AC 2009-639: FORMING AND MANAGING PROJECT TEAMS IN A LARGE CAPSTONE DESIGN COURSE

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Forming and Managing Project Teams in Large Capstone Design Courses

Abstract

ABET and most companies recruiting new engineers expect graduating seniors to have teamwork and leadership experience and skills. In capstone design, good teamwork is closely connected to attaining an optimal design project solution. However, good teamwork does not happen automatically. This paper describes our approach at Michigan Technological University (MTU) with large classes of 100-150 students. The focus of the paper is on three key items: (1) forming balanced project teams; (2) monitoring team dynamics and development, and (3) evaluating each team's technical progress through a design review panel. Results show that our processes are transferable and significantly decreased the occurrence of dysfunctional project teams; they have also resulted in increasingly successful project outcomes.

I. Introduction

Background

The two-semester capstone design course in the Mechanical Engineering Department was taught for many years by different professors, but little documentation existed in terms of successes and challenges, particularly in the area on how to improve teamwork. A design committee influenced the direction of the course. However, the committee members were caught in a campus culture that for years was risk-averse and lacked a global vision for engineering education. Capstone course outcomes were very uneven, ranging from award-winning teams to dysfunctional teams producing hurried, mediocre, and superficial project results.

Change was introduced in 2004 with a pilot capstone design course taught in a distance learning format.[1] With new members on the design committee, changes were implemented to ensure that graduating seniors had a solid capstone design experience. Initially, the emphasis was on teaching creative problem solving as foundation to conceptual design .[2] Next, the focus was on improving design communication and report documentation, as well as on making the logistics more manageable for large classes exceeding 100 students in twenty projects or more.[3] These improvements occurred within the context of better teamwork and project outcomes.

Motivation and Stakeholders

In addition to technical competence, employers recruiting engineers expect graduating seniors to have teamwork and leadership experience and skills. These "soft" competencies ideally are honed through participating in a capstone design project. In capstone design, good teamwork is closely linked to an optimal design project outcome. However, good teamwork does not happen on its own; neither does the development of leadership skills. Our teambuilding effort in the 2007/08 academic year focused on team formation and development. In the 2008/09 academic year, the process was used by a different instructor whose primary goal was to better match student capabilities with project requirements. The same doctoral student assisted both instructors. For 2009/10, the process will be enhanced by using team management software discovered through benchmarking capstone design at Rose-Hulman Institute of Technology.

Among the stakeholders of a successful capstone design course and experience at MTU are:

1. Future employers of the engineering graduates.
2. Other departments (engineering, science or business) whose students would like to participate in interdisciplinary project teams.
3. Mechanical engineering faculty participating as team advisors, design review panel members, topical experts, or design committee members.
4. Graduating seniors where a successful capstone design experience is often of great interest to recruiters who ask crucial questions about leadership and teamwork.
5. Society at large who will benefit from engineers able to apply creative problem solving with a global understanding while working on teams whose members are very diverse.
6. University administrators who can see the benefits to their institutions through satisfied industrial sponsors of capstone design projects and enhanced prestige.

Capstone Design Course Objectives

One of the goals of the capstone design course is meeting the ABET 2000 criteria listed as the first eleven items in Table 1. A broader objective is to prepare students to compete successfully in the global marketplace. The last four criteria relate to thinking skills that will enable students to satisfy sponsor expectations, and these are best achieved within the context of a diverse team.

Table 1 Key Course Components that Address the Objectives and Criteria

Why	**What**	**Features**				**Projects**		
Objectives	***Criteria*** Relevant Crucial Focus of Paper	**HBDI**	CPS	12 Steps	Pugh	Logistics	Projects	Advisors
Meet ABET Criteria Succeed in a Globally Competitive World Learn the Conceptual Design Process Meet Project Sponsor Requirements	1. Development of student creativity	Relevant	Crucial	Relevant		Relevant	Crucial	
	2. Use of open-ended problems		Relevant	Relevant	Relevant	Relevant	Crucial	Relevant
	3. Solution alternatives and decision rationales		Relevant	Relevant	Crucial		Crucial	Relevant
	4. Use of modern design theory and methods			Relevant	Relevant	Relevant	Relevant	
	5. Formulation of design statements and specs			Relevant	Relevant		Crucial	Relevant
	6. Feasibility considerations			Relevant	Relevant		Relevant	Relevant
	7. Consideration of production processes			Relevant	Relevant		Relevant	Relevant
	8. Concurrent engineering design		Relevant	Relevant	Relevant		Relevant	Relevant
	9. Detailed system description			Relevant	Relevant		Relevant	Relevant
	10. Realistic constraints (DFX, economics, etc.)			Relevant	Relevant		Crucial	Relevant
	11. **Teams used in problem solving and design**	Focus of Paper	Focus of Paper	Focus of Paper	Focus of Paper	Focus of Paper	Focus of Paper	Focus of Paper
	12. Communication skills and documentation	Relevant	Relevant	Crucial	Relevant	Relevant	Crucial	Relevant
	13. Understanding/doing whole-brain thinking	Focus of Paper	Crucial	Relevant	Relevant		Crucial	
	14. Applying creative problem solving /analysis	Relevant	Crucial	Crucial	Crucial	Relevant	Crucial	
	15. Achieving an excellent project outcome	Relevant	Crucial	Crucial	Crucial	Relevant	Crucial	Relevant

Two additional objectives may at times appear to be in conflict: satisfying the project sponsors, who pay through a grant or contract for their teams, and a thorough teaching of the conceptual design process. Many students and faculty assume that students will learn the process and associated thinking paradigms simply by doing a design project. However, two ways of acquiring knowledge are involved and necessary for optimal learning: explicit knowledge, with the underlying thinking skills made transparent, and tacit learning, where the skills are applied and experienced, yet are often non-verbalized.[4,5]

By integrating the creative problem solving process into a structured, iterative conceptual design process, a dynamic is created for efficient learning which involves both explicit and tacit components. The goal is to provide a structure that will encourage the student project teams to follow the optimal sequence of steps for a superior project outcome coupled with a solid understanding of the conceptual design process.[6] The diagram in Figure 1 shows the central role of teams among the five essential components of a comprehensive capstone design course that exceeds ABET criteria to be best-in-class, based on years of experience educating engineering students and engineers working in industry. The designations A,B,C,D refer to particular thinking modes of the HBDI model (discussed in Section II of this paper).

