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# USING STUDENT PREFERENCES TO GUIDE DESIGN TEAM COMPOSITION

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## ABSTRACT

For five years now Stanford's Mechanical Engineering Design Division has experimented with restrictions on how students choose the members of their design teams. The constraints are based on voluntary student responses to a short questionnaire, essentially a sampling of questions from the Myers-Briggs Type Indicator widely used for vocational and educational counseling. This has produced teams performing qualitatively and quantitatively better, as measured by prizes won in the nationwide Lincoln Foundation Design Competition, than did teams of the thirteen years preceding. In 1995, Stanford teams won all but two of the twelve prizes awarded. This article describes these experiments, lists the results, describes how to construct a suitable questionnaire, reviews pertinent psychological theory, and gives mathematically precise instructions for constraining construction of the teams. The current procedure also incorporates information obtained from a recent survey on team satisfaction in a different project design course. This modified method seeks to generate satisfied teams without sacrificing prize-winning ability.

KEYWORDS: student design teams, Myers-Briggs Type Indicator, Jung, cognitive modes, Lincoln Foundation Design Competition, creativity.

## INTRODUCTION

The idea of using questionnaires to guide the formation of design teams had its origins in 1989 in a Workshop on Creativity for design professors put on at Stanford by Bernard Roth, Rolf Faste and the author. To determine the effectiveness of the workshop, participants were surveyed both before and after the two-week intensive experience to determine their "Gough Creativity Index" (GCI), a measure of creativity devised by the psychologist Harold Gough (1981). The GCI is an empirically determined linear transformation on the four scores generated by the Myers-Briggs Type Indicator (MBTI), a questionnaire used widely for psychological, educational and vocational counselling. As the author reported in July 1993, the workshop indeed enhanced the creativities of the participants, but a result more important for the work at hand on team composition was the verification of the GCI as a valid creativity measure. This raised an intriguing question: could the GCI predict success of a design team? If so, it might be able to guide the constuction of better teams.

In 1990, this idea was first tried out on Stanford's graduate engineering team design course ME210 taught and coordinated by Larry Leifer. After responding to the MBTI, the students were asked voluntarily to make teams whose MBTI scores differed in at least two of the four variables. That year the class was so small that all teams had only two people, yet the number and quality of prizes won in the Lincoln Foundation design competition increased noticeably in both quantity and quality. Analysis of the teams verified the hypothesis that teams having a high GCI member tended to win more and better prizes. The overall increase in the number of such teams followed simply from the team composition rule, which prevented two people with high GCIs from working together, thus distributing the creativity more widely among the teams than before.

These initial findings were refined in later years and applied to teams of three and occasionally four in the same course. Mathematical theories were developed for using detailed numerical score information instead of only the signs of the scores, the usual practice among MBTI counsellors. Vector analysis permitted decomposition of the score vector into components (Wilde, September 1993) as well as the computation of Jungian cognitive modes, one of which corresponds closely to the GCI (Wilde & Barberet 1995). Evolving modifications of these indices were used in later years to guide team construction, with the success of the teams increasing as stronger constraints on team composition were enforced. In 1995, Stanford teams won eleven out of the twelve Lincoln awards given. A more detailed account of performance over the five years during which these ideas have been applied is given later in the article, which also compares these years with the thirteen preceding.

The MBTI has been replaced by a much briefer sampling of questions called a Preference Questionnaire (PQ). This not only saves time but also de-emphasizes the counselling aspects, inappropriate for an engineering course. Students wishing to investigate the counseling side further are encouraged to do the MBTI under the supervision of a licenced counselor. The PQ is thus viewed simply as an expression of personal preferences rather than an indicator of "personality type", the latter being a concept which makes some students uncomfortable. Indeed, the data are used to place students in broad "Preference Groups" rather than narrower personality type categories. Then the team composition rule is simply not to team up with people in the same Preference Group. This not only distributes the creative talent fairly but also prevents accumulation of other qualities which have been found to generate friction on a team sometimes.

This is discussed in the next section, which concludes with a brief listing of other innovations that may have contributed to the course's success during the period. Following that in the "Satisfaction" section is a description of a survey on team satisfaction in a Mechatronics project course. These further results are eventually incorporated into the composition procedure currently used. A brief review of the underlying personality and mathematical models precedes a detailed computational description of how to classify the student PQ scores into Preference Groups to achieve good team performance and morale both. Along the way suggestions are given for constructing a Preference Questionnaire to generate the underlying information. There is a short discussion of team size, and a qualitative description of the sorts of people in the Preference Groups.

