Hands-on Activities, Interactive Multimedia and Improved Team Dynamics for Enhancing Mechanical Engineering Curricula*

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The focus in engineering education is moving from an emphasis on theory to a balance between concrete experiences and analysis. This paper reports on such initiatives made to the Mechanical Engineering curricula at the US Air Force Academy and at the University of Texas, Austin. In particular, these two institutions have been collaborating for the last four years to improve ME courses through new initiatives in three areas: 1) use of hands-on activities, 2) incorporation of interactive multimedia, and 3) new tools to improve team dynamics. The development, implementation and assessment for this project are described below, along with extensive references describing the details of each individual improvement. For example, we have quantitatively measured significant improvements in team performance for our design courses. We have also seen dramatic increases in student interest level in the machine design courses. Based on these results, specific suggestions on how these educational enhancements might be implemented at other institutions are given.

OVERVIEW AND EDUCATIONAL OBJECTIVES

BEGINNING IN 1997 and continuing to the present, the US Air Force Academy (USAFA) and the Univ. of Texas at Austin (UTA) have collaborated on a project to improve Mechanical Engineering curricula through the use of hands-on activities, interactive multimedia and tools to enhance team dynamics. This has been motivated by an understanding of learning styles interpreted through three behavioral indicators (Myers Briggs, VARK and 6 Hats) and four learning process descriptions (Kolb, Bloom's taxonomy, Scaffolding and Inductive/deductive flows). Our primary learning styles indicator has come from the Myers Briggs Type Indicator (MBTI); although the two other behavioral indicators (VARK and 6 Hats) also received substantial treatment as shown below. The project focused initially on our undergraduate design methodology courses. However, the impact of this work eventually affected a large number of other courses in our departments. We have endeavored to extend, significantly, what others have done in this area [1–6] to enhance our curriculum.

The three educational objectives which have driven this project are:

1. Reformulate course content and delivery 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. 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 23 papers and 1 book [7], and they have affected 7 classes at USAFA and 8 classes at UTA (some of which are interdisciplinary classes). Over 700 students at USAFA, and a similar number at UTA, have benefited directly from this work. In addition, colleagues at the University 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.

LEARNING STYLES AND PROCESSES

For our study, we selected three methods to categorize student's learning styles: MBTI, VARK, 6 Hats, and four models of the learning process: Kolb, Bloom's taxonomy, Scaffolding, and Inductive/deductive flows.

Each of these is described briefly below. Although these educational or psychological theories are, of course, not our original work, there are aspects of *the use* of these in our educational innovations that are original. These include:

- the particular mix of three methods to categorize student's learning styles and four models of the learning process which gives our work a more balanced foundation than may be possible if one bases their approach on one or two theories only;
- our particular adaptation of MBTI and 6 Hats to team organization is original;
- our work showing correlation between MBTI and particular learning propensities is original.

MBTI overview

The MBTI-type indicator includes four categories of preference (Table 1) [8–13]. Although MBTI categorization is well established, its use as an indicator of the way people learn is far less common. The second of the four categories provides insight into 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 [14–18].

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 [1]. 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. The third area is Read/Write (R). This area shows a student's preference for information displayed as words. 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 allows the student to show mild, moderate, or strong learning preferences for each of the four areas.

Table 1. Overview of MBTI

Manner in Which a Person Interacts With Others			
E	Focuses outwardly. Gains energy from others.	Focuses inwardly. Gains energy from cognition	**I**
	EXTROVERSION	**INTROVERSION**	
Manner in Which a Person Processes Information			
S	Focus is on the five senses and experience.	Focus is on possibilities, 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 decisions.	Focus on process oriented decision-making.	**P**
	JUDGEMENT	**PERCEPTION**	

