Using Problem Solving Preferences to Promote Teaming in a Mechanical Systems Design Course

James M. Widmann
California Polytechnic State University
San Luis Obispo, CA

Abstract

At California Polytechnic State University in San Luis Obispo, Mechanical Engineering students are required to take a course in Mechanical Systems Design. It is a junior level course where students learn the fundamentals of machine components (gears, bearings, screws, etc); furthermore, the students gain experience in the integration of these components into complex Mechanical Systems during a weekly 3-hr laboratory. During the laboratory portion, the students work in teams to solve open ended design projects. Two projects are given during the quarter. For the first project, the students work in teams of three to develop and build a mechanical system to accomplish a simple task. During the second, a "paper" design of a more complex system is completed. The second project is accomplished by dividing the task into subsystems which are designed by teams of four. Each team of four is then required to select a representative to insure successful integration of the final system with other teams. Team formation is based on the student's problem solving preferences in a manner devised by Prof. Douglas Wilde of Stanford University. This paper will examine the success of this team forming strategy not only from the standpoint of quality of design produced but also by team member's satisfaction. The success of the three-person and four-person teams at performing the design tasks is evaluated. Assessment of the design quality is both quantitative in terms of measurable performance as well as qualitative. Assessment of team satisfaction is primarily through student survey feedback.

Introduction

A common problem facing engineering educators who teach courses involving design teams is how to quickly group the students into effective teams. This problem can be further compounded in teaching systems design courses where it may be desirable to have various teams interact to design a complex system through the breakdown of tasks into subsystem design problems. In this scenario "weak" teams can lesson the effectiveness of the integration task. Levi and Clem[1] show that effective and successful teams generally benefit from a number of factors including organization support, good technical and social (including interpersonal and teaming) skills of the group members and team relations with the organization in which they operate. In the context of a 10 week course in mechanical design it is easy to provide the organizational support necessary for team success; however there is often little time for educating team members in teaming skills, leaving faculty the task of forming student teams quickly so the important creative and analytical processes necessary in mechanical design can be addressed.

Many researchers have examined the problem of team formation in industrial settings. Chen and Li[2] present an involved process based on a combination of skills (both technical and teamwork) and personality. Zakarian and Kusiak[3] propose a method team formation based on the Analytical Hierchy Process (AHP) and Quality Functional Deployment (QFD). Although likely effective, these methods are too involved and are not appropriate for an educational setting where presumably an assessment of technical skills would indicate that all students have very little experience with the subject prior to taking a course. For student design team formation, a brief poll of faculty (Davol, et al.[4]) in the Mechanical Engineering Department at California Polytechnic State University, San Luis Obispo (Cal Poly) indicates that there are three types of team forming strategies currently employed: 1) self-selection by the students, 2) random assignment of the students to teams by the faculty, and 3) assignment using skills-based assessment of those students who are unable to self-select. Some faculty use a combination of the above 3 methods to form teams. Other possibilities recommended in the literature for student team formation include self-selection based on student led skills assessment (Gardner[5]) and formation based on problem solving preferences as determined through personality type indicator by Wilde[6], the subject of this paper.

Wilde's recommended method of team formation is based on teaming students with identifiably diverse problem solving preferences in an attempt to both enhance team creativity and lead to high student satisfaction by avoiding interpersonal conflicts between team members. The determination of the student problem solving preferences is based on a survey akin to the Myers-Briggs Type Indicator (MBTI)[7]. The use of the MBTI in business and industrial settings as a tool for counseling, vocation training and team forming is continuing to grow. Many researchers have applied personality typing to different engineering disciplines to see how personalities affect team performance and what personalities are attracted to specific disciplines [8-14]. McCaulley[15] outlines an introduction to Jungian psychology and the MBTI as it applies to engineering design. Others have called for a caution regarding the apparent enthusiasm and outline problems associated with using the MTBI, especially in the workplace[16,17].