## PERFORMANCE

For almost three decades Stanford's Design Division has had a year-long MS course on Engineering Design in which teams of two, three or four students design, build, test, present and write a report on some device representing a consumer or industrial problem, usually suggested by a manufacturer, hospital or research institution. Since 1977 the reports have routinely been submitted for consideration in the Lincoln Foundation design competition, open to all North American engineering schools. The reports are read and evaluated by designers and design professors, who award twelve prizes to those they consider best. The judges, who change from year to year, do not know the authors or their university connections. Thus it seemed promising to use prizes won as a measure of effectiveness of team performance, especially since every year the dozen or so Stanford projects submitted had won about four prizes, enough to provide comparisons between teams with high and low GCIs. In 1991, the very first year of experimentation with restricting team composition, the high GCI teams clearly were more successful at winning Lincoln prizes, not only more of them, but also of higher quality. Table 1 summarizes the prizes won at Stanford, during not only the five-year period of the experiment, but also the thirteen uncontrolled years preceding.

The table shows that the percentage of prize-winning teams doubled (from 29% to 60%) during the experimental second period. Then the high GCI teams had a higher winning frequency (63%) than did the other teams, whose performance (50%) had already been improved from 29% simply by diversification . The period 2 study also showed that the quality of prizes won was also considerably better for high GCI teams, which won a proportion of Silver, Gold and Best of Program medals (42%) triple that for the other teams (14%). The most spectacular year was 1995, when a particularly talented class won ten out of the twelve prizes awarded nationally. Diversification thus improves the quantity of prizes, and spreading the especially creative people around also greatly raises the quality.

Other changes to the course were made during the same period which also contributed to the enhanced prize-winning capability, although of course one cannot separate the effects. Professor Leifer lists them as:

1. The concept of design as a social process was emphasized.
2. Noun-phrases were used to predict design performance.
3. An open-loft community replaced a closed-door environment.
4. The first five weeks of the course focussed on team-dynamics.
5. Computer use for design was demoted.
6. Computer use for design-knowledge communication was promoted.
7. Design documentation was promoted as the main deliverable, not just as homework.
8. Conceptual prototyping replaced drafting and detail design.

These innovations will doubtless be explained more fully in subsequent publications.

## REVIEW OF PERSONALITY & MATHEMATICAL MODELS

Now that the effectiveness of Preference-Guided team composition has been demonstrated, it is time to describe precisely what it is. This will require psychological terminology and vector mathematics developed in previous papers. The present minimal review intends only to make this article comprehensible without simultaneous reference to the earlier works, which must however be consulted for deep understanding of the subject.

 

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## SUMMARY OF LINCOLN PRIZE AWARDS TO STANFORD TEAMS

| PERIOD | YEARS | HIGH GCI TEAMS NUMBER | HIGH GCI TEAMS PRIZES | HIGH GCI TEAMS % | OTHER TEAMS NUMBER | OTHER TEAMS PRIZES | OTHER TEAMS % | ALL TEAMS NUMBER | ALL TEAMS PRIZES | ALL TEAMS % |
|---|---|---|---|---|---|---|---|---|---|---|
| 1: 77-8/89-90 | 13 | unknown | unknown | - | unknown | unknown | | 138 | 40 | 29% |
| 2: 90-1/94-5 | 5 | 49 | 31 | 63% | 14 | 7 | 50% | 63 | 38 | 60% |
| TOTALS | 18 | | | | | | | 201 | 78 | 39% |

**TABLE 1**

All questionnaires have four categories of inquiry, here called "variables" and always kept in the same order for convenience in the subsequent vector analysis. Each question gives two choices, one of which is considered by convention "negative" and the other "positive". The percentage of each possibility is noted -- 70% negative and 30% positive for example. The larger percentage, minus 50%, is reported as the score for that variable, which in the example would be the signed number -20 without the % sign. A zero means that both choices were selected equally. The full set of four scores is presented as a four-vector, e. g., (-20, 30, -5, 10).

Following Jung the choices, although not the variables, have been given names by Myers and Briggs that will be used here. For convenience, the variables will be given names in this article. The first varaible, called "sociability", has "Extraversion" for the negative choice and "Introversion" for the positive one. The MBTI convention is to report the score with the corresponding letter, here capitalized, instead of an algebraic sign. Thus in the example, the -20 would be written "E20" for the MBTI. The second variable, called here the "information-gathering method", has choices "Sensory" and "iNtuitive". In the example the second component 30 would be N30 by MBTI convention. Third is the "decision-making method" with choices "Thinking" and "Feeling" -- T5 in the example. Last is the "approach": "Judgmental" vs. "Perceptive", giving the last component in the example as "P10". The MBTI score set for the example would therefore be E20, N30, T5, P10. Usually the numbers are suppressed for the MBTI, the results being only the four letters, here ENTP, identifying one of sixteen ($2^4$) possible "personality types". The team formation method described here avoids such psychological characterization because it uses a less precise 40 question Preference Questionnaire rather than the 128 question MBTI.