Table 2. Overview of 6 Hats communication styles/roles

White Hat	**Red Hat**
• I focus on objective facts.	• My feelings sway my decisions
• I enter into a discussion without preconceived ideas	• I have good intuition
• I seek to know the statistical evidence concerning a decision	• My personal opinions/emotions play a significant role in my decision making process
• I try to think totally objectively about a situation	• I am suspicious of other people's decision making process
• I seek to differentiate between facts and opinions	
• I am more interested in facts than opinions	
Yellow Hat	**Black Hat**
• I usually see the positive side of things	• I can quickly see why an idea will not work
• I can often see the good parts of even a bad idea	• I often can tell an idea will not work by judging from past experience
• I am usually optimistic that a new idea will work	• I like to play the 'devil's advocate'
• I believe that most new ideas have significant value	• I can readily detect poor logic in someone's argument
• I usually 'look on the bright side' of a problem	• I am often pessimistic of others ideas
• My comments are usually positive and constructive	
Green Hat	**Blue Hat**
• I am creative	• I like to lead the problem solving process
• I often generate new ways of thinking about a problem	• I tend to think as much about the problem solving process as the problem itself
• I easily think 'outside the box'	• I focus on the big picture, summarize and draw conclusions
• I am constantly thinking of alternatives	• I find myself trying to keep the group focused
• I am not likely to settle for the 'status quo'	• I often help the group clearly define the problem
• I can easily generate new concepts	

6 Hats overview

In the original 6 Hats work [19], six communication styles/roles were 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 the 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 balance communication styles/roles as well as to ensure that certain styles/roles are represented. In addition, the communication styles/roles (as identified by 6-Hats) can be used to facilitate effective group communication by identifying strengths and potential weaknesses and common conflicts that arise between certain 'hats'. Table 2 shows the 6 different hats and associated characteristics.

Kolb cycle overview

The Kolb model describes an entire cycle around which a learning experience progresses [20]. 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 [21–23]. The cycle is shown in Fig. 1.

Bloom's taxonomy overview

Bloom's taxonomy gives 6 levels at which learning can occur [24] (Table 3). In general, a higher level corresponds to a more advanced or mature learning process. Thus, we aspire to focus our instruction in higher education toward the higher levels.

Scaffolding and inductive/deductive learning overview

The term 'scaffolding' encompasses the idea that new knowledge is best assimilated when it is linked
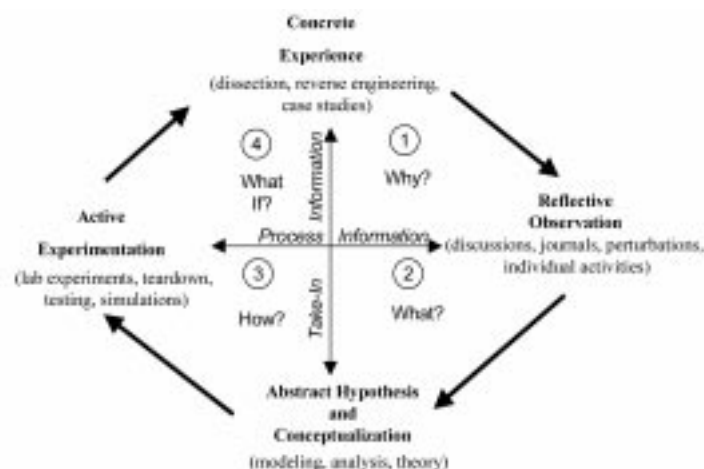

Fig. 1. Kolb cycle.

Table 3. 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

to previous experience [25, 26]. 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 (deductive) or from specific to general (inductive). For example, showing the theory followed by working an example is a form of a deductive process. Most courses use deductive approaches. The literature argues that this approach is not always appropriate; stating that a mix of the two approaches provides the best learning environment.

METHODOLOGY AND ASSESSMENT FOR THREE EDUCATIONAL OBJECTIVES

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

Reformulated courses

Figure 2 shows an overview of the courses that have been enhanced through this effort. As previously mentioned, courses at other institutions have also been affected. Details concerning methodology and assessment for these courses are given below. Note that before these courses were reformulated, they had minimal or no hands-on or

multimedia content specifically designed into the fabric of the course. The basic chronological flow in the curriculum is demonstrated by the arrows with the first course occupying the top left position (Intro to ME at UTA and Intro to Mechanics at USAFA).

