prototype

10. Original Redesign

- Develop new F.S.
- Choose alternative
- Build and test prototype
- Alternatively, apply concepts in new field

The execution of this process in the present course begins by giving the students a household product to reverse engineer and redesign. The students are initially asked to predict how they think the product should work and gather customer requirements for later use in a QFD matrix (House-of-Quality). They then conceptualize both black box and more refined models of the predicted product's functionality and possible physical solutions (without taking the product apart). Only after this predictive phase is completed do they actually disassemble the product.

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The remainder of the project is spent mathematically modeling or experimentally testing some aspect of the design, and creating an evolved product. Whether that evolved product represents only parametric changes from the original design or includes entirely new subsystems is left to the discretion of the students. This reverse engineering experience currently concludes around lesson 22 of the course.

STUDENT EVALUATION OF THE COURSE RESTUCTURING

To determine the effectiveness of the new approach, the average survey results for this semester were compared to those of previous semesters as shown in Table 1. Though the overall mean is only slightly improved, the standard deviation indicates a significant change. This reduction in variance could be predicted as the redesigned product used in the restructured course provides a stable example throughout rather than merely islands of theory interspersed by a non-related case study. This is perceived as a positive impact on the course. Further analysis based on MTBI personality types is addressed to further improve instruction.

TABLE 1
SURVEY MEANS AND STANDARD DEVIATIONS

SEMESTER	$\overline{\overline{X}}$	σ
SPRING 1996	73.7	8.5
FALL 1996	77.4	6.8
FALL 1997	77.7	5.6

USING MBTI DATA TO IMPROVE THE RESTRUCTURED COURSE

A significant amount has been written concerning methods for improving design courses including recent works by Evans, Harris, Moriarty, Wood and Koen [Evans, Harris, Moriarty, Wood, Koen]. For more information in this rather broad area, see the fairly comprehensive reference list in Dutson [Dutson] which focuses on capstone courses but is also relevant to lower level design courses which include projects. A narrower branch of this effort to improve the teaching of design includes those that have attempted to take learning styles into account when structuring a design course. A brief overview of this work is given in Felder [Felder 1996]. Examples of the broad range of applications of learning theory to design, as well as to engineering curriculum in general, include applications of the Kolb model [Stice], use of the

Piaget's model of early learning [Lumsdaine], and incorporation of the Felder-Silverman Learning Style model [Felder1988].

Use of student's and professor's MBTI data for purposes of improving engineering courses has been investigated as well. McCaully et. al. in conjunction with the Center for Applied Psychological Type have determined MBTI type for thousands of engineering students at various universities. This data has been analyzed for application to student learning as well as for possible use in career counseling and student retention strategies [McCaully1990, 1983, 1976]. Other examples include using MBTI to develop self instruction materials [Irey], using MBTI comparisons between freshman and senior students to determine the change in preference brought about during the four years of engineering curriculum [Rodman, Rosatti] and work which has shown the potential to increase academic success of struggling students by strengthening their non-preferred areas [Yokomoto].

The present work builds on what is known from MBTI type preferences and student learning in order to guide continuing improvements in the restructured sophomore level design course at the USAF Academy. The MBTI type includes four categories of preference [Myers, Jung, Kersey, Lawrence]. The first category describes whether a person interacts with their environment, and especially with people, in an initiating (extroverted) or more passive (introverted) role. Extroverts tend to gain energy from their surroundings while introverts usually gain energy by processing information internally. The second category gives information on how a person processes information. Those who prefer to use their five senses to process the information (sensors) are contrasted with those who view the intake of information in light of either its place in an overarching theory or its future use (intuitors). This sensor vs. intuitor category is seen by most researchers to be the most important of the four categories in terms of implications for education [Myers, Lawrence].

