INCORPORATING LEARNING STYLES TO ENHANCE MECHANICAL ENGINEERING CURRICULA BY RESTRUCTURING COURSES, INCREASING HANDS-ON ACTIVITIES, & IMPROVING TEAM DYNAMICS

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Beginning in 1997 and continuing to the present, the U.S. Air Force Academy (USAFA) and the Univ. of Texas at Austin (UTA) have collaborated in a project to use learning style theory to enhance Mechanical Engineering curricula. Our primary learning styles indicator has come from the Myers Briggs Type Indicator (MBTI); although two other learning styles indicators (VARK and 6 Hats) and four models of the learning process (Kolb, Bloom's taxonomy, Scaffolding and Inductive/Deductive) were also incorporated. The project focused initially on our undergraduate design methodology courses. However, the impact of this work has now affected a large number of other courses in our departments. We have endeavored to extend, significantly, what others have done in this area [Bonwell 1998, Dunn 1978, Eder 1994, Felder 1988, 1996, Lumsdaine 1995, McCaulley 1990] to enhance our curriculum.

I. OVERVIEW & EDUCATIONAL OBJECTIVES

The three educational objectives which have driven this project are:

1. Reformulate course content to better correspond with what is known about diverse learning styles.
2. Use hands-on and multimedia content in conjunction with learning styles theory to enhance specific "target" lectures which students previously identified as low-motivation or low-interest.
3. Use learning style theory to enhance team dynamics, both in terms of initial team formation and improving team communication.

The project, overall, has resulted in dramatic increases in learning effectiveness for many of our courses. Specifically, a completely revised syllabus for the Design Methodology classes at both USAFA and UTA has resulted in significant increases in student ratings for those classes. Similar results occurred due to evolution of our machine design courses. Our assessment indicates that the addition of hands-on content and multimedia in a number of these courses has significantly improved motivation and interest, especially for certain under-represented learning styles. Finally, the team dynamics work has resulted in a new team formation algorithm, which has led to significant improvements in team performance and better team communication.

Overall, these enhancements have resulted in the publication / presentation of 17 papers (3 still in review) and 1 book, and they have affected 7 classes at USAFA and 8 classes at UTA (some of which are interdisciplinary classes). Over 600 students at USAFA, and a similar number at UTA, have benefited directly from this work.

In addition, colleagues at Univ. of Missouri-Rolla, Stanford, University of the Pacific, and MIT have collaborated with us in this work and, as a result, some of these techniques are included in their classes as well.

II. LEARNING STYLES & PROCESSES

For our study, we selected three methods to categorize student's learning styles: (1) MBTI, (2) VARK, and (3) 6 Hats. In addition, we have incorporated four models of the learning process: (1) Kolb, (2) Bloom's taxonomy, (3) Scaffolding, and (4) Inductive / Deductive flows. Each of these is described briefly below.

II.1 MBTI Overview

The MBTI type indicator includes four categories of preference [Jung 1971, Keirsey 1984, 2000, McCaulley 1976, 1983, 1990]. The first category describes whether a person interacts with their environment, 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 [Borchert 1999, Feland 2000, Jensen1998-1, 1999-2, Myers 1985].

The third category for MBTI preference represents 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 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 perceiver) constitute a person's MBTI "type". Table 1, which is adapted from Manual: the Myers-Briggs Type Indicator [McCaulley 1976, Myers 1985], gives a brief overview of the four MBTI categories.

TABLE 1: OVERVIEW OF MBTI

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**	

II.2 VARK Overview

The present work also builds on student learning preferences, as obtained from an instrument called the VARK Catalyst. Rather than being a diagnostic tool for determining a student's learning preference, the VARK test serves as a catalyst for reflection by the student [Bonwell 1998]. The student takes a simple 13-question test that is aimed at discovering how they prefer to receive and process information.