Methodology for courses

In an effort to accommodate various learning styles, our Design Methodology classes (Intro to Design + Capstone Design at USAFA and Thermal Systems Design + Engr Design Methods + Capstone + Product Design at UTA) have been evolved to include both a reverse engineering/ redesign emphasis as well as an original design component [7, 16, 21, 27, 28]. The course is divided 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 (Fig. 3). A suite of design methods guides the redesign process. The specific redesign methodology used is shown in [7, 16, 21]. The original design portion focuses on an ASME student design 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.

A similar reformulation has been undertaken in our Machine Design courses. A remote controlled (RC) car (Fig. 4) 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 can be optimized. Typically, students are asked to analyze approximately six 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
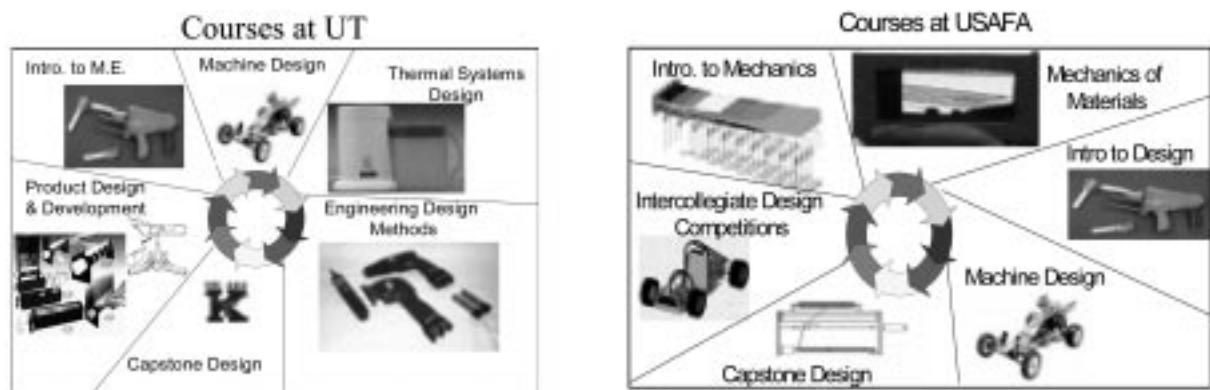

Fig. 2. Reformulated courses.

Fig. 3. Example consumer products.

of a RC car competition that is held in place of a comprehensive final exam [29].

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 [16, 21, 30]. Examples at USAFA include an *immediate* jump of 16% 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 longer term implications at USAFA have also been measured. For the four years after the reformulation took place the student feedback shows a 14% increase in 'the instructor's ability to provide clear, well organized instruction' and a 14% increase in 'the instructor's effectiveness in facilitating my learning'. During this same four-year period, students' responses show only a 2% increase in 'instructor's enthusiasm'. This is important because it indicates that the two 14% increases do *not* come simply from more enthusiastic instructors.

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 the material between their first design course and their capstone course.

Fig. 4. Remote-controlled car.

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 and other hands-on content is included [7, 16]. 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 for both our design methodology and machine design courses. In particular, the new course structures allowed us to traverse the complete Kolb cycle [21], providing particular emphasis in the areas of 'concrete experience' and 'active experimentation'. Also, 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.

Enhancing target lectures

Our second educational objective is to use hands-on and interactive 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 [31–35].