The third category for MBTI preference attempts to describe the manner in which a person evaluates information. Those who tend to use a logical "cause and effect" strategy (thinkers) are contrasted with those who use a hierarchy based on values or on the manner in which an idea is communicated (feelers). The final MBTI type category indicates how a person makes decisions or comes to conclusions. Those who tend to want to be sure that all of the data has been thoroughly considered (perceivers) are contrasted with those who tend to summarize the situation as it presently stands and make decisions quickly (judgers). The four letter combination of these indicators ("E" vs. "I" for extrovert and introvert; "S" vs. "N" for sensor and intuitor; "T" vs. "F" for thinker and feeler; "J" vs. "P" for judger and preceiver) constitute a person's MBTI "type". Table 2, which is adapted from Manual: the Myers-Briggs Type Indicator [Myers, McCaully 1976], gives a brief overview of the four MBTI categories.

TABLE 2
OVERVIEW OF THE MBTI CATAGORIES

Manner in Which a Person Interacts With Others			
E	Focuses outwardly on others. Gains energy from others.	Focuses inwardly. Gains energy from ideas and concepts.	I
EXTROVERSION		INTROVERSION	
Manner in Which a Person Processes Information			
S	Focus is on the five senses and experience.	Focus is on possibilities, future use, big picture.	N
SENSING		INTUITION	
Manner in Which a Person Evaluates Information			
T	Focuses on objective facts and causes & effect.	Focuses on subjective meaning and values.	F
THINKING		FEELING	
Manner in Which a Person Comes to Conclusions			
J	Focus is on timely, planned conclusions and decisions.	Focus is on adaptive process of decision making.	P
JUDGEMENT		PERCEPTION	

In the present study, the MBTI data for students was obtained along with the student's rating for each individual lecture in the course. As previously mentioned, the goal of the study is to direct future refinement of the course to enhance student learning. To this end, a four step process was employed.

Step 1: Obtain Averaged Lecture Values for 23 Lectures for S-type and N-type Students
Students rated each of the 23 lectures shown in Figures 2-5 on a 0-100 scale. The lecture ratings from students having sensor (S) MBTI type were separated from those students who were intuitors (N) on the MBTI scale. The individual S-type student's rating were averaged for each lecture as were the individual N-type student's ratings. These are the individual data points on the curves labeled "S-type Student's Lect. Rating" and "N-type Student's Lect. Rating" in

Figures 2-5. These averaged lecture ratings are labeled $\overline{X}_{S_i}$ and $\overline{X}_{N_i}$ for i =1,2,…23 where

the first subscript indicates the MBTI type and the second subscript indicates the lectures number.

Step 2: Obtain Overall Averaged Lecture Ratings and Standard Deviations for S-type and N-type Students

A mean and standard deviation was calculated for the overall S's and the N's ratings across the 23 lectures. As can be seen in the Figures 2-5 the mean for the S-types was 80.4 while the mean for the N-types was found to be 76.3. The mean and the standard deviations for the two different types will be labeled $\overline{X}_N$, $\overline{\overline{X}}_N$ and σ_S , σ_N for S-types and N-types respectively. Table 3 summarizes these calculations.

TABLE 3
Means and Standard Deviations for S-Type and N-Type

TYPE	$\overline{\overline{X}}$	σ
S	80.4	4.88
N	76.3	6.80

Step 3: Obtain Measure of Four Content Areas For Each Lecture

The three professors who were involved in teaching this course individually evaluated each lecture indicating if they thought that lecture did or did not have a high level of the four content areas shown in Table 4. The results from the three professors were combined, providing a somewhat averaged set of values indicating the quantity of the four areas of content for each lecture. Figure 2 shows that of the 23 total lectures, 5 of them were determined by the professors to have a high level of "hands-on" content. Similarly, Figures 3,4 and 5 respectively show that there were 13 lectures which had heightened "relevancy", 11 lectures where the content was significantly "abstract" and 10 lectures where the content fit into a "step-by-step" approach. Note that a lecture determined by the professors to have a "very high" component of one of the four types of content from Table 3, was given a score of 2 for that content type for the lecture where, if the component was somewhat lower in that lecture, yet still very significant, the score was recorded as a 1. These lecture content ratings are labeled $LC_i^{HANDS-ON}$,

$LC_i^{ABSTRACT}$, $LC_i^{RELEVANCE}$ and $LC_i^{STEP-BY-WTEP}$, i =1,2,…23 where the superscript indicates the content area and the subscript indicates the lecture number. The four categories of lecture content selected are detailed in Table 4.