After taking the test, the student receives a "preference score" for each of four areas. The first area is Visual (V). This area indicates how much the student prefers to receive information from depictions "of information in charts, graphs, flow charts, and all the symbolic arrows, circles, hierarchies, and other devices that instructors use to represent what could have been presented in words." The second area is Aural (A). This area indicates the student's preference for hearing information, i.e., the student learns best from a lecture, tutorial, or talking with other students. The third area is Read/Write (R). This area shows a student's preference for information displayed as words, and is perhaps the most common instructional method used in Western education. The fourth area is Kinesthetic (K). In short, this area indicates a student's preference for "learning by doing." By definition, the "K" area refers to a student's "perceptual preference related to the use of experience and practice (simulated or real). The scoring of the test also allows for the student to show mild, moderate, or strong learning preferences for each of the four areas.

II.3 6-Hats Overview

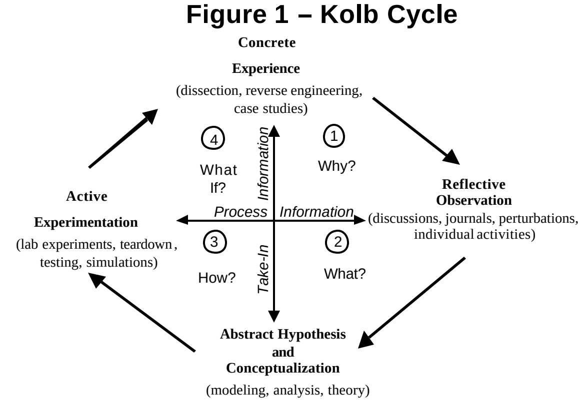
In the original 6-Hats work [DeBono 1985], six communication styles/roles are identified. Each style/role is associated with a certain color. When a person is using that particular style/role, they are said to be wearing that "hat".

The current work focuses on the use of these 6 styles/roles in a different manner than the original work. The idea in this present work is simply that each individual has established patterns of communication which can be identified using the 6-Hats categories. Once these preferred communication styles/roles are identified, they may be used in a design team formulation strategy (TFS) to both balance communication styles/roles as well as to ensure certain styles/roles are present.

II.4 Kolb Cycle Overview

The Kolb model describes an entire cycle around which a learning experience progresses [Kolb 1984]. The goal, therefore, is to structure learning activities that will proceed completely around this cycle, providing the maximum opportunity for full comprehension. This model has been used extensively to evaluate and enhance teaching in engineering [Murphy 1998, Otto 1998, Stice 1987, Terry 1993]. The cycle is shown in Figure 1.

Figure 1 – Kolb Cycle



II.5 Bloom's Taxonomy

Bloom's taxonomy gives 6 levels at which learning can occur [Krathwohl 1964, Terry 1993]. In general, a higher the level corresponds to a more advanced or mature learning process. Thus, we aspire to focus our instruction in higher education toward the higher levels. The six levels are given in Table 2.

TABLE 2 – Overview of Bloom's Taxonomy

Level	Name: Description
1	Knowledge: List or recite
2	Comprehension: Explain or paraphrase
3	Application: Calculate, solve, determine or apply
4	Analysis: Compare, contrast, classify, categorize, derive, model
5	Synthesis: Create, invent, predict, construct, design, imagine, improve, produce, propose
6	Evaluation: Judge, select, decide, critique, justify, verify, debate, assess, recommend

II.6 Scaffolding and Inductive/Deductive Learning

The term "scaffolding" encompasses the idea that new knowledge is best assimilated when it is linked to previous experience [Agogino 1995, Hsi 1995, Linn 1995]. A well-planned flow of material that builds on itself and integrates real-world examples obviously helps provide this "scaffold" for learning.

The terms "deductive learning or inductive learning" refer to learning from general to specific or visa-versa. For example showing the theory and then working an example is a form of an deductive process. Most courses use deductive approaches. The literature argues that this approach is not always appropriate [Felder 1996]. It appears that a mix of the two approaches provides the best learning environment.