The score vector is transformed to give estimates of other psychological entities used to classify students for team formation. The simplest is to find the projection of a score vector in the direction of a particular personality type, for example the ISTJ, whose unit direction vector, following the sign conventions, is (1, -1, -1, -1)/2 (Wilde, Sep. 1993). The ISTJ component of the example vector is thus the scalar product (-20, 30, -5, 10) • (1, -1, -1, -1)/2 = -55/2 = -27.5. The negative sign indicates that the vectors make an obtuse angle, the example vector more or less pointing away from the ISTJ direction. Directly opposite to the ISTJ direction is ENFP, in which all choices, and consequently signs, have been reversed (E for I and - for +, etc.). The projection of the example score vector in the ENFP direction is thus the same as on ISTJ except for the sign; it is +27.5. Type pairs having all components opposite in sign, ISTJ and ENFP for example, are said to be "complementary".

The Gough Creativity Index involves another transformation of the score vector. The formula is GCI = 250 + (-1, 3, -0.5, 1) •$\boldsymbol{v}$ , where $\boldsymbol{v}$ is the score vector. The example vector would therefore have a GCI of 372.5, well above the creativity threshold of 350 established empirically by Gough. Normalization of the GCI vector gives the unit diresction vector (-0.30, 0.90, -0.15, 0.30), of interest in the next paragraph.

Another important transformation gives four opposed pairs of what Jung called "cognitive modes", which are methods of mental performance. Wilde and Berberet pointed out that the direction vector of one of these cognitive modes, that for "Extraverted iNtuition" (EN), is (-0.5, 0.71, 0, 0.5), very close to the GCI unit vector. For this reason, using the EN vector instead of the GCI vector has only a small effect on the classification scheme, as was verified in the last three years of the experimental period. Another mode, called "Extraverted Feeling" EF has been found to be important for good teamwork, and a third mode called "Extraverted Thinking" ET is considered when making teams of four or more. The specific mode transformations are given in the description following of the current classification procedure.

The numerical scalar products obtained are needed to estimate whether or not the modes involved are indeed influential for the subject. Myers and McCaulley's numerical ranges for various degrees of clarity of preference for the original four variables have been applied to the transformations discussed. The rule, which has worked for the teams studied, is only to use a component for classifying a person if its value exceeds 20, indicating at least what Myers and McCaulley call a "clear preference" for the mode involved.

Over the experimental period most of the teams were trios except during the first year when there were only two on a team. After the first year, the class was partitioned into three Preference Groups so that teams could be composed of one member from each Preference Group. Two of the groups were complementary, the third including everyone else. At first the complementary types were ENFP and ISTJ as in the example; for the last two years the complementary cognitive modes EN and IS (Introverted Sensing) were used. In all cases the first group contained those with the highest GCIs; the second, those with the lowest. To exploit the recent results on team satisfaction discussed in the next section, the current procedure is slightly different.



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## SATISFACTION

Last spring Drs. Carryer and Kenny surveyed teams of four, together for six weeks, to design, build, test and present projects in Stanford's Mechatronics course. Since these projects were not candidates for Lincoln Foundation prizes, team performance was not studied. Instead, team members were asked to express their satisfaction or dissatisfaction with their team experience. Individual preferences were evaluated by the Keirsey (& Bates) Temperament Sorter, a 70-item MBTI style questionnaire, but team compositions were not constrained.

Of the eleven quartets, five were clearly satisfied and four dissatisfied. The satisfied teams always had at least one EN "brainstorming" member or EF "teamwork" member. Apparently winning EN teams have high morale, but they are not the only ones. Teams with a member strongly oriented toward teamwork also feel good about themselves even when they lack the ideas to bring out a strong product. This effect is taken into account in the new current procedure described in the next section.

A second effect of great interest was that all the dissatisfied teams had two or more members with ISTJ components exceeding 20. The old procedure had inadvertently prevented this situation from happening in the Engineering Design course as an unintentional byproduct of its spreading of the EN creative talent. This new information thus reinforces rather than changes the team construction rules. Discouragement of ISTJs from working together is particularly needed because the Mechatronics survey found that 89% of them teamed up in pairs, a fraction higher by the way than for the other preference groups studied, which varied from 60% to 73%.