TABLE 4
LECTURE CONTENT CATAGORIES

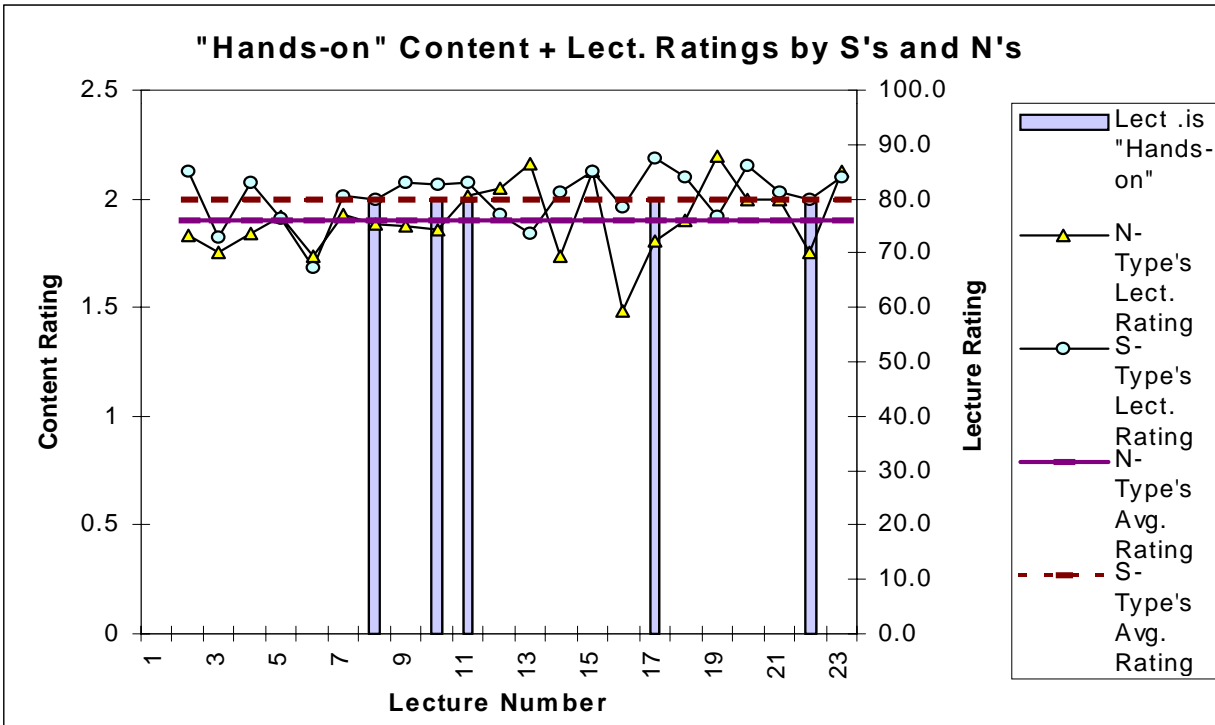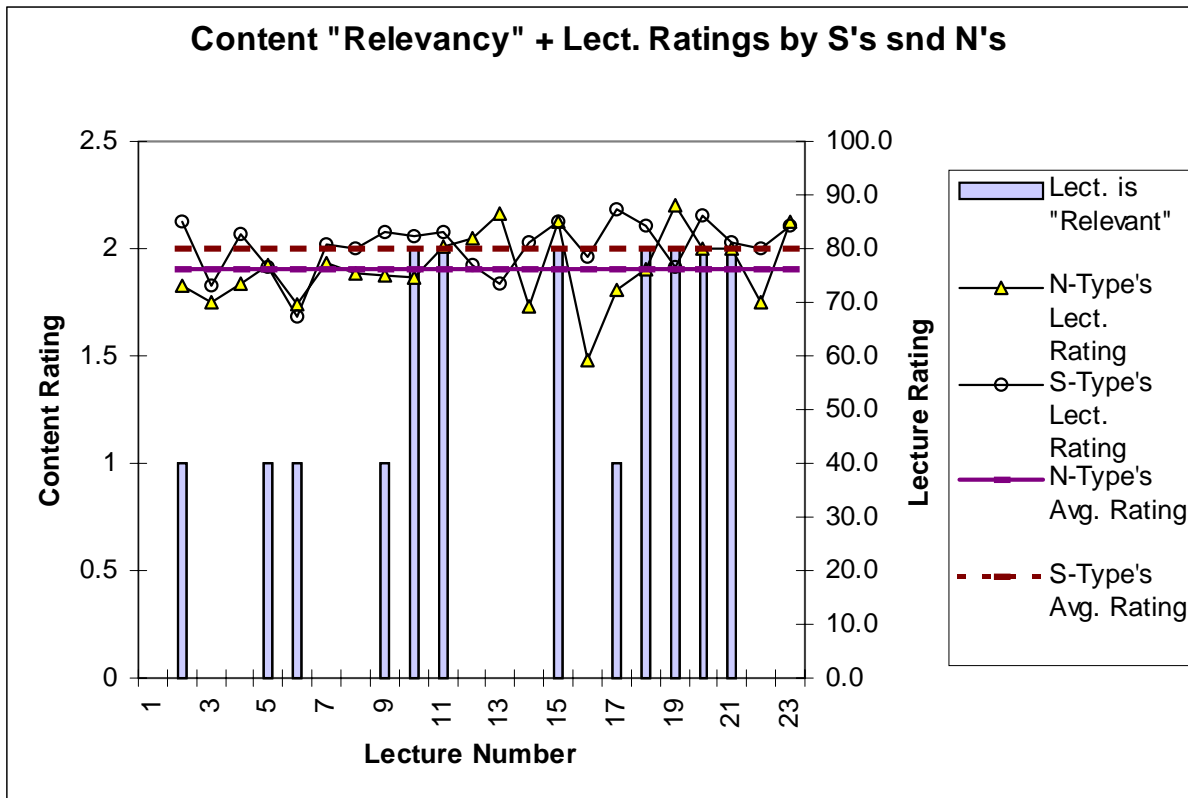| LECTURE CONTENT CATEGORY	DESCRIPTION OF THE CATAGORY
Hands-On	Measures to what extent the students were give products to physically manipulate
Relevancy	Measures the extent lecture content was related to student's projects or to examples from engineering industry
Abstractness	Measures the extent to which the content required students to exercise a global, creative or theoretical thought process
Step-by-Step Methodology	Measures the quantity of step-by-step methodology or "cook book" type content of the lecture