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 [16, 21, 27, 30]. Enough of these devices were distributed in
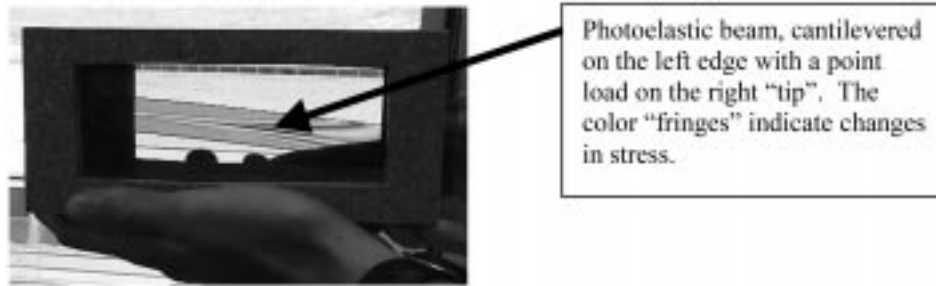
Fig. 5. Photoelastic beam, cantilevered on the left edge with a point load on the right 'tip'. The color 'fringes' indicate changes in stress.

class for each student or pair of students to manipulate a device. A specific design method or theory was presented and related directly to the hands-on device.

For our Introduction to Mechanics and Solid Mechanics courses, various hands-on photoelastic devices were developed [14, 17, 36, 37]. 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 Fig. 5. Each device was constructed for under $30. In one study, the hands-on content was mixed with multimedia visualization content [17, 38–42] and in another study the interactive multimedia was used alone [38, 43]. Our interactive multimedia was designed and developed to supplement, not replace, classroom lectures and reading of the text. This multimedia contains visualizations of stress distributions and complex machine components such as planetary gear systems. It also contains open-ended interdisciplinary design problems where the students are asked to design a system toward a specific set of design specifications. After the student specifies various parameters, the dependent variables are automatically computed, shown visually and then compared with the design criteria. See [41, 43] for details on downloading and using this interactive multimedia. An example of this is shown in Fig. 6.

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 4 shows data from one of our assessment studies [27]. A short four-question survey was given to the students after each class. The targeted lectures

Fig. 6. Example of interactive multimedia courseware.

Table 4. Percentile ranks for targeted lectures

30-second 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

(which were previously identified as 'low motivation/low interest', i.e. they were in the 30–40th percentile rating band), experienced a reversal of that trend and were rated in the 62nd and 52nd percentile overall by the MBTI S-Types and N-types respectively. The 'mean' lecture is a 50th percentile lecture and the rating followed an approximately normal distribution (each entry in the table represents approximately 75 individual data points). 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 [14, 16, 17, 27].

The response to the photoelastic devices was very positive. We saw again that the MBTI S-Type and VARK K-Type found the content more useful than their N-Type and non K-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 increased their scores by 18% [14]. This data demonstrates that the photoelastic devices positively affected the performance of both learning styles, with a more dramatic impact on the A-Types.

Three different assessment techniques were used to determine the effectiveness of the multimedia courseware:

1. 30-second surveys filled out by the students after each lecture.
2. Quick quizzes taken before and after using the courseware.
3. Specific exam questions designed to measure students' understanding of the concepts covered in the courseware.

The use of three different assessment instruments accomplishes two goals. First, the use of a variety of instruments reduces the 'noise' in the results simply by creating redundant measures. Second, the three techniques allowed us to measure different components of effectiveness [43]. The 30-second surveys, measuring the interest level of the students, showed an increase of between 6% and 15% of positive evaluation over standard lecture mode. The quick quiz assessment, measuring a conceptual understanding of the basic material, indicated between 4% and 11% increase in understanding. Although these increases may not be seen as dramatic, they are based on a fairly large data set (approximately 500 points) and use a control group for a baseline. Noise in the results has been statistically minimized by revolving the

control group between different sets of students. Finally, the exam question, measuring a slightly longer-term mastery of course material, indicated a 23% improvement in correct responses.

The addition of hands-on and multimedia content to these targeted lectures fits well with 'scaffolding' theories. The hands-on or multimedia gives the student a 'starting place' in which to frame the new ideas they are learning. The enhanced content allows us to move completely around the Kolb cycle by increasing concrete experience (through the increase in hands-on activities) and adding active experimentation (through the 'interactive' part of the multimedia). We postulate that this content also takes us farther down the Bloom's taxonomy. Specifically, the real-world devices (hands-on) provide numerous examples of how the design and analysis methods fall short of being 'perfect' models. In addition, the open-ended design problems in the interactive multimedia are intrinsically NOT closed form and have no single best solution. Finally, the use of hands-on material and multimedia is an example of inductive presentation flow.