III. METHODOLOGY & ASSESSMENT FOR THREE EDUCATIONAL OBJECTIVES

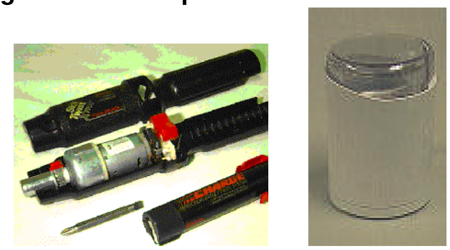
Below, a methodology and assessment are given which correspond to each of the 3 educational objectives listed above. Only overviews of our work in each area are possible here due to space considerations. The references provide far more detail in each category.

III.1. Reformulated Courses

III.1.1 Methodology for Courses

In an effort to accommodate various learning styles, our Design Methodology classes have been evolved to include both a reverse engineering / redesign emphasis as well as an original design component [Jensen 1998-1, 1999-2, 2000-2, Lefever 1996, 2000, Otto 1996, 1998, 2000]]. The course is split approximately in half, with the first half covering redesign and the second half covering original design. Typically, in the redesign portion, small design teams (3-5 students) compete to improve on customer requirements using toys or small consumer products (Figure 2). A suite of design methods guides the redesign process. The specific redesign methodology used is shown in [Jensen 1998-1, Otto 1998, 2000]. The original design portion focuses on an ASME student competition, an assistive technology device for people with disabilities, or similar project. Both the redesign and original design portions include full embodiment of the design.

Figure 2 – Example Consumer Products



A similar reformulation has been undertaken in our Machine Design courses. A remote controlled (RC) car (Figure 3) has been introduced to function as a sort of mechanical breadboard. The car is used in the second half of the course where machine components are analyzed and designed. A RC car has been identified that has a number of parts which can be analyzed for failure as well as a number of parts which could be optimized. Typically, students are asked to analyze approximately 6 of the systems including subsystems such as fasteners, shafts, gears and clutches. In addition to requiring certain types of analysis, as covered in class, students are asked to analyze/optimize a number of systems which have NOT been covered (but are addressed in the text or supporting materials). This approach is adopted in the context of a RC car competition that is held in place of a comprehensive final exam [Wood 2000].

Figure 3 – Remote-Controlled Car

III.1.2 Assessment of the Reformulated Courses

The reformulation of the design classes to include a reverse engineering/redesign component has led to substantial improvements in course ratings at both USAFA and UTA as documented in [Jensen 1998-1, 2000-2, Otto 1998]. Examples at USAFA include a 16% increase in student's ratings on the "intellectual challenge and encouragement of independent thought" and a 13% increase in the student's perception of the instructor's concern for their learning. The UTA courses experienced similar improvements, even up to a 50% increase in course ratings. In addition, the evolution of these courses gives the students two iterations (redesign and original design) to use the design tools. We have found this extra iteration increases the retention of this material between their first design course and their capstone course.

The decision to include redesign content is also reinforced by a number of learning styles issues. First, our work has demonstrated that certain types of students (MBTI Type-S and VARK type-K) perform significantly better when reverse engineering/ redesign type content is included [Jensen 1998-1]. These students typically have an aversion to purely abstract content. The inclusion of the reverse engineering/redesign component allows them to learn the design methods while manipulating an actual product, as opposed to applying the methods only to abstract paper designs, as is sometimes done in original design projects. Second, various models of the learning process were found to correspond more fully with the new course structures. In particular the new course structures allowed us to traverse the complete Kolb cycle [Otto 1998], particularly providing emphasis in the areas of "concrete experience" and "active experimentation". We are able to move farther down the Bloom's taxonomy of learning, providing more opportunities for levels 4-6. A redesign component also significantly enhances consistency with scaffolding theories by creating a framework for discussing design tools. Finally, it creates a very natural "inductive" environment by simply having a specific product as the example while discussing the design theories and methodologies.

Assessment regarding the reformulation of our Machine Design courses has also been very positive. The trends show an increase in reception by the students, especially regarding the ability to reason independently and the relevance of the content material. Students resonated with the refined course. The course material was evaluated as very difficult and challenging, yet the students perceived that an active and project-learning forum greatly added to their ability to understand and retain the material [Wood 2000].