FIGURE 2

"Hands-on" Content + Lect. Ratings by S's and N's

FIGURE 3

Content "Relevancy" + Lect. Ratings by S's snd N's

FIGURE 4

Content Abstractness + Lect. Ratings by S's and N's

FIGURE 5
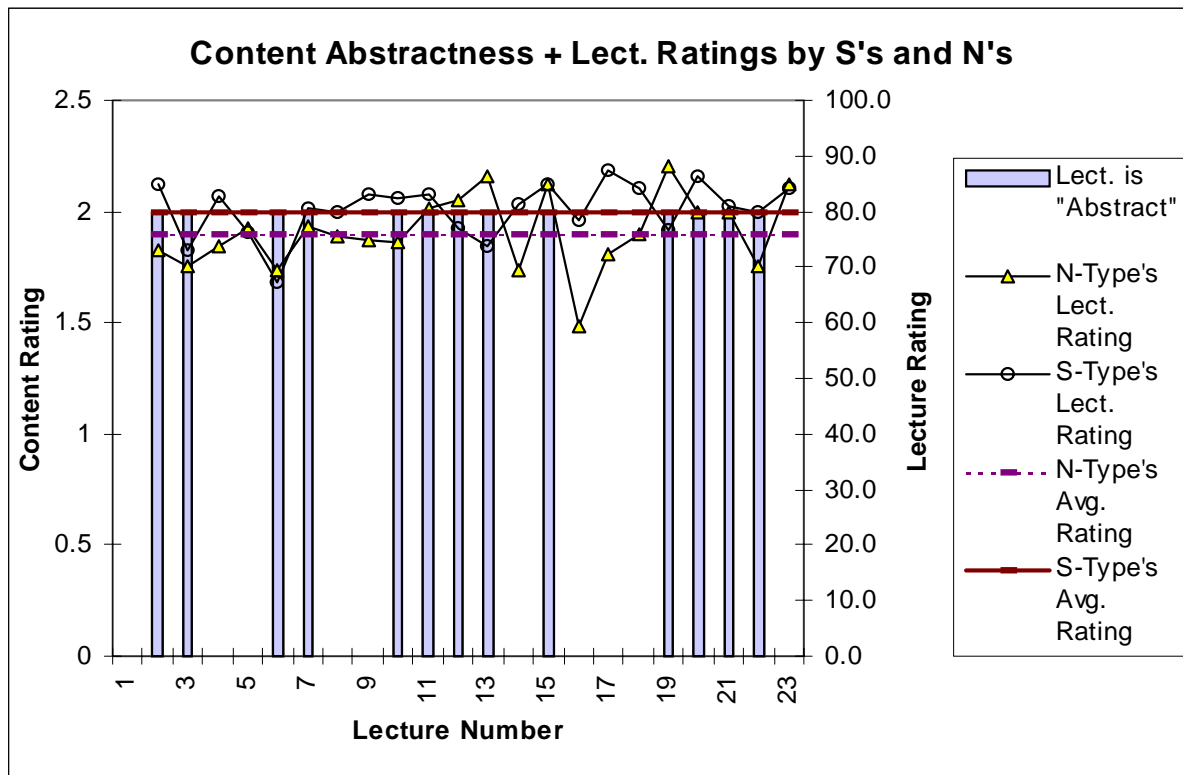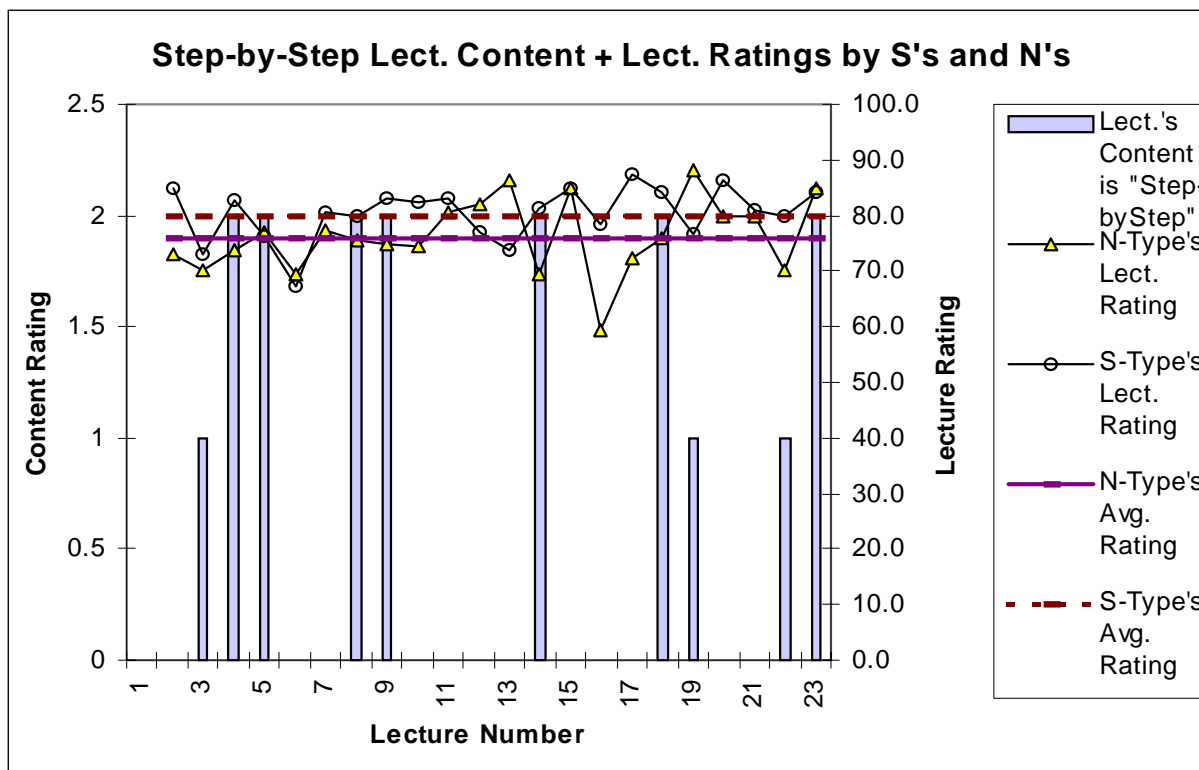