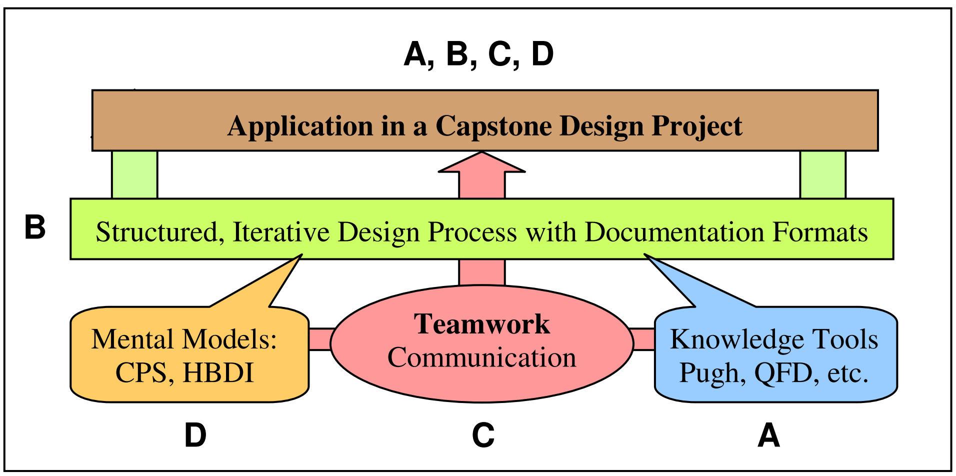

Figure 1 Central role of whole-brain teams for achieving optimal results in capstone design

Objectives for Developing Effective Design Teams

Within the context of the criteria listed in Table 1, the objectives for achieving Criterion 11 were:

1. Confirm a "robust" process for forming effective project teams that could be adopted by different faculty members and institutions.
2. Improve a process for monitoring team development which can identify, resolve, or prevent team dynamics problems and dysfunctional teams.
3. Achieve excellent project outcomes by all teams through application of the widely diverse thinking skills present in balanced teams with appropriate design tools, communication, and an engineering design review.

Students often confuse conflict in a team with *team dysfunction.* But conflicting views need to be expressed especially during the early stage of team development and conceptual design to promote creativity. Detrimental dysfunction occurs when teams are unable to move on to the development of integrated concepts, evident during the embodiment phase of design. It is most commonly seen in the uneven distribution of the work load, with a lack of communication or understanding of what others are doing on the team. Left to themselves, a five-member team will typically have two self-starters, two followers who need supervision but will do work, and an "outsider" unwilling or unable to contribute, either due to attitude or academic shortcomings.

Expecting a complete elimination of dysfunctional teams is not realistic in a course that includes a wide variety of projects and communication challenges with some sponsors. However, by educating the students about the different thinking preferences and the team dynamics within their purposely formed diverse teams, the number of dysfunctional teams can be minimized. Diverse teams require more careful monitoring by the instructors and advisors, until the team leadership has solidified and the teams are past the storming stage. When the advisors understand the design process and are engaged with the students, this special attention is not an extra burden.

Design project success is ultimately gauged by sponsor satisfaction. However, there is an educational aspect to the projects which is difficult for the sponsors to appreciate since they may not be familiar with the course material and academic goals. To achieve a better measure of a successful project, the students are evaluated by the instructor and team advisors throughout the project and by a *design review panel* at the midpoint in the project.

Constraints

To achieve successful project results and effective teamwork for all teams, the team development objectives listed above were constrained by the following requirements:

1. Balanced teams, whose members exhibit the full range of thinking modes, leadership, and communication skills, must be formed at the start of the course.
2. Project requirements must be identified by the sponsor and the project manager, with the teams or students then optimally matched in engineering capabilities to the projects within the constraint of achieving balanced teams.
3. The development of team dynamics and leadership must be monitored and issues resolved within the constraints of available staff: class instructor, assistant, advisors and faculty experts.
4. Resources to pay for the thinking skills assessment and other staffing must be obtained and proved to be especially difficult during the last years of economic downturn.

II. Forming Project Teams

Common Team Formation Schemes

Different schemes have been used by faculty members to form engineering design teams. A summary report states that "each of these methods has its advantages and disadvantages; however most are fatally flawed [because] they do not consider the strengths and weaknesses of the individuals involved and how to structure the mix to get the 'best' out of all team players."[7] The identified schemes[8] are:

a. Let students choose their own teams
b. Select students alphabetically
c. Select students by institution's student number code

d. Select team members based on previous performance
e. Select groups based on a heterogeneous mixture, i.e., sex, age, nationality, specialization
f. Select the team leaders and let them pick one additional member in turn
g. Select team members based on sitting or standing position
h. Select team members based on astrological star sign or month of birth
i. Select team members based on their Personality Type[9] and/or Learning Style[10]
j. Issue coded labels to students who then form groups based on the codes.

The first three schemes are used most frequently. When students choose their own teams, they commonly pick their friends or others who think like them. The result is often sloppy and can miss crucial angles in the project. Both (a) and (f) can alienate people who are not chosen for the team because they are "different." Information on previous performance (d) may not be available or could lead to dispirited "bottom" teams or arrogant "top" teams that can suffer from internal competition instead of functioning cooperatively. As stated in Reference 7, random selection overall "will produce average results at best. The only methods that will guarantee above average results are (e) and (i). Heterogeneous mixtures of students usually perform well due to their blending of expertise, experience and perspectives. However, even apparently well-balanced teams such as these sometimes fail to perform." Therefore, even when teams are carefully balanced, their development and team dynamics need to be monitored.

Many reports and papers that mention the use of teams in engineering design classes over the last decade do not explain how the teams were formed. Among methods that are identified for forming balanced teams are: Felder-Silvermann[11,12], MBTI,[13,12], Kolb[12,14], deBono's 6 Thinking Hats[15], and the HBDI[16,17,12]. An interesting comparison between the HBDI (Herrmann Brain Dominance Instrument) and the MBTI (Myers-Briggs Type Indicator) was published in a *Harvard Business Report* in 1997.[18] The two tools have been available for many years, yet only the MBTI is widely used in education due to its low cost. Because the MBTI is based on Jungian constructs, engineers tend to feel uncomfortable with this psychological "either-or" assessment tool. In contrast, the HBDI is based on the function of the brain, with results displayed in a graphical, easily understood form. It has been successfully employed for almost twenty years with many engineering students at several institutions in the U.S. and abroad to form mentally balanced project teams.[19-21] A comprehensive report in the UK investigated thirteen instruments or models available for assessing differences in learning styles at the college level; it concluded that there simply is no better tool for this purpose than the HBDI.[22] The next section presents a brief overview of the Herrmann brain dominance model and instrument (HBDI) used to assess student thinking styles in our capstone engineering classes.

A recent paper describes "best practices" for team formation and team assignment to projects.[23] This approach involved four or five teams each time it was taught. The process that evolved over seven years is as follows: (a) Teams with the greatest amount of diversity in majors and education level are formed first. (b) Presentations about the available projects are made to the teams, and they can indicate their preferences. (c) Teams are then assigned to projects by the instructor. Not all students were happy with their project, and these students were sometimes allowed to switch. One project was canceled and the students distributed to other teams due to a serious negative attitude by an engineering student toward a technical writer. No attempt was made to identify learning or thinking styles to develop appreciation for diversity.

The Herrmann Brain Dominance Model
The Herrmann Brain Dominance Instrument (HBDI) was used by the two instructors to form mentally balanced project teams. In such teams, the students learn to communicate and work with people who have different thinking preferences.[6,7,8] In addition, in the Fall 2007 class, the six creative problem solving mindsets (each involving two thinking quadrants of the Herrmann model) were explicitly linked to the 12 steps of conceptual design, ensuring that the team will cover the cycles of divergent and convergent thinking required for good design in the optimal sequence—which in turn can lead to optimal project results.[2] The four distinct ways of thinking and "knowing" of the Herrmann model are shown in Figure 2.