III.2 Enhancing Target Lectures

Our second educational objective is to use hands-on and multimedia content in conjunction with learning styles theory to enhance specific "target" lectures that students previously identified as low-motivation or low-interest. Lessons learned by previous researchers who have incorporated hands-on content were used as a starting point [Aglan 1996, Carlson 1995, Catalano 1996, Kresta 1998, Regan 1996].

III.2.1 Methodology for Targeted Lectures

For our sophomore, junior, and senior design courses, our hands-on content took the form of low cost, simple devices like a fingernail clipper, mechanical pencil or quick grip clamp [Jensen 1998-1, 1999-2, 2000-2, Lefever 1996, Otto 1998]. Enough of these devices were distributed in class for each student or pair of students to manipulate a device. A specific design method or theory would be presented and related directly to the hands-on device.

For our Intro. to Mechanics and Solid Mechanics courses, various hands-on photoelastic devices were developed [Borchert 1999, Jensen 1999-1, Shakerin 1999, 2000]. Again, enough devices were used so that each student or pair of students had their own device. These devices were designed to qualitatively illustrate different stress distribution concepts. One such device is shown in Figure 4. Each device was constructed for under $30. In some cases the hands-on content was mixed with multimedia visualization content [Bowe 2000, Jensen 1998-2, 1999-1, Talreja 2000].

Figure 4 – Photoelastic Device

III.2.2 Assessment for the Targeted Lectures

Although our assessment shows that all learning style types benefited from the new content, students with specific learning styles were seen to benefit more dramatically than others. Table 3 shows data from one of our assessment studies [Jensen 1999-2]. A short 4-question survey was given to the students after each class. The targeted lectures (which were previously identified as "low motivation / low interest"), experienced a reversal of that trend and were rated in the 62^{nd} and 52^{nd} percentile overall by the MBTI S-Types and N-types respectively. As with the reformulated courses described above, the learning styles that indicated the greatest benefit were those that focused on non-abstract (tactile or visual) learning processes [Borchert 1999, Jensen 1998-1, 1999-1, 1999-2].

Table 3 – Percentile Ranks for Targeted Lectures

1 min. Survey Question	MBTI S-TYPE	MBTI N-TYPE
Lecture was interesting?	70	48
Lecture helped me learn?	58	50
Lecture helped me to apply material?	59	58
Lecture motivated me to explore subject further?	59	53
Average	62	52

The response to the photo-elastic devices was very positive. We saw again that the MBTI S-Type and VARK K-Type found the content more useful then their N-Type and nonK-Type counterparts. In particular, S-Types were able to increase their scores on quizzes given before and after the material by 26% while N-Types only increased their scores by 18% [Borchert 1999].

Although the vast majority of our assessment has shown these techniques to be positive, one example to the contrary is given in [Bowe 2000, Talreja 2000]. In this case students in our Intro. to Mechanics course at USAFA definitively stated that they did NOT prefer our multimedia content to a traditional lecture. Although originally baffled by this, follow-up assessment has provided a hypothesis, for which we are currently running an "educational experiment", to verify. It seems that the connection between the multimedia and the student's primary goal of simple survival was not properly established. In addition, the multimedia, which used finite element results to provide visualization of basic stress distributions associated with certain loading types, was probably posed at slightly too high a level for this course. It is worthy of note that, although the student's perception was negative, our assessment showed that the multimedia DID provide insight into the conceptual material and enhance problem solving ability, exactly as it was designed to do. After fine-tuning our presentation and lowering the complexity of the material slightly, we expect a reversal of the student's negative perception. We plan to report the results next summer.

The addition of hands-on and multimedia content to these targeted lectures fits well with "scaffolding" theories. The hands-on or multimedia give the student a "starting place" in which to frame the new ideas they are learning. The use of hands-on material and multimedia is thus an example of inductive presentation.