Step-by-Step Lect. Content + Lect. Ratings by S's and N's

Step 4: Obtain the Percentile Rating for Each Content Area as Rated by S-types and N-types

In order to determine an S-type and N-type percentile rating for each of the four content areas, the average number of standard deviations off from the mean for each content area is first computed. As an example, the computation for the content area of "hands-on" for S-type takes the following form.

$$Avg.\ Std.\ Dev.\ off\ Mean = \frac{\sum_{i=1}^{23}\left\{LC_i^{HANDS-ON} * \left(\frac{\overline{X_s} - X_{s_i}}{\sigma_s}\right)\right\}}{\sum_{I=1}^{23} LC_i^{HANDS-ON}} \quad (eq.\ 1)$$

Calculations for the other three content areas and for the N-types proceed similarly. Using results from (eq. 1) in the probability distribution function for normal data, a percentile rating for each of the content areas can be found for the S-type and for the N-types. The results are summarized in Table 5 where the number of standard deviations off from the mean is given with the associated percentile in parenthesis.

TABLE 5
NUMBER OF STD. DEV. OFF MEAN (PERCENTILE)
FOR CONTENT AREA AND TYPE

CONTENT AREA	S-TYPE	N-TYPE
HANDS-ON	0.46 (67.3)	-0.26 (39.7)
RELEVANCY	0.31 (61.8)	0.35 63.7)
ABSTRACTNESS	-0.22 (41.3)	0.28 (60.6)
STEP-BY-STEP	0.08 (53.2)	-0.06 (47.6)