## CURRENT PROCEDURE

The procedure currently used combines the extensive work on Lincoln prize performance with the more recent study on team satisfaction and some anecdotal experience gained informally along the way. A few words are in order here on how to construct the Preference Questionnaire supplying the raw information. The author used questions from the Keirsey Temperament Sorter, a 70-item questionnaire in the book of Keirsey and Bates, in which the variables being measured are clearly identified. The questions are themselves sampled from the MBTI, which is available only to licenced practitioners. Readers can easily construct their own PQ, of whatever length seems useful, from the Temperament Sorter, which is widely published and can be found on the World Wide Web at URL http://sunsite.unc.edu/jembin/mb.pl. Note however that the first sociability variable only has half as many questions as the others, so the scores must be adjusted to match the theory used here.

The PQ responses give, for each student, a preference vector $\boldsymbol{v}$ from which five projections are computed, most conveniently on a spreadsheet. The projection values of 20 or more are the only ones used for classification. The five unit direction vectors are given in Table 2. As indicated, one vector represents a personality type and three represent cognitive modes. Another is a direction given the label "Right-brain extravert"; it is the unit vector halfway between **EN** and **EF**. Its name reflects the fact that for right-handed people both the iNtuition and the Feeling functions originate in the right temporal lobe of the brain (Herrmann). The mode names "Synthesizer" and "Teamwork" were proposed by Wilde and Berberet; the type name "Technologist" is a new version for this engineering context of the more general term "Administrator" employed earlier by Wilde (Sep. 1993).

Preference Group I is comprised of all students whose ISTJ component is 20 or greater. Group II is made up of students having a projection of 20 or more in any of the three subgroups IIa, b or c. Students not previously classified having an ET component of 20 or greater are placed in PG III. The remaining students, those having projections less than 20 in the preceding three categories, are put in Preference Group IV. Students having high scores in more than one of the first three groups should be placed in the earlier group regardless of numerical score value. For example, a 25ISTJ and a 37ET would call for a PG I, not a PG III, classification.

Let $C$ be the number of students in the class and $n$ the number of people on a typical team. Each of the first three PGs should have no more than $C/n$ students. If PG I, II or III has more than $C/n$ students, just keep the ones with the highest projection values. This is equivalent to raising the selection threshold above 20 as needed. Some of the first three PGs may have fewer than $C/n$ students; in such cases PG IV may have more than $C/n$ . The team composition rule is then to have no more than one member from any PG having less than $C/n$ students; exactly one member from any PG having exactly $C/n$ ; and at least one member from any PG having more than $C/n$ .

PG II has an internal hierarchy of inclusion recognizing the combined effects of productivity and satisfaction. The highest priority goes to the ENFs in IIb, since they combine both desireable attributes. They usually don't fill the quota; next in line are the high productivity ENs in PG IIa. Any room left over goes to the team-oriented EFs in IIc. If this gives $C/n$ students, the class is reasonably sure of having all teams satisfied without a decrease in prize-winning ability. This scheme is the one currently in force in some Stanford Design project courses.

 

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## CLASSIFICATION VECTORS

| Group | Name | Symbol | Vector |
|---|---|---|---|
| I | Technologist type | **ISTJ** | ( 0.5 , -0.5 , -0.5, -0.5) |
| IIa | Synthesizer mode | **EN** | (-0.5 , 0.71, 0 , 0.5) |
| IIb | Right-brain Extravert direction | **Enf** | (-0.71, 0.5 , 0.5 , 0 ) |
| IIc | Teamwork mode | **EF** | (-0.5 , 0 , 0.71, -0.5) |
| III | Organization mode | **ET** | (-0.5 , 0 , -0.71, -0.5) |

**TABLE 2**

## TEAM SIZE

The current procedure is designed for constructing quartets as in the satisfaction study, although most of the teams in the Lincoln experiment were trios. This is because at Stanford there are more likely to be $C/4$ PG I students available than there are $C/3$. Thus success and satisfaction can be more confidently guaranteed for quartets than trios. It is also easier for a given size staff to concentrate on supervising fewer teams. Trios were used in the past because before students were constrained in their team choices quartets too often became unstable in the sense that a member would shirk responsibility. This was difficult on a trio because the lack of effort was too easily noticed. In retrospect it appears this might have happened when two team members came from the same PG, making one in a sense redundant. When choices were constrained during the experiment, however, the quartets that formed accidentally due to students entering or leaving the course performed as well as the trios. Apparently diversification stabilized the larger teams. This year, when the class had four times as many students as good projects, it was natural to use quartets from the beginning.