Each person is a unique and valuable mix of these thinking preferences and has one or more strong dominances. Dominance has advantages: quick response time and higher skill level. People use the dominant mode for learning and problem solving:

- Quadrant A thinkers typically analyze a situation carefully before making a rational decision based on the available data and the bottom line.
- Quadrant B thinkers will follow a very detailed, cautious, step-by-step procedure.
- Quadrant C thinkers prefer to talk the problem over with a team and will solve the problem intuitively; they are also more customer-oriented.
- Quadrant D thinkers will see the situation in a broader context and will look for alternatives.

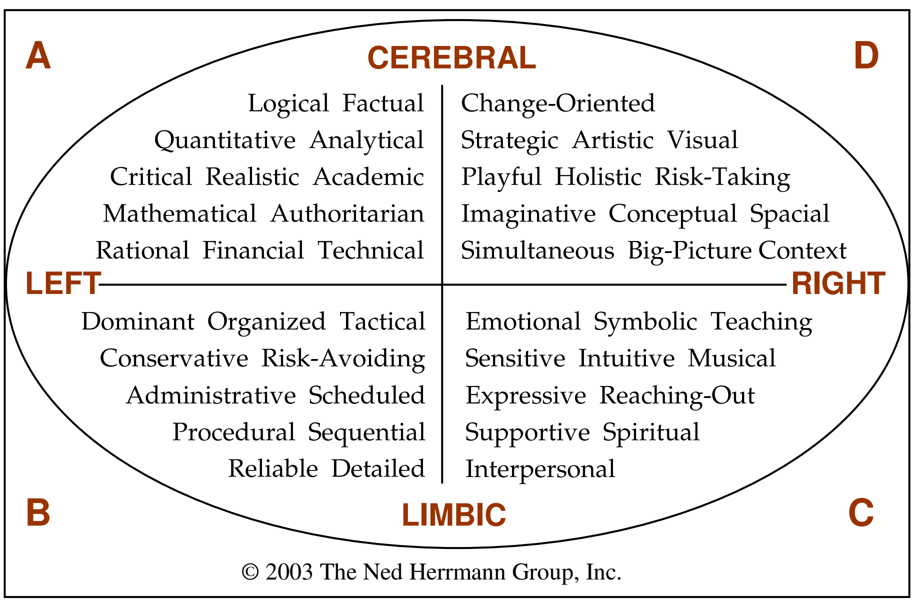

Figure 2
Thinking characteristics and behavioral clues of the four-quadrant Herrmann model of brain dominance

Because it takes more mental energy to think in less preferred modes, using these modes is exhausting and uncomfortable and thus may be avoided. Also, people dominant in diagonally opposite modes (refer to Figure 2) have great difficulty communicating and understanding each other because they see the world through very different filters. Is there a best way? Ned Herrmann found that each brain mode is best for the tasks it was designed to perform. ***People can learn to use all modes comfortably*** for whole-brain thinking and problem solving. Both the explicit information about the four-quadrant model and the tacit experience of working in diverse teams helps students to develop an ability to effectively communicate with all types of thinkers.

Students in the Fall 2007 and Fall 2008 capstone courses completed the HBDI survey form online about two weeks prior to the start of classes. The overall HBDI preference map with the profile “tilt” of each student in the two classes is shown in Figures 3 and 4, respectively.

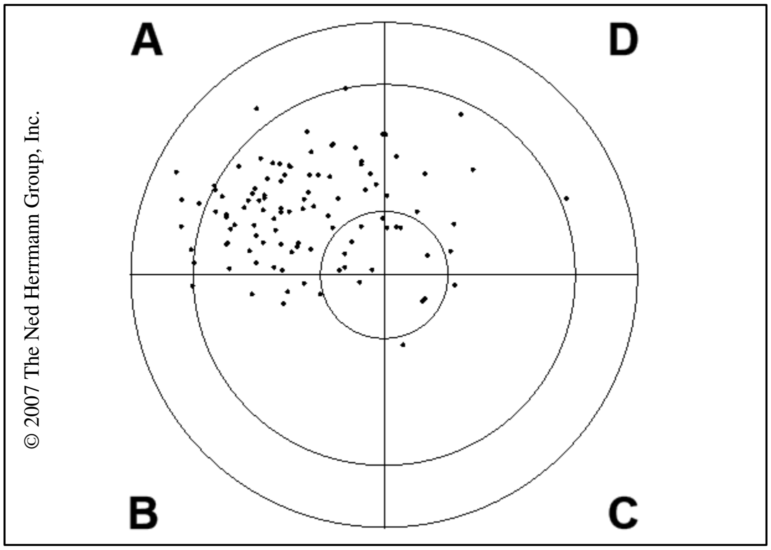

Figure 3
Brain dominance map (profile tilt pattern) for the Fall 2007 capstone design class, N = 106, with average HBDI scores per quadrant: A=97, B=75, C=46, D=69.

Profile tilt is calculated by plotting the coordinates (A-C, B-D) on a grid made up of the diagonal lines. An example is shown in Figure 4 for the extreme dot on the right: A - C = 47 - 78 = -31, B - D = 32 - 131= -99. The point (-31,-99) is plotted on the diagonal grid as shown.

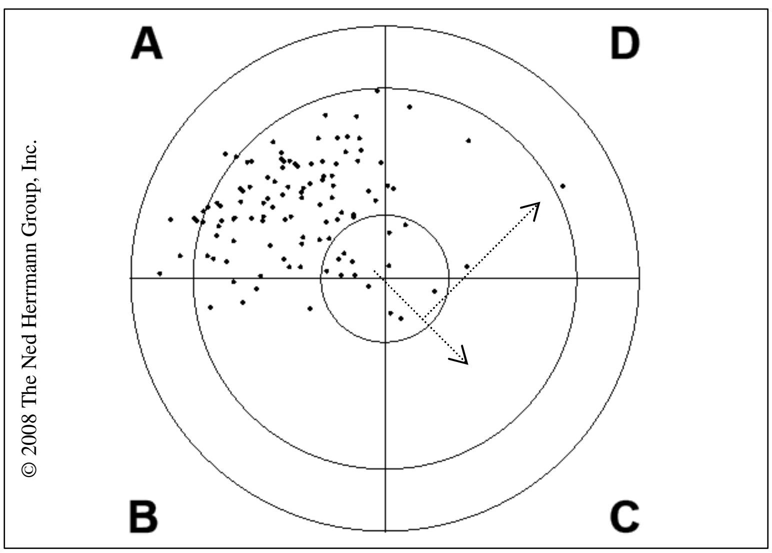

Figure 4
Brain dominance map (profile tilt pattern) for the Fall 2008 capstone design class, N = 107, with average HBDI scores per quadrant: A=98, B=75, C=42, D=71.

HBDI data for teams can be displayed in two additional useful ways: as a team average profile and as a *group composite,* with all profiles in the design team superimposed on each other. Each group graph can give valuable insight into group behavior, dynamics, and communications challenges. Figures 5 and 6 show two examples of capstone teams. Diverse Team 5 was formed with multidisciplinary students chosen by the sponsor to meet specific requirements. Team 6 was formed with latecomers to the class (after the other teams were already in place) and resulted in an extremely homogeneous group which subsequently encountered a number of problems. Note the range or diversity of thinking represented in each quadrant in Team 5 as compared to homogeneous Team 6. Although a heterogeneous team may experience communication challenges in the early stages of working together, it will have a much better chance of achieving a superior project outcome, due to a balance of right-brain and left-brain thinkers on the team.

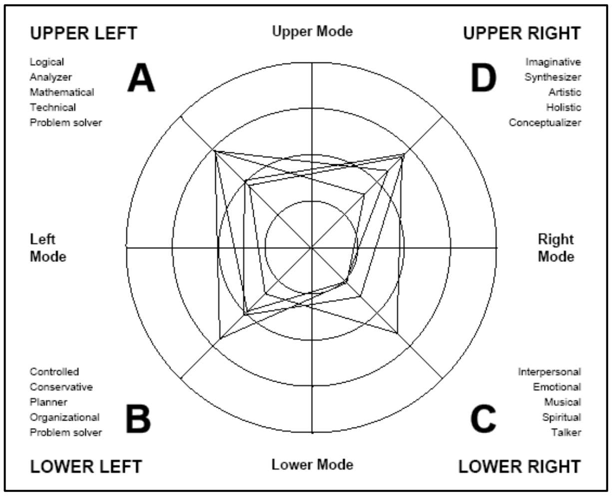

Figure 5
HBDI composite of a heterogeneous team.
Average HBDI: A=82, B=69, C=52, D=80

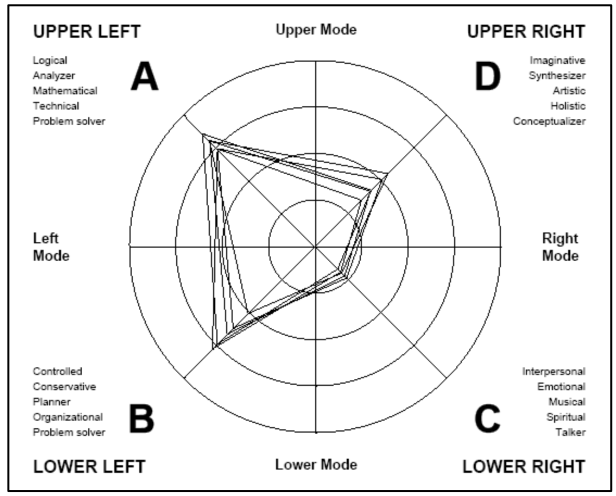

Figure 6
HBDI composite of a homogeneous team.
Average HBDI: A=105, B=89, C=28, D=60

In the HBDI, a score > 66 indicates a strong preference, a score between 34-66 comfortable usage, and a score < 34 a tendency to avoid these thinking modes. These regions are delineated by the inner circles in Figures 5 and 6. Nearly 20 years of engineering student HBDI results have revealed that typically, 20% or more of capstone seniors are uncomfortable with quadrant C thinking (which is used in communication and teamwork). Unfortunately, the 2008 class had 32% of its students with quadrant C thinking scores less than 34. Figure 6 shows five such students. It was thus not possible to make up completely balanced project teams for this class since more than half the teams had to be assigned more than one low-scoring C-quadrant thinker.

How Balanced Teams Were Formed
After students completed the on-line HBDI survey form, the results were presorted into homogeneous groups and color-coded. Because the Fall 2008 class had few right-brain dominant thinkers, the groupings resulted as shown in Table 2. Then, each name on the student class list was marked with the color of the respective homogeneous group.

Table 2 Homogeneous Groups for the Fall 2008 Capstone Design Class (N=107)

Line	***Color***	***Dominance***	***N***	***HBDI Average***			
				A	***B***	***C***	***D***
1a	Yellow Left	D + A, low C	16	**101**	58	**37**	**89**
2a	Red	Multi (C, whole-brain)	**9**	72	78	63	73
1b	Yellow Right	D	13	73	64	50	**103**
2b	Green	B	10	88	**100**	44	57
3	Purple	A + B, very low C	17	**110**	**96**	**31**	50
4	Blue	A (extreme), low C	20	**117**	70	**36**	59
5	Brown	A	22	**99**	71	45	71

In addition, two other marks were added as relating to quadrant C thinking preference:

a. Because very few engineering students are C-dominant, the 20% with the highest C scores were identified and marked with an additional orange dot, even though they almost always have stronger dominances in other quadrants.
b. Then all students with C scores less than 34 were marked with a penciled circle next to their color code. These students tend to avoid this type of thinking and would rather work alone; thus a team with more than one of these will have a good chance of being dysfunctional.

Next, a "draft" team roster was prepared for each project, with each line identified by one of the five colors. For Fall 2008, teams with a left-brain yellow needed a red for Line 2; teams with a right-brain yellow needed a green for Line 2, as shown in Table 2. Only one student per line was assigned to ensure formation of a balanced team. An extra line was added for six-member teams and filled with a remaining student for increased diversity if possible. For four-member teams, a student with a strong double dominance was selected to fill two slots.

From this point on, the two instructors used a slightly different approach and emphasis for actually forming the teams.

Option A—Balanced Team Emphasis (used for the Fall 2006 and Fall 2007 classes):
First, a list was compiled for each project with the names of all students who had included the project among their five top preferences. Next, a roster with a student from each homogeneous group or color was completed for each project, using the following steps:

1. Students with special capabilities (including students from other departments/majors) were assigned to projects to meet specific project needs and sponsor requirements, and their names were entered on the roster according to their identified color.
2. Some projects were very popular; others had only a few interested students. Students were next assigned to projects by starting with projects having the fewest interested students.
3. For each project, a student with high C was entered on the project roster on the identified color line, together with the orange dot marking.
4. Similarly, a low-C student was entered on the roster, with the penciled circle marking.
5. Then the roster was completed for the remaining open lines. If more than one student was available for any one color and project, the criterion was to balance the GPA of the team.
6. Finally, the average HBDI profile of the team was checked. If it deviated markedly from the class average, students with the same color code and project preferences were switched. Also, the rosters were checked to make sure each team had at least one student with CAD capability, one with communication skills, and one with leadership experience.

Option B—Emphasis on Project Requirements (used for the Fall 2008 class):
Teams were formed with the goal of meeting specific project technical needs and not having the majority of the members on the team with the same thinking preference.

1. Ahead of time, the instructors, project advisors, and project manager discussed with the sponsors the scope of the project and the special capabilities that the team should have for the project. However, these were considered to be suggestions only. Project scopes can sometimes be misleading to students, and interest in the project (based on project scope description) does not determine if the students will do well in the project.

2. A skills survey was e-mailed to the students, along with the project descriptions. They were asked to list projects that interested them and the courses they had taken from the curriculum, together with their fabrication skills, leadership experiences, and work experiences. For example, knowing if students have taken or are enrolled in modal analysis or noise control will help identify their interest in projects with those requirements. Merely asking if they have taken CAD and FEA is not sufficient to help identify student skills useful in projects. All this information was compiled along with the HBDI results for each student.
3. The HBDI results for the entire class were examined to determine thinking preference with the fewest students. In this case, it was "red" for students with high quadrant C preference. Each one of these students was placed on a team of his or her preference. Since the list was smaller than the number of projects, the remaining projects were assigned a student with leadership experience. Thus each team had at least one potential leader.
4. The students with the most critical engineering skills were then assigned to the projects.
5. Next, the HBDI results of the students already on the projects were examined to determine what thinking preferences were missing. The rosters were then completed with students having these thinking preferences and an interest in the project, as was done in Option A.
6. Finally, the projects were examined for heterogeneity—the inclusion of the different thinking preferences. In this class of more than 100 students, this was difficult to achieve on the first try and required some iterations. Meeting project technical needs and preventing highly homogeneous teams took priority over student interest in a project.

III. Team Management

A two-pronged approach was used to manage the team dynamics: one involved logistics and tools, the other was paying extra attention to developing the team leaders.

Logistics and Tools

The following were key team management tools and factors that contributed to good teamwork. Assignments for the Fall 2008 class differed from the Fall 2007 class, but goals stayed the same.

- Information: With the HBDI packets, students received information on the team development process[24] and the implications on communication and resolving conflicts through a process of *creative abrasion*.[18] Smooth teamwork early in the project was praised by the students; however, it is not always desirable since conflicting ideas and diverse views can make for a superior, more creative project outcome. Students also received periodic updates and reminders via the web on teamwork—see Appendix A and Appendix B.
- Teaming tools: The first assignment was to develop a set of team ground rules. These were reviewed by the instructor and discussed in the team leader seminar. They also received tips on meeting agendas and management, as well as a lecture and template on project planning (including the creation and maintenance of updated Gantt charts).
- Monitoring team development: The teams' progress through the forming, storming and norming stages[24] was monitored, mainly through completion of a *peer contribution rating form*[6] at midterm and at the end of each semester. Most teams (at the beginning of the second term) were well on their way to reaching the performing stage of team development.
- Resolving problems: The teams were enabled to deal with conflict (which often arose from differences in thinking preference[18]). Scheduling conflicts were another common problem,

but most teams found a creative way to deal with those. Lack of motivation, commitment, and a poor work ethic proved to be most difficult. If a student chose not to change and contribute an average of 6-7 hours/week on the project, the consequences were a penalty in points distributed according to the contributions each member made to the team project. Uneven work loads could not be avoided at times due to competency constraints and language barrier in the case of foreign exchange students.

- <u>Positive factors contributing to good teams:</u> enthusiasm; splitting the work fairly (based on the capabilities of members for effectiveness and efficiency); appreciating one another's strengths; willing to learn new skills; doing whatever it takes to get the project done; wanting the team to excel; going beyond expectations; pride in the team's accomplishments, and enjoying working together.
- <u>Personal or systemic issues:</u> Some students had few abilities for making useful contributions to their team or project—how did they make it through engineering this far? Some slackers were unwilling to change; they had low goals for themselves and no initiative. Students in general found it easier to make negative comments about team dynamics or the achievements of their project instead of focusing on the positives. Puzzling were contradictory comments by different members of the same team. Discrepancies were also noted between a few "official" final reports which were complimentary of teamwork and individual confidential peer reviews, which revealed some deep-seated animosity, misunderstandings, and problems. However, these teams still managed to do good work and complete their projects.

Team Leadership

Having the right people in the right place within a team is a very important factor for project success. However, it is often difficult to get these people in the right place, which is why good leaders who understand the power of the HBDI are important along with effective leadership training. Team leaders for the design teams either volunteered or were chosen by the team for having special knowledge or experience in the project area or sponsor's organization.

For the <u>Fall 2007 class,</u> a leadership seminar was instituted to address teaming issues and provide additional information for each team based on their team's composite HBDI results. Once or twice a month, the instructors called a Saturday brunch meeting for the team leaders to discuss team dynamics, give tips on applying teaming tools, and have the leaders share information with each other. This peer support was found to be especially useful. Time pressures made it impossible to continue the seminar beyond the first semester. Attendance was voluntary; leaders did not receive any credit nor pay extra tuition. Two teams had an amiable change in leadership when two leaders with low C scores were replaced at mid-term. Another team often complained about their unorganized leader; they met with their advisor to resolve the issues, but they did not carry through on the recommendations. Due to the heavy teaching load, the instructor was unable to take care of team problems outside of the leadership seminars.

<u>FALL 2007 HBDI DATA:</u>

Average HBDI scores of 21 leaders:	A=92	B=73	C=53	D=74
Average HBDI of team members:	A=98	B=75	C=45	D=68

For the <u>Fall 2008 class</u>, each team had a primary leader or captain, assisted by a co-leader (or two in the case of one team). Two leaders from each team were required to attend a weekly Project Management and Leadership meeting on special topics with one of two advisors. This meeting was limited to 15 minutes in two different groups (to keep the group size small), and the teams could bring up teaming and communications problems for discussion and answers. At the end of the first semester, the advisors evaluated the leadership. One team changed leadership at the request of the leaders and the team members.

FALL 2008 HBDI DATA:

Average HBDI scores of 19 leaders:	A=97	B=71	C=46	D=75
Average HBDI scores of 20 co-leaders:	A=98	B=80	C=43	D=71
Average HBDI of team members:	A=99	B=77	C=40	D=68

For both years, it was found that on the average, team leaders had higher interpersonal communication and big-picture thinking preferences than the team members at large. Where there were co-leaders, these often had complementary thinking preferences, with the co-leaders on the average being more organized. However, when a leader with a strong quadrant D thinking preference was paired with a co-leader who had a strong preference for quadrant B thinking, the differences on occasion led to contradictions and temporary confusion for the team.

Weekly lectures on teamwork in a regular class format for the leaders were unpopular and were discontinued. The teams no longer had project advisors but faculty experts to consult about the technical aspects of their project. The design instructors met briefly each week with the topical experts and team advisors. Having separate advisors for team dynamics issues worked out well and will be continued.

IV. Design Review Panel and Project Success

In early 2007, the departmental design committee decided to establish a review process for the capstone design projects, to be done at the end of the first semester. The objective was to ensure that projects were progressing satisfactorily and that teams who had been slacking would be required to do remedial work before being allowed to enroll for the second semester. This work would have to be done either during Christmas break or during the summer (for spring classes).

Each capstone design team was assigned to a panel consisting of one capstone advisor or topical expert and an additional engineering faculty member (neither closely involved with the team), and one doctoral student. The class instructors were also present but did not participate in the panel discussion. The teams were given 12 minutes to make their presentation, with 7 minutes for questions and answers and 5 minutes for panel discussion. The panel also scrutinized in depth each team’s written project progress report ahead of the oral presentation.

Figure 7 shows the results of the panel reviews and indicates a steady increase in the number of teams who passed “without conditions.” The panel review process has proved to be a valuable tool for improving the capstone design project work. It mirrors a process used in industry and gives the students valuable experience and inspiration to finish their projects well. For the Fall 2007 class, the deficiencies were mainly in the lack of applying adequate engineering analysis. For the Fall 2008 class, the deficiencies were for a number of reasons, from lack of interaction with the sponsor to inadequate documentation of the work. For both years, the panel members were impressed by the professional quality of the oral presentation skills of the students as well as their teamwork.

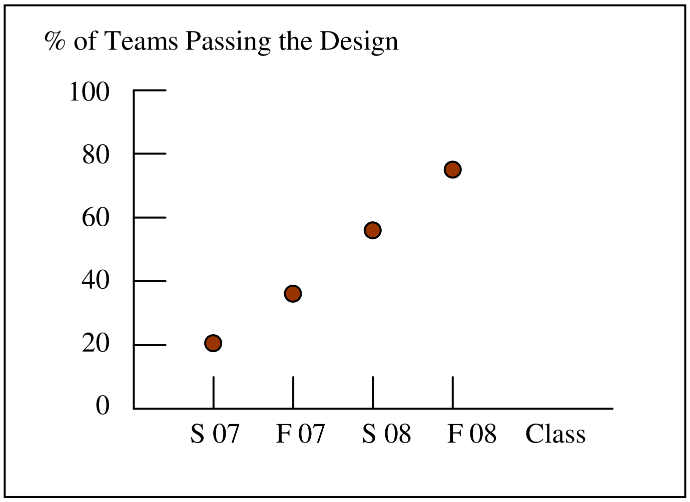

Figure 7
Improvement in the number of teams who passed the panel review "without conditions"

No formal assessment tools were used to evaluate the success of the capstone design course upon completion of the projects at the end of the second semester. However, achievements have been gauged by:

a. Client/sponsor satisfaction: all sponsors at Michigan Tech have been satisfied, with repeat business from a number of sponsors despite the worsening economic climate. A special citation was given to the MEEM department by one of the sponsors of a Fall 2007 project.
b. Informal feedback from engineering faculty members attending final project presentations on the increasing quality of the design solutions, oral presentations, written reports, and posters.
c. Comments from project sponsors and repeat attendees at the Senior Design Day events that the projects are producing realized prototypes, proven with testing, not just reports.
d. Project teams are increasingly winning awards during the annual Expo at Michigan Tech in the spring, as shown in Figure 8. Results for the Fall 2008 class (from the Spring 2009 Expo) will be available at conference time.

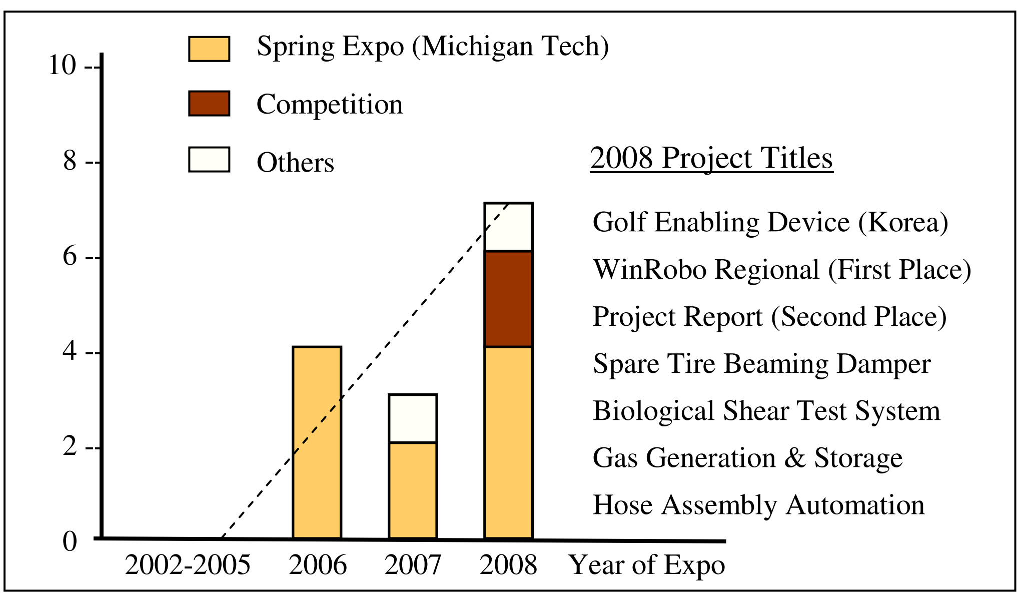

Figure 8 Mechanical Engineering Capstone Design Awards[3]

V. Final Team Evaluation Results

Overall, identified team malfunctions were substantially reduced when anecdotally compared with years before the HBDI was used to help form balanced teams, as judged by unbiased staff.

Final Student Feedback from the Fall 2007 Class

The main assessment tool used to collect student feedback was the last peer contribution rating form completed at the end of the course. On this confidential form, students were identified who received negative feedback from their team members.

From HBDI data analysis, it was discovered that a noticeable correlation existed between the occurrence of problems and the degree of right-brain thinking preference, as shown in Table 3 which also indicates the student's ranking on a continuum from 1 (extreme left-brain thinker) to 106 (extreme right-brain thinker).

Out of 73 left-brain students, only three (or 4%) were identified by their peers as still having some problems. Out of 33 students having strong right-brain thinking preferences in one or both quadrants (accompanied by a lesser preference for quadrant A thinking), nine (or 27%) were identified by their team members as still having problems. However, teams with a problem member still managed to do well, and one won an award. No clear answers are available to explain why more right-brain students had trouble with their teams. However, from years of experience with right-brain thinkers, some conjectures can be offered.

Table 3 Correlation between Degree of Left-Brain Thinking and Problems with Team

Rank	**Problem Traits**	**HBDI**	Left Brain	Right Brain	Team Grade	Indiv. Grade
Strong left-brain preferences (Quadrants A + B), ranging from 77% to 56% left-brain						
8	No initiative, few contributions	Very high A, low C	72%	28%	92%	C
57	Lazy, uncaring, few contributions	High A	60%	40%	92%	C
62	Poor attitude	High A, high B	60%	40%	90%	B
Stronger right-brain preferences (Quadrants C + D), ranging from 45% to 72% right-brain						
74	Difficulty with strong A thinkers	Less A, higher C+D	55%	45%	92%	B
77	Thinking style clashed with team	Less A, low C, high D	54%	46%	92%	BC
83	Little interest, little work done	Less A, high D	52%	48%	92%	C
87	Not willing to learn, poor English	Low A, high D	50%	50%	91%	B
88	Almost no participation in team	Low A, very high D	50%	50%	96%	F
92	Poor attitude, poor English	Low A, high D	48%	52%	94%	C
98	Other priorities	Very low A, high C+D	45%	55%	89%	BC
104	Extremely disorganized (low B)	Low A, very high D	40%	60%	89%	BC
106	No interest; no communication	Low A+B, high C+D	28%	72%	90%	C

In general, it is a characteristic of strong quadrant D thinkers that they get bored easily with a mundane project and thus lose interest. Some creative thinkers find it difficult to express their ideas, and some teams seem unable to appreciate creative ideas. Also, some students do not value their own strengths in quadrant D—a mental block against creative thinking encouraged by most educational systems. Moreover, some right-brain students may have developed an attitude problem by having endured four years in an educational climate hostile to their brain dominance pattern. In the future, care will be taken to include a student with a whole-brain "mediator" or "translator" thinking preference profile on teams that have extreme right-brain thinkers to improve the team dynamics by facilitating communication with all members of the team.

Were Objectives Related to Forming and Managing Project Teams Met?

- Even though the emphasis was somewhat different (HBDI versus student technical capabilities), both approaches to team formation on the whole worked well to achieve diverse teams. A balance in quadrant C thinking was crucial to avoid dysfunction. Wider adoption will require lower costs for student HBDIs and possibly an HBDI practitioner on staff. The HBDI was especially appreciated for allowing potentially dysfunctional teams to be identified early.
- The peer contribution rating form with student feedback at midterm and at the end of each term was a key for monitoring team development. It enabled teams to make mid-course corrections to improve team dynamics and effectiveness. It also allowed the instructor to grade each student (including slackers) fairly. The leadership seminars (Fall 2007) and the leaders' meetings with team advisors (Fall 2008) were found to be very useful for monitoring team dynamics and solve problems quickly, before they affected the team's performance.
- The panel review was a prime ingredient for keeping student teams on track and focused on project work that is balanced between creativity and analysis in the context of quality oral and written design documentation. With many faculty members involved on the panels, a brief review of the whole-brain design process for the panel members could be beneficial; some very analytical thinkers (faculty as well as students) tend to begrudge the time spent by the teams on seeking creative or innovative alternatives for solving the sponsor's problem.

Student Comments

Why go through so much effort to form balanced (or heterogeneous) project teams? What do students think about the benefits? Below is a synthesis of the insight gained by four different students in the Singapore 2008 MBA Entrepreneurship course (University of Nottingham). The students first worked in a homogeneous team; then for their class project, they were assigned to heterogeneous teams. This outcome is typical for the classes taught there for the last 10 years.

> ***Typical Homogeneous Team Experience***
>
> *"In the quadrant A homogeneous team, the tasks were carried out analytically and critically. The solutions were based on facts; they were everyday solutions (tried, tested or "safe"). The team got things done quickly, with little disagreement or debate, since we shared a common vocabulary. We felt very comfortable with this team, as we all had similar approaches to problem solving. But after watching the presentations of the other homogeneous teams, we realized we had missed some important angles and challenges."*

Typical Heterogeneous Team Experience

"The heterogeneous team took longer to become organized and to make decisions, but the experience was much more dynamic, even though the team members were uncomfortable with each other at first. The solutions generated included unusual possibilities, where a novel idea and synthesis eventually led us to an optimal solution in the team project. But it was not easy to achieve consensus, and we had to learn to communicate and value different viewpoints and thinking styles as we applied the whole-brain creative problem solving process and the Pugh method. In the end we were surprised at the effectiveness of the team in producing a successful project outcome due to the team members' diversity."

VI. Recommendations

Almost all institutions face the same constraints in teaching capstone design: high investment in faculty time, tight curricula, limited time for students to spend on team development activities that are not directly related to their project, and lack of funding or interest for research into psychological teaming tools[27,28] not perceived as relevant to engineers. Thus the approach taken is fundamentally a pragmatic one—to use what works together with continuous improvement to achieve consistently excellent results. For example, using the HBDI to form balanced teams has been shown to increase team effectiveness on the average by 66% by the U.S. Forestry Service in an assessment spanning 30 years.[29] Some benchmarking activities and opportunities for continuous improvement are summarized in Section VII.

The following factors were found to be significant for enhancing team development and the resulting successful project outcome. Thus the following recommendations are offered:

1. **Form balanced teams** by using both the HBDI and key student capabilities as determined from their work experiences and courses taken. It is rarely possible to determine ahead of time all the specific skills that might be useful in a particular project; thus having a full array of diverse skills in the team is valuable. Each team should have members with these skills or knowledge: hands-on experimenter or "tinkerer" (machining), finite element analysis, solid modeling, oral and written communication, and leadership. It is crucial to distribute students with high and low quadrant C thinking preferences across all teams. With mental diversity a key objective, the focus is taken away from selection merely on gender or ethnic background.

   TIP 1: Students with special knowledge such as computational fluid dynamics or acoustics and noise control usually have their top choice in projects that need this capability. If not enough students are available, volunteers need to be sought and asked to immediately register for these courses (at least one per project).

   TIP 2: Project assignment is simpler when students are asked to only indicate their top five choices of projects (not in order of priority). For Fall 2008, two projects did not have any interested students, and the teams were formed based solely on capabilities and the HBDI. These two teams are doing an excellent job. Project assignment may be simpler if students were asked to identify only larger areas of interest, such as testing, automotive, product development, measurements, material handling and assembly, process optimization, or environmental and social concerns.

2. **Monitor and support team development** through the four stages of forming, storming, norming, and performing[24] with training for the team leaders, using team ground rules, peer contribution rating forms, team project reports, and other teaming tools and team role assignments[30]. The most serious team dynamics problems could be traced back to differences in thinking preferences and the related communications challenges. Attitude problems were more difficult to handle, especially when involving someone with "a chip on the shoulder."

   TIP 1: It is beneficial when the advising faculty members have an understanding of team development and the HBDI model.

   TIP 2: Years of experience has shown that students would benefit by having their HBDI assessment and an introduction to creative problem solving and teamwork in the freshman year, especially when this learning is reinforced in subsequent coursework and projects. If implemented college-wide, forming multidisciplinary capstone teams would become easier.

3. **Conduct a project design review** by a departmental design panel at the end of the first semester (based on oral as well as written team reports) to recommend whether a team can progress to the second semester or if remedial work or repetition of the first semester is warranted. The panel review has led to a marked and steady increase in project quality, because it forced the students to not just concentrate on design but to apply their knowledge of engineering analysis to the project, as well as to pay attention to team dynamics. Teams which had deficiencies in their projects at mid-course were inspired to overcome the flaw to go on to finish among the top teams.

   TIP 1: Project advisors had a key role for monitoring the team's technical progress, resolving team dynamics problems, and encouraging slackers to get back on track. When inexperienced faculty members or foreigners were assigned this role, success varied significantly.

   TIP 2: Separating the advising functions was successful, with senior faculty members assigned to teams as topical experts as needed, and two faculty members available to monitor team development and meet weekly with the team leaders to resolve problems.

4. **Provide adequate resources** for managing large classes and teams and handling the paper flow generated through homework assignments and two or three major project reports per semester. These resources have included experienced graduate assistants, a technical writer, mailboxes for each team to expedite returning graded work, and web-based communication between staff and project teams, as well as posting all lecture notes, PowerPoint slides, quizzes, grades, and project reports on the web. Crucial departmental support was provided through an administrative project coordinator and a project manager as liaison between the department and the industrial sponsors of particular projects. Also, the teams were assigned separate cubicles with computers and locked filing cabinets in a Design Center.[2]

VII. Comparison with Experiences at Rose-Hulman and Future Work

While on sabbatical as visiting professor at Rose-Hulman, one of the authors was able to interact with design faculty and participate as advisor on five capstone design teams. He was especially interested in learning about their team management processes. Four approaches are compared in Table 4 for two different MEEM instructors at Michigan Tech and two different departments at Rose-Hulman (in mechanical engineering and computer science & software engineering).