As can be seen from Table 5, the S-types rate lectures which are high in hands-on content better then average 67.3 % of the time while N-types rate these same lectures above average only 39.7% of the time. This is an expected result in light of the fact that S-types prefer to use their five senses to evaluate information while N-types prefer to process this information internally. The percentile ratings for the content category of abstractness are almost reversed from those for the hands-on category. The S-types give above average ratings to the lectures which are high in abstractness only 41.3% of the time while the N-types give these lectures above average ratings 60.6% of the time. This also is an expected result as the N-types prefer to interact with information that is abstract, considering its applications or place in the bigger picture. Table 5 shows that the heightened relevancy of a lecture causes high ratings for both S and N-types (61.8% and 63.7% respectively). As the relevancy category was closely linked to the on going student project for the class, it is assumed that the high rating comes from a type independent desire to do well on the project, and therefore earn a good grade in the course. Particularly at the USAF Academy, where student demands are quite high, lecture content which is perceived to be beneficial to the timely completion of project work seems highly valued by the students. The content area of step-by-step was not seen to produce a very significant difference between the S and N-types. The small difference that does occur indicates that S-types slightly prefer this type

of lecture content while N-types slightly disapprove of this kind of content. This difference, while smaller then was expected, is in accordance with the MBTI theory as N-types prefer content which is more globally oriented and encourages thinking outside of normal step-by-step procedures.

In light of these results, a refinement of the restructured course is planned which will attempt to include a hands-on experience in lectures which are intrinsically abstract and an abstraction of the content for lectures which are intrinsically hands-on. In addition, ties between the lecture content and the student redesign project will be further strengthened. It is anticipated that this will elevate the N-type ratings on more hands-on lectures and S-type ratings of the abstract lectures. More importantly, the hope is that this will increase the motivation, and therefore learning, for both S and N-types.

CONCLUSIONS

A major restructuring of the introduction to engineering design course at the United States Air Force Academy was accomplished in the Fall of 1997. The most significant part of the restructuring was the insertion of a new redesign component. Student surveys given before and after the restructuring indicate that the restructured course had a significantly lower variance in the ratings indicated by a lower standard deviation. It is proposed that this occurred due to the ability in the new course to consistently relate the content to the student's redesign project. MBTI data were also included in the student surveys and correlated with the student lecture ratings and with four specific lecture content areas. It was determined that N-type students respond positively to abstract content and negatively to hands-on content while S-type students respond In the opposite manner; preferring hand-on content and disapproving of abstract content. Both the S-type and the N-type rate lectures which are especially relevant to their projects and engineering practice highly. The restructured course will be refined in view of these results to include increased hands-on and abstract content in a manner designed to meet the preferred learning styles of both the S and N-type students. In addition, a plan is in place to continue the use of the surveys in future courses in order to measure the effectiveness of the refinements made to the restructured course.

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BIOGRAPHICAL INFORMATION

DANIEL D. JENSEN
Dr. Jensen received his B.S. in Mech. Eng ('85)., M.S. in Eng. Mechanics ('88) and Ph.D. in Aero. Eng. ('92) all from the Univ. of CO at Boulder. His industrial experience includes Texas Instruments (mechanical design), Naval Research Labs (Ph.D. work), NASA Langley funded post doc and consulting at Lockheed and Lawrence Berkeley National Labs. He taught at Univ. of the Pacific for 4 years and now teaches at the USAF Academy in the areas of design and analysis.

MICHAEL D. MURPHY
Captain Murphy received his B.S. in Engineering Sciences ('88) from the U. S. Air Force Academy and his M.S. in Mech. Eng. ('95) from Oregon State Univ. His engineering experience includes the Armament Testing Lab at Eglin AFB, Boeing Commercial Airplane Group, and consultant to the Air Force Judge Advocate General. He is an Air Force Senior Pilot who has taught in both the Dept. of Mathematics and Eng. Mech. at the USAF Academy.

KRISTIN L. WOOD
Dr. Kristin L. Wood is currently an Associate Professor of Mech. Eng., at The Univ. of Texas at Austin. He completed his M.S. and Ph.D. degrees in Mech. Eng. at the Cal. Tech., where he was an AT&T Bell Laboratories Ph.D. Scholar. He received his B. S. in Eng. Science from Colorado State Univ. ('85). The current and near-future objective of Dr. Wood's work is to develop design strategies, representations, and languages which will result in more comprehensive design tools and design teaching aids at both the college and pre-college levels.