Reprinted from Journal of Engineering Education, April 1995, Vol. 84, No. 2

Thinking Preferences of Engineering Students: Implications for Curriculum Restructuring

MONIKA LUMSDAINE
Visiting Scholar

EDWARD LUMSDAINE
Dean of Engineering
Michigan Technological University

ABSTRACT

The thinking preferences of engineering students at the University of Toledo have been assessed in a longitudinal study, using the Herrmann Brain Dominance Instrument (HBDI). The scores and profiles reveal thinking preferences in four different ways of thinking and "knowing": A = analytical-logical-quantitative, B = sequential-organized-detailed, C = interpersonal-sensory-kinesthetic, and D = innovative-holistic-conceptual thinking. With the HBDI, we have a tool that can assess the effects of curriculum restructuring. Data from 1990-1993 fall freshmen classes and 1991-1994 spring senior classes have been evaluated, where the 1994 seniors are the first group for which freshmen data are available. Conclusions drawn from the results are: 1) Overall, there has been a shift from "plug-and-chug" quadrant B thinking to increased "creative" quadrant D thinking, because more students with strong quadrant D preferences are being developed and retained, primarily due to the new creative problem solving course. 2) Avoidance of quadrant C thinking (teamwork skills) is persisting and creates classroom climates that are uncomfortable for some students, a high percentage being females. Students are not developing the teamwork and interpersonal thinking skills demanded by industry. 3) A majority of students are still being cloned in the A-dominant profile of the faculty. Students who have developed independent ways of practicing right-brain thinking and all students who were involved in creative problem solving as class assistants became more whole-brained or right-brained. Quadrant C and D thinking activities must be integrated into the curriculum each term for students to develop their full potential and reinforce the whole-brain thinking skills introduced in the first-year creative problem solving course.

I. BACKGROUND

We introduced an emphasis on creativity into the College of Engineering at the University of Toledo with the fall term of 1990. The keynote speaker of the two-day faculty seminar for teaching excellence[1] was Ned Herrmann, the father of brain dominance technology and inventor of the Herrmann Brain Dominance Instrument (HBDI).[2] At the same time, creative problem solving was instituted as a required one-credit hour course for all first-year engineering students.* The innovations that we emphasized in this new course included the philosophy of zero defects (this means no grading on a curve); writing and sketching as thinking tools; teamwork; and applying the creative problem solving process to a design project while introducing students to the Pugh method of design concept evaluation.[3,4] Over the following three years, almost three dozen faculty members volunteered to teach this innovative course, many of them several times.** This course not only encourages students to become aware of and appreciate different thinking strategies, it constitutes a teaching laboratory for the instructors for trying out new techniques to address different learning styles.† This approach formed the basis of the curriculum restructuring efforts in the College.[5,6]

Figure 1 gives a brief overview of the Herrmann model of thinking preferences. A sample Herrmann Brain Dominance profile is shown and discussed in Appendix A (to provide an introduction to the terminology and format of the HBDI results and their interpretation for those not familiar with this instrument). Each quadrant in the Herrmann model represents a cluster of distinct thinking abilities and ways of "knowing." Each person embodies a coalition of these abilities in various proportions. Differences in thinking preferences are expressed in different vocabularies and in different problem solving outcomes. However, thinking preference does not mean competence. We can learn to use our primary and secondary preferred modes more effectively through training, motivation, and practice, and we can learn to strengthen less preferred modes.

To assess the effects of the changes being introduced into the curriculum, we designed a longitudinal study in cooperation with Ned Herrmann. During the first week of the creative problem solving course (in the fall term for most students), the students completed the HBDI survey. These students were then reassessed again in the spring of their fourth year. Starting in early 1991, we also made the HBDI available to all seniors on a volunteer basis to collect data for comparison. The average engineering faculty profile obtained in 1990 at Toledo (Figure 2) is typical of engineering faculty at several institutions that have been surveyed with the HBDI. When we analyzed the HBDI results after the first year of our study, we found that

*At Michigan Tech, creative problem solving is a three credit-hour course taught by an instructional team of two faculty (preferably interdisciplinary) and two undergraduate assistants (sophomores).

**Some of these faculty members applied what they learned in other courses; others remained relatively unchanged, and a few became hostile to the creativity course.

†The Ned Herrmann model is occasionally mistaken for the 4MAT system based on the Kolb learning cycle. A comparison of the two models is given in Reference 4, pp.108-111. The 4MAT system values each of its four styles of learning equally, and instructors are encouraged to use all segments of the cycle, even though they themselves may have preferences for particular modes. We have found that the 4MAT system addresses all four thinking quadrants in the Herrmann model. Using the creative problem-solving approach or the 4MAT system will make for better thinking and learning since both involve the whole brain.

the senior profile resembled the faculty profile very closely.

Nine questions: Based on an analysis of our very early