Table 4 Comparison of Different Capstone Team Management Approaches

Used *Emphasized*	*MTU Fall 2007*	*MTU Fall 2008*	*Rose-Hulman CSSE Dept*	*Rose-Hulman ME Dept*
Team Formation				
Self select				
HBDI (diversity in thinking)			informally	
Sponsor/project requirements				
Student expertise/skills				
Teamwork experience				
Communication/leadership				
Student project preference				
Team Management				
Team size (change allowed?)	5 (4-6)	6 (5-7)	3-8, w/change	4 (3)
Tools taught				
Peer review for monitoring				
Leader seminar or training				
Student reflection/feedback				
Sponsor/client feedback				
Design Process				
Explicit structure			self-directed	self-directed
Creative problem solving				
Tools				
Documentation formats				
Design review panel				
Presentations/reports				
Sponsor/client relationship				
Meet project objectives				

Both institutions with large groups of students are motivated and involved in proposed changes to improve the capstone design experience for their teams. Michigan Tech has approved a move of the design theory coursework, including team development, to the junior year, as is already done at Rose-Hulman in computer science and software engineering. This department in turn is seeking to make teams more diverse as has been done at Michigan Tech, together with requiring better documentation, broader perspectives in problem solving and an increased flexibility for dealing with change. One of the authors was able to observe a clearly dysfunctional team close-up—this team was self-selected and showed little diversity in the four factors that are crucial to team performance: experience, discipline, sociological, and cognitive[26].

In addition, this author learned about the benefits of the CATME[25] team management tool developed at Rose-Hulman in cooperation with other universities. He is planning to implement it at Michigan Tech to streamline the team forming process—while also investigating how the HBDI results could be integrated into the software while trying to reduce the costs of the HBDI.

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Appendix A: Reminder on How to Hone Your Teamwork Skills

Use the following checklist to examine how your teaming skills are measuring up. Circle each item where (or why) you think you need to pay attention or make some improvements.

1. Be prepared to make MEEM 4910 (and your team responsibilities) your priority.
   a. Make time to attend team meetings.
   b. Carry out your assigned tasks on time.
   c. Show initiative.
   d. Have a professional, positive attitude.
   e. Respect your team mates and their different thinking styles.
   f. Maintain communication: monitor/respond to your team e-mail daily.

2. Having good teaming skills is important:
   a. Teams are used throughout industry.
   b. Teamwork is used throughout life.
   c. You learn team skills by working in your project team with "different" thinkers.
   d. The success of your project is enhanced by the effectiveness of your teamwork.
   e. Future employers check up on the quality of your past team contributions.
   f. Your project grade is affected by how much you contribute.

3. Developing good teamwork skills is hard work:
   a. It takes attention, self-awareness, and effort to become an effective team member.
   b. Developing such personal skills is a life-long but rewarding endeavor.
   c. Example: Develop a habit of giving constructive, not negative, comments.

4. Changes in project direction (from conceptual design to hands-on prototyping) may set the team "back to zero" in the team development stages (forming, storming, norming, performing). Also, team member roles may change.
   a. At which stage is your team now?
   b. Has your team role changed?
   c. What can you contribute to get the team to the performing stage?
   d. Are you fully committed to your team and achieving a good project outcome?
   e. Are you prepared to brush up on engineering skills or learn new ones as needed?

5. Traits of a team at the performing stage are:
   a. Team members have accepted each other's strengths and weaknesses and have defined workable team roles.
   b. The team becomes an effective, productive, cohesive unit.
   c. Team members feel attached to the team and confident of its abilities.
   d. Team members fully share accountability for the team's actions, and they operate from a basis of trust and mutual respect.
   e. Team members try to distribute the work load fairly; then all carry out their responsibilities to the best of their abilities.

Identify your major shortcomings—then ask your team members to help you overcome them. If you have a humble and sincere attitude, they will be more than glad to help you achieve success, and everyone on the team—including you—will have a win-win outcome by the end of the term.

Appendix B: Review of Team Development (Start of Semester 2)

The beginning of the second semester is a good time to review the development of your team. Most teams should be well along the norming stage. Review the five points below to see how they can enhance your team to move fully through the performing stage and avoid some of the pitfalls that could keep you from achieving optimal project results.

1. Forming: <u>In a truly cohesive team, the members trust each other</u>. They are able to admit mistakes or weaknesses to their team members, and they are able to ask for help. "Trust is the confidence among team members that their peers' intentions are good and that there is no reason to be protective or careful around the group." Review the implications of the different HBDI profiles in the team—are all strengths appreciated and used effectively? Are the members using less comfortable thinking styles when needed?

2. Storming: <u>In a truly cohesive team, the members engage in unfiltered conflict around ideas</u>. Conflict is not feared or avoided in order to maintain superficial harmony. Instead, different ideas are thoroughly examined and debated in an atmosphere of mutual trust and respect, not interpersonal politics. Go back to "creative abrasion" in the *Harvard Review Paper* handed out at the beginning of the first semester on how to use conflict productively. The overarching purpose should be to produce the best possible solution in a reasonable amount of time.

3. Norming: <u>Each member fully commits to decisions and plans of action</u>. When there is no open debate, team members rarely buy in and commit to decisions, although they may feign agreement during meetings. "Great teams ensure that everyone's ideas are genuinely considered, which then creates willingness to rally around whatever decision is ultimately made by the group. In case of an impasse, the team leader is allowed to make the call." One of the best tools for ensuring commitment is the use of clear deadlines throughout.

4. Performing I: <u>The members hold one another accountable for delivering on those plans</u>. Without full commitment, team members avoid accountability, and behaviors or actions that are counterproductive to the good of the team are not called out. Expectations for each member's performance must be explicit, and the members should have high standards.

5. Performing II: <u>A truly cohesive team focuses on the achievement of collective results</u>. Failure to hold one another accountable creates an environment where inattention to results occurs—team members put their individual needs above the collective goals of the team. "The ultimate dysfunction of a team is the tendency of members to care about something other than the collective goals of the group. An unrelenting focus on specific objectives and clearly defined outcomes is a requirement for any team that judges itself on performance."

The quotes are from The *Five Dysfunctions of a Team* by Patrick Lencioni, Jossey-Bass, 2002. Although the five steps sound simple and map into the four stages of team development presented to you earlier, the steps require a high level of discipline and persistence for full implementation that only few high-performing teams fully master.

Tip 1: Review and revise your <u>team goals</u> if necessary.
Tip 2: Review your <u>team ground rules</u> and make changes based on the team goals and your first-semester experiences and progress.
Tip 3: Attention to the five steps should result in exciting (not boring) <u>team meetings</u>.
Tip 4: Continue to use a <u>detailed project plan</u> with individual responsibilities and due dates clearly outlined and each person held accountable for carrying out the assigned tasks.