This paper reports the results of using problem-solving preferences based on a simple personality indicator to quickly form teams in a mechanical engineering design course as presented by Wilde[6]. This method of team formation is relatively quick and provides a framework for a brief discussion with students on the importance of diverse problem solving styles and viewpoints when generating creative and successful mechanical systems designs. Of interest in this study was measuring the success of the teams at completing the task assigned as well as the student's assessment of team performance and relative satisfaction of working on their teams.

Course and Curriculum

During their junior year, students of mechanical engineering at Cal Poly are required to enroll in an introductory course in mechanical systems design. The course consists of three hours per week of lecture where traditional mechanical component design, analysis and selection is presented. Topics include the design and use of shafts, gears, bearings, power screws, fasteners, springs, etc... In addition to lecture, each week the students attend a three-hour laboratory where they gain experience combining these basic elements into mechanical systems. The primary means of experiential learning is through the solution of open-ended problems requiring the design of relatively complex mechanical systems. The course is considered the last preparation for the students before the work on the Senior Capstone System Design Project which involves the design, test and construction of a solution to an industrial sponsored problem. In their Senior Capstone Experience the students will also be working in teams.

As taught by the author, the ten weeks of laboratory experience focus on the completion of two team-based projects: one involving the design, building and testing of a small electric-powered machine and the other a "paper" design of a complex system requiring the integration of sub-systems designed by different teams. The use of teams is considered essential not only to the successful solution of the problem at hand, but to give students experience working on teams to create successful designs. It is widely recognized that teaming skills and experience are desired by the industrial employers of engineering graduates as stipulated by the Accrediting Board for Engineering and Technology (ABET). Additionally the student's experiences, success on the projects and subsequent confidence in their design abilities are greatly influenced by the functioning of their team.

Review of Team Construction Method

For the purposes of team formation, the method of Wilde uses problem solving preferences of the students as measured using the MBTI. The MBTI is indicator of temperament based on the work of psychologist Carl Jung[18]. The MBTI seeks to categorize personalities into 16 distinct types based on the answers to a questionnaire. The 16 types are combinations of measures of preferences in four categories. Also an indication of the strength of the preference is given in the scoring of the questionnaire. Each of the four categories measure strengths of two opposite preferences:

1) Source of personal energy/focus of attention: Those individuals who have a preference for gaining energy through interactions with others are considered to have a Extrovert (E) preference while those who relate best to their inner self and gain energy from being along with their thoughts indicate a preference for Introvert (I).

2) How information is gathered: Those individuals who like to gather facts and pay particular attention to details indicate a preference for Sensing (S) while those who have a preference for speculation, imagination or would rather "see the big picture" indicate a preference for the Intuitive (N).

3) How decisions are made: Those who prefer to make decisions based on developed laws, criteria and are logical and objective indicate a preference for Thinking (T). Those who prefer to make decisions based on values or on how others will be impacted indicate a preference for Feeling (F).

4) Approach or relationship to the world around: Those individuals who indicate a preference for closure and are outcome oriented and decisive are assigned as Judging (J). Those individuals who are more process-oriented like to gather additional information and like to keep options open indicate a preference for Perceiving (P).

The results of the MTBI are a four letter classification of the preference of the individual (e.g. ENFP). In addition to the letter classification, strength of preference can also be measured. Usually the survey would have a number of questions which indicate the preference of the individual towards on or other categories. Wilde describes how to scale the number of questions to determine the strength of an individual's preference to be used in team forming.

Most research in the area of team formation using the MBTI have focused on the use of the 16 categories without reference to the strength of potential team members preference for the personality type. Wilde proposed that to create teams creative and successful teams for solving design problems, the strength of preference should be considered and also that only subset of the data is important. For example, Wilde's work breaks down students into three or four groups based on temperament types elucidated by Kiersey and Bates[19]. During the first lab meeting of the course, the students are given a brief introduction to the MBTI. The students are briefly informed about the MBTI and any counseling and vocational aspects of the test are de-emphasized. The students are then told that the indicator would only give the instructor a sense of what their individual problem solving preference was. It is explained that their teams will be formed trying to create a diversity of problem solving techniques and to avoid personality conflicts. Again the students were told that the indicator would not be used as a measure of aptitude, vocation and warned that it would give no indication of motivation.