Professor Gabrielle tells us that design teams at RPI have five members, one of whom is a group leader chosen by the team or by the faculty and who receives special leadership training supervised by a university counselling center. Such leaders would most likely be in PG III. Teams of five could have either two members from PG IV (of size $2C/5$), or else use a fifth Preference Group partitioned out of PG IV. At Stanford this fifth PG would be comprised of the IN Introverted iNtuitives ("Inventors") discussed under PG IV in the next section.

## PERSONALITY DESCRIPTIONS

Although the Preference Groups are mixes of several MBTI personalities, an approximate characterization of the groups will be given here to aid understanding. A professor knowing all the students very well could in principle construct the PGs without a formal Preference Questionnaire, and there may be times when quick assignment to a PG may be needed.

PG I people have clear components of ISTJ, the "Technologist" or "Administrator". They tend to be independent, practical, factual and careful with dificult details, good at setting and meeting deadlines. Every team should have a PG I to anchor it in reality, but the Mechatronics survey showed that teams with several PG Is have trouble functioning as a unit, possibly because of their independence, pessimistic bent, and the tendency of some to be unassertive in group discussions.

PG II is a wider mix whose major type components are centered on the ENFP "Facilitator", a friendly, flexible imaginative type exactly complementary to that of the quietly competent PG I. Less people-oriented are the more rational idea-generating ENTP "Innovators", but PG II can also include the decisive ENFJ "Diplomats" and ESFJ "Benefactors" whose main function may be to build a humane atmosphere in which the quieter members can feel safe about giving up some of their independence for the good of the team.

PG IIIs are the ET organizational types, the practical ESTJ "Managers" and the visionary ENTJ "Directors". Liking things well organized, they can improve product efficiency and keep the team from wasting time and resources. Sharing some characteristics of both PG Is and PG IIs, they often cooly mediate the inevitable disagreements between them. There is no formal study to support this next statement, but there have been situations where having more than one PG III on a team has produced power struggles until all parties worked out separate areas of responsibility to prevent conflicting responsibility. This situation can still occur under the current procedure, since PG Is and PG IIIs can also have a significant ET cognitive mode.

PG IV is the most mixed group, being comprised either of people with less clear preferences toward the first three groups, or those with clear preferences in other directions. A large subgroup favors the IN "Invention" cognitive mode dominating the INTJ "Inventor" and INFJ "Visionary" types. The colorful ES "Experimental" cognitive mode includes ESFP "Performers" and ESTP "Producers", both terms being used here in the theatrical sense. A few PG IVs use a "Need-finding" IF mode exactly complementary to the ET mode of PG II. The introverted cognitive modes, including the IT "Analysts" as well as the IN and IF modes already mentioned, are valuable resources for a team well enough balanced to provide a safe environment for their expression. PG IV generates variety among the teams, and it doesn't seem to hurt when a team has two PG IVs since chances are they will be quite different from each other.

A standard quartet produced by this method has a manager moderating beween a quiet technologist and a gregarious brainstormer, with a fourth person of temperament different from all three of the others. Trios will have three out of these four elements on board.

## EPILOG

A reviewer aptly asked, "Can the author test his hypothesis by reverting to the old random way of creating teams



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and analyzing how they perform? This would provide some evidence that the increase from an average of 29% during 1977-90 to 60% resulted from team composition only. This did in fact happen when the author was absent from campus Autumn Quarter 1995, depriving the 1995-6 course of anyone to enforce the constraints. The class of 14 unstructured teams, one of which did not finish their project, won three Merit awards (and no Bronze, Silver, Gold or Best of Program awards), a performance indeed comparable both quantitatively and qualitatively to that in the earlier 1977-90 period when the students constructed their teams without any guidance.

## CONCLUDING SUMMARY

It does indeed seem possible to improve team performance and morale by slightly constraining how students pick their team mates. Doing this intelligently requires knowledge of each student's view point as expressed by free choices made on a collection of questions sampled from the psychological inventory known as the Myers Briggs Type Indicator. The goal here is not personal or vocational counseling, however, but the generation of a team encompassing varied viewpoints. Especially important is the juxtaposition of the opposing attitudes of productivity and creativity, moderated by a neutral manager and a "wild card" personality differing from the other three. In five years of testing, this approach doubled the amount of Lincoln Foundation prizes awarded to Stanford teams, 1995 seeing a sweep of all but two of the twelve prizes available nationally. Guidance of this sort doesn't just blend student talents effectively. It also provides valuable experiential education in how to get the most out of interacting with quite different personalities in an engineering team setting.

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