Team enhancements

To complement our efforts in implementing hands-on activities, learning styles and interactive multimedia, we invested significant effort into understanding and improving team dynamics throughout the curricula. Our two focus areas in this effort were strategies to more effectively form teams, and strategies to facilitate communication within teams.

Methodology for team enhancements

Based on previous research in the area of team formation and team dynamics [44], we developed and evaluated a new technique for forming teams and identifying their most likely communication strengths and weaknesses [15, 45]. The new technique uses both MBTI and a new instrument we developed from the 6-Hats communication style literature [19]. The technique is simple to implement. It requires that each student first determine their MBTI type. We use either the web-based Keirsey form [10], or other MBTI instruments as seen in [46, 47]. These take the student 10–15 minutes to complete. Each student must also complete a '6-Hats Communication Styles Instrument' [45]. This takes an additional 10–15 minutes. Although our team formation technique has a number of very explicitly stated objectives, the

Table 5. Overview of team formation strategy (TFS) assessment

Team effectiveness criteria measured	Percent improvement of teams that met both MBTI and 6-Hats TFS over teams that did not
Good leadership, creative, good mix of positive interactions and constructive criticism	31%
Logical decisions, no procrastination, good intuition, good brainstorming	100%
Conflicts resolved, productivity, shared workload, alternative solutions to problems, overall enjoyment	131%

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 [45]. A summary of this algorithm in conjunction with the MBTI algorithm is as follows:

MBTI team formation strategy (TFS)

1. Either put an 'Extroverted Intuitor (EN)' on the team or as a secondary option, put an 'Introverted Intuitor (IN)' on the team and assure that someone else on the team is an 'Extrovert'.
2. Make sure there is a Sensor (S) on the team.
3. Make sure there is a 'Judger (J)' on the team.
4. Make sure there is a 'Perceiver (P)' on the team.
5. Make sure there is a 'Thinker (T)' on the team.
6. Make sure there is a 'Feeler (F)' on the team.

6-Hats team formation strategy (TFS)

1. Place a student on the team who has 'Green' as their primary 6-Hats type
2. Place a student on the team who has 'Yellow' as their primary 6-Hats type
3. Place a student on the team who has 'Black' as their primary 6-Hats type
4. Place a student on the team who has 'Blue' as at least their second 6-Hats type

In our design-team (sophomore, senior and graduate) courses and in our cooperative learning groups (introductory mechanics courses), these techniques have led to measured 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 [15].

Assessment on the team enhancements

The learning style 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. The results, as measured by this team effectiveness survey, show a dramatic increase when team formation criteria from BOTH of these techniques (MBTI and 6-Hats) are used. Table 5 shows some specifics of the improvements in team effectiveness.

USEFULNESS TO OTHER INSTITUTIONS

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

- It is NOT necessary to have an extensive knowledge of learning styles to implement our techniques. The MBTI, as used in our work, is based on the Keirsey instrument [9, 10] or other MBTI instruments as seen at [46, 47]. These are available, along with sufficient background, on the web. The use of some of these instruments is free and takes 10–15 minutes for students to complete.
- The specifics for reformatting a design course to include a reverse engineering/redesign component are given in a detailed, simple-to-follow format in [16, 21, 28]. Similarly, the information needed to reformulate a machine design course is provided in [29].
- As described in the various papers, the hands-on content is low cost and easy to manufacture and use [14, 27]. The most expensive hands-on demo is approximately $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 references. Although the RC cars are much more expensive per unit (about $250/car), teams of 3–5 students can effectively work to analyze or redesign the car, resulting in a more manageable dollar per student cost.

- The 6 Hats-based instruments are included in a simple, easy-to-use format in the paper [45] and are available in an Excel version. As opposed to some of the complicated MBTI-based team formation algorithms found in the literature, 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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