III.3. Team Enhancements

III.3.1 Methodology for Team Enhancements

Based on previous research in the area of team formation and team dynamics [Brickell 1994, Wilde 1993], we have developed and evaluated a new technique for forming teams and identifying their most likely communication strengths and weaknesses [Feland 2000, Jensen 2000-1]. The new technique uses both MBTI and a new instrument we developed from the "6-Hats Communication Styles" literature [DeBono 1985]. The technique is simple to implement. It requires that each student first determine their MBTI type. We use the web-based Keirsey form [Keirsey 2000], which takes the student about 10 minutes to complete. Each student must also complete a "6-Hats Communication Styles Instrument" which we have developed [Jensen 2000-1]. This takes an additional 10-15 minutes. Although our team-formation technique has a number of very explicitly stated objectives, the overarching goal is to ensure breadth of communication styles and information processing preferences within a team. A specific algorithm designed to accomplish this goal is given in the paper.

In both our design teams (sophomore and senior) courses and in our cooperative learning groups (intro. mechanics courses), these techniques have led to improvements in team effectiveness. In addition, these methods have provided the professors with concrete tools for addressing communication issues among the teams. Specifically, students are trained to appreciate and capitalize on differences in communication and information processing styles within their group. Furthermore, we use these techniques to coach teams to communicate both honestly and respectfully, which we believe facilitates team unity and effectiveness [Feland 2000].

III.3.2 Assessment on the Team Enhancements

The learning style based team formation and team communication work has had very positive results. A survey instrument was developed to measure the ability of teams to accomplish several specific goals. These goals were taken directly from the goals of the MBTI and 6-Hats team formation strategies, but would also be considered standard team effectiveness criteria. Examples of these goals include good team leadership, creativity, problem solving, conflict resolution, and ability to meet deadlines. The results, as measured by this team effectiveness survey, show a dramatic increase when team formation criteria from BOTH of these team formation techniques (6-Hats and MBTI) techniques are used simultaneously. Specifically, the overall team effectiveness index rose 84% when these two techniques were used in tandem as compared to when either technique is used exclusively [Jensen 2000-1]. Also, both the 6 hats and MBTI based techniques have provided professors with concrete tools for use in identifying team weaknesses and strengths in the communication area [Feland 2000].

IV. USEFULNESS TO OTHER INSTITUTIONS

The three educational enhancements described briefly above have already been implemented in various forms at our own institutions (USAFA and UTA). In addition, various forms of our enhancements have been used at Univ. of Missouri-Rolla, Stanford, MIT and University of the Pacific. Some of the features of these educational enhancements which makes them suitable for wide use are:

(a) It is NOT necessary to have a extensive knowledge of learning styles to implement our techniques. The MBTI, as used in our work, is based on the Keirsey instrument [Keirsey 1984, 2000], which is available, along with sufficient background, on the web. The use of this instrument is free and only takes about 10 minutes for students to complete.

(b) The specifics for reformatting a design course to include a reverse engineering / redesign component are given in a detailed, simple-to-follow format in [Jensen 1998-1, Otto 1998]. Similarly, the information needed to reformulate a machine design course is provided in [Wood 2000].

(c) As described in the various papers, the hands-on content is low cost and easy to build [Borchert 1999, Jensen 1999-2]. The most expensive hands-on demo is about $30 (with the exception of the RC cars).

Pictures of some of the hands-on devices used in the design classes as well as the photoelastic devices are included in the papers. Although the RC cars are much more expensive per unit (about $200 / car), teams of 3-5 students can effectively work to analyze or redesign the car, resulting in a more manageable $ per student cost.

(d) The multimedia we have developed for use in Mechanics courses [Bowe 2000, Borchert 1999] is currently available in Power Point form from the authors. We anticipate that this content will be available in the coming year in interactive web-based form from Wiley Publishers.

(e) The 6 hats based instruments are included in a simple, easy-to-use format in the paper [Jensen 2000-1] and are available in a Excel version. As opposed to the some MBTI based team formation algorithms, the one used in this work is simple, easy to use and has been quantitatively shown to increase team effectiveness. In addition, it lends itself easily to aiding in team communication counseling.

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