For the classes first design project, the students worked in groups of three to a team; therefore, the students were sorted into three groups based on their indicated problem solving preferences after Wilde. The first group is labeled the Technologist: These are the students that show showed a clear preference towards the ISTJ personality type. These students indicated a preference to be independent, practical, and good with details and deadlines. The idea is that this personality type would ground the team in reality and make sure that the project goals were technically met. The second group consists of students who showed a strong preference towards ENFP. These are a more diverse group of individuals who might fill the role as facilitators, innovators or provide teamwork enhancement. The idea is that these personality types may bring a creative ability or build an atmosphere of trust in the team and bring it together when conflicts arise. The third group is the set of students who showed a strong preference towards Organizational (ExTJ). These students indicated a preference for high level or efficiency and organization. For the second project, students worked in teams of 4 and therefore a fourth grouping of student was added. This group consisted of those with the weakest preference to the first three groups above. This group is clearly the most mixed and may contain students with strong preferences in modes different from the first three. The idea is that they should add diversity to the design teams by avoiding the matching of like problem solving preferences in team members.

In grouping the students, problems associated with strict adherence to Wilde's method of classification were apparent. Since many students will have preferences in more than one of the groups as detailed above, Wilde recommends classification based on their strength of preference. For the 72 students in the design course, there were not enough students who showed a "clear" preference for groups 1 and 3 and therefore some students with less strong preference were added to these groups to make up the difference. It is unclear if this is a common situation with mechanical engineering students at other universities.

After the students were sorted into groups, the students were allowed to self-select their teammates with the condition that the teams must be comprised of one student from each group. For the second design task, a further restriction was placed that the students must not have worked with any individual on the first project. This was due to the author's sense that it would best for students to gain experience with working with as many different people as possible in the class.

Task Descriptions

Design Project #1 – The Space Elevator. The first project involved the design build and test of a prototype mechanical "Space Elevator" car that could climb a 20 foot cable under its own power. The device was required to use an electric motor. Student teams were given a basic parts kit containing Lego® gears and they were allowed to augment the kit while keeping track of the cost of any further purchased parts. A collection of small electric motors was available for purchase as well. The machines were required to be turned on using an electrical switch, would have to attach themselves to the cable and climb the 20 feet vertically. A quantitative performance metric involving energy consumption and cost was given to the students. The highest score was given to those students that a) completed the course, b) used the least amount of energy and 3) had the least material cost. There were 24 teams of 3 students each who designed and built machines. The deliverables for the project included the machine, a formal presentation and a design report. These were all factored into the student's grade. The duration of the project was 3 weeks.

Design Project #2 – Metal Forming Machine. The second project involved the design of an extrusion stretch forming machine. Usually these machines are hydraulically powered. The students were asked to design machines that were all-electric (did not involve the use of hydraulics in any way). The task of designing the machine was given to three teams, all responsible for a subsystem. The design of each subsystem required structural design and provisions for precision feedback position control of motion of large heavy items, some under significant load. Each subsystem was designed by teams of four students. Each one of these teams was required to select a member to serve on an integration team. The integration teams responsibilities included setting relevant design standards, agreement on design requirements, creation of drawing standards, insurance that interface issues between subsystems were addressed and the final binding of a single design report. Note that the selection of the integration team members was entirely up to the students. As a member of the integration team did not excuse the student from responsibilities to the subsystem team although it was encouraged that the team should reduce their responsibilities. Twelve students divided into three groups of four design one machine. For the entire class there were six machines designed by 18 teams of four. The deliverables for the project included a formal presentation and a single bound design report including detailed drawings and a solid-model of the complete design. The duration of the project was six weeks.

Methods and Results

An attempt to assess the success of the team formation technique was done by looking at the success of the students on their task and through a survey. Student success at the tasks was measured in several different ways. For the first task, Design Project #1, there was both a quantitative and qualitative assessment. The primary goal of the project was to design and build the device to climb the 20 feet. Of the 24 teams, 22 were successful at completing the task. Of the two teams who were unable to reach the top, one had an irreparable component failure the day of the trial and the other despite all their efforts produced a machine not likely to ever climb the cable. In the author's experience, this basic 92% success rate was much higher than anticipated and higher than the historical 60-70% success rates for similar tasks posed to similar classes. Qualitatively the student's designs exhibited a high level of creativity and thoughtful design.

For the second project, the student's designs were assessed by the author as an expert in mechanical design of stretch forming machines. The results of the task were well developed concepts for the machine. Assessment of success of the task was that there were 13 workable designs out of 18 possible. Further assessment was made with the grading of the presentations and reports.

To measure student's perception of the functioning of their teams as well as overall student satisfaction, a survey was administered for each project. The survey consisted of 13 questions on a 5 point Liken scale and 2 questions on a 10 point scale. The survey attempted to measure the student's assessment of their team's performance in four areas. First was the students group rating of how they performed on the task. The second set of questions concerned the relationships among the team members, the third sought to determine the students perception of creativity and diversity in their groups and the fourth to rate the organizational aspects of their team. The final two questions consisted of an overall rating of their team performance and the rating of the student's satisfaction with the team in comparison to their previous teaming experience at Cal Poly. The survey and the results are given in Figure 1.

Figure 1. Survey Questions and Average Student Responses

Rating Scale for Survey Questions 1-13

1	2	3	4	5
Never	Sometimes	Many Times	Most times	Always

	Task #1 Average	Task #2 Average
Task Criteria		
1) Did group members regularly commit to task assignments?	4.07	4.16
2) Did group members complete assigned tasks on time?	3.93	3.63
3) Did each group member do their fair share of work to complete the project?	3.89	4.03
5) Was the quality of the team's work acceptable?	4.03	4.17
Relationship Criteria		
6) Did group members act in a cooperative fashion?	4.20	4.40
7) Was there active participation by all group members?	4.00	4.30
8) Was there a climate of trust and mutual respect?	4.21	4.47
9) Were conflicts handled in an open and constructive fashion?	4.27	4.44
Diversity and Creative Criteria		
4) Did different team members contribute in different ways?	4.29	4.36
11) Was the team creative in its problem solving?	4.09	4.14
Organizational Criteria		
10) Was the team well organized?	3.75	3.83
12) Did the team develop their ideas in an efficient and logical manner?	3.92	4.21
13) Did the team have an identifiable leader?	3.20	3.61
Overall Ratings		
0 1 2 3 4 5 6 7 8 9 10 Very Poorly Very Well 14) Overall Rating: How well did your team perform?	8.03	8.48
0 1 2 3 4 5 6 7 8 9 10 Worse Same Better 15) In comparison to other teams you have worked on at Cal Poly, rate your overall satisfaction with working on this team.	7.19	7.98

As shown by the student's response to the survey, the students thought that there team performance was quite good. Additionally the students responded that their satisfaction with their teams was higher than most teams that they had worked on in the past as students. In the area of Social relations the students felt the team worked the best. Also there appeared to be strong creativity and diversity in the teams. Less strong, but certainly acceptable were the students responses to the task questions with the lowest response coming on whether students finished tasks on time. Also the students felt as if the team organization was not as strong as their social balance.

In addition to the quantitative survey questions, the students were asked to comment on what worked well for their teams and what areas of team functioning could have been improved. It is interesting to note that for those teams that were not successful at the task (two teams in design project #1 and 5 teams in design project #2) that most comments pointed to the lack of success as caused by the low participation of one group member. For task #1, six out of 24 groups reported this problem and for task #2, two out of 18 groups reported this problem.

Statistical correlation of the first 13 survey questions was performed with respect to the students overall ratings and is given in Table 1. It was found that the students responses to the task criteria all correlated strongly to both the students overall performance rating and their satisfaction. Strong correlation also existed between the students overall satisfaction and the Social Relationships among team members. Less well correlated were the students' responses to their overall team performance and the social relations. Also strong correlation existed between the student's sense of their team organization and their performance and satisfaction. Interesting from the students standpoint, there seemed to be no correlation between the students' sense of diversity, creativity and leadership and team performance and satisfaction

Table 1.- Correlation Factors (r) between Survey Questions and Overall Student Ratings

Survey Question	Task #1- Overall Performance (Q14)	Task #2– Overall Performance (Q14)	Task #1-Overall Satisfaction (Q15)	Task #2– Overall Satisfaction (Q15)
Task				
Q1	.36	.57	.61	.59
Q2	.45	.50	.49	.54
Q3	.50	.47	.53	.56
Q5	.47	.50	.64	.46
Relationship				
Q6	.30	.42	.51	.52
Q7	.34	.30	.62	.49
Q8	.23	.42	.55	.64
Q9	.29	.38	.42	.55
Diversity and Creativity				
Q4	.10	.27	.25	.34
Q11	.32	.27	.22	.33
Organizational				
Q10	.67	.59	.66	.55
Q12	.39	.45	.33	.46
Q13	.14	.19	.04	.22

Integration Team Membership

Recall for the second project, an integration team was formed to work on coordinating the activities of the subsystem design teams. The membership of the team consisted of one member from each subsystem team. The integration team member became the de-facto leader of each team. The members of the integration team were without exception volunteers from each group. Table 2 shows the membership of the integration teams (6 total) sorted by their problem solving preference.

Table 2. Number of Students in Integration Team by Group Number.

	Group I	Group II	Group III	Group IV
Number of Students	6	2	6	4

Discussion:

The findings presented here offer some preliminary support for the team forming method proposed by Wilde based on student problem solving preferences as determined using the MBTI. Note that in the absence of formal team training this method seems to result in reasonably effective and satisfied teams (note that further work by Wilde[20] recommends complete student education in the area of Jungian typology as well as teaming skills). Additionally, students in these teams seem to feel more satisfied than with their previous experience with other methods of team formation. In light of the work of Lent et al.[21] which indicates the positive effects of collective efficacy on student teams, it should be explored whether the students when exposed to the team formation method in this study felt the teams would be good based on the initial grouping and therefore this knowledge had a positive effect on actual team performance and satisfaction. The students clearly felt that for most part relationships among team members was good and personality conflicts were not a major issue with their teams.

It is interesting to note that students on the four person teams of the second project felt they performed better and were more satisfied than the three person teams despite the project possibly being less interesting. This difference could be due to a number of factors including: 1) the students at that point in the quarter were now more comfortable in the class, 2) the teams of four brought a greater diversity to their problem solving or 3) the students were less likely to self-select known team members due to the further team formation restriction that required all team members to be new to each other. This last point may have led to teams where students did not give preferential social treatment to certain known team members such as "friends". It is interesting to note that when given the opportunity to select a formal team leader, the Group III, personality preference did not rise as the overwhelming choice signifying that this group should not be confused as "natural" leaders. Also it cannot be overemphasized to the students that this type of personality grouping can in no way predict the motivation level of team members and cannot be considered a replacement for lack of skill, training and effort on the part of the students.

References

1. Levi, D., and Slem, C., "Team Work in Research and Development Organizations: The Characteristics of Successful Teams," *International Journal of Industrial Ergonomics*, Vol 16, 1995, pp. 29-42.

2. Chen, S., and Lin, L., "Modeling Team Member Characteristics for the Formation of a Multifunctional Team in Concurrent Engineering," IEEE Transactions on Engineering Management, Vol. 51, No. 2, May 2004, pp. 111-124.

3. Zakarian, A. and Kusiak, A., "Forming Teams: An Analytical Approach," IIE Transactions, Vol 31., 1999, pp. 85-97.

4. Davol, A., Maddren, J., Mello, J., Murray, W., Niku, S., Owen, F., Pascual, C., and Schuster, P., Personnal Correspondance, Dec. 2004.

5. Gardner, R., "Rising to the Top," *ASEE Prism*, Vol. 14, No. 4, Dec. 2004, pp. 44.

6. Wilde D.J., "Using Student Preferences to Guide Design Team Composition,"*Proceedings of the Design Engineering Technical Conferences*, Sept. 1997.

7. Myers, I. B., and McCaulley, M. H., *Manual: A Guide to the Development and Use of the Myers-Briggs Type Indicator*, Consulting Psychologists Press, 1985.

8. Desmond, C., "Are Engineers Really Like Dilbert?" IEEE Communications Magazine, Sept. 2002, pp. 14.

9. Bradley, J.H., and Hebert, F. J., "The Effect of Personality Type on Team Performance," *Journal of Management Development*, Vol. 16, No. 5-6, May-June 1997, pp. 337-354.

10, Dilworth, L, and Richter, K., "QFD and Personality Type: The Key to Team Energy and Effectiveness," *Industrial Engineering*, Vol. 27, No. 2, Feb. 1995, pp. 57-61.

11. Varvel, T., et al., "Team Effectiveness and Individual Myers-Briggs Personality Dimensions," *Journal of Management in Engineering*, Vol. 20, No. 4, Oct. 2004, pp. 141-146.

12. Carr, P.G et al., "Relationship Between Personality Traits and Performance for Engineering and Architectural Professionals Providing Design Services," *Journal of Management in Engineering*, Vol. 18, No. 4, Oct. 2002, pp. 158-166.

13. Gardner, W.L., and Martinko, M. J., "Using the Myers-Briggs Type Indicator to Study Managers: A Literature Review and Research Agenda," *Journal of Management*, Vol 22, No. 1, pp.45-83.

14. Johnson, H. and Sijngh, A., "The Personality of Civil Engineers," *Journal of Management in Engineering*, Vol 14, No. 4, July/August 1998, pp. 45-56.

15. McCualley, M.H., "The MBTI and Individual Pathways in Engineering Design," *Engineering Education*, vol. 80, July/Aug., 1990, pp. 537-542.

16. Kerth, N. L., et al., "Call for the Rational Use of Personality Indicators," Computer, Vol.31, Jan. 1998, pp. 146-147.

17. Zemke, R., "Second Thoughts about the MTBI," *Training*, Vol. 29, No. 4, April 1992, pp 43-47.

18. Jung, C. G., "Psychological Types," in *The Collected Works of C. G. Jung*, Princeton University Press, 1971

19. Keirsey, D. and Bates, M., *Please Understand Me: Character and Temperament Types*, Prometheus Nemeisis Book Co., 1984.

20. Wilde, D. J., "Team Creativity," *Education that Works: The NCIIA 8th Annual Meeting*, March 2004.

21. Lent, R. W. et al, "Exploration of Collective Efficacy Beliefs in Student Project Teams: Implications for Student and Team Outcomes," *Proceedings of the 2002 American Society for Engineering Education Annual Conference & Exposition*, Sept. 2002.

Jim Widmann

Jim Widmann is an Associate Professor of Mechanical Engineering at California Polytechnic State University, San Luis Obispo. He received his Ph.D. in 1994 from Stanford University. Currently he teaches mechanics and design courses. His research is in the area of design optimization and its applications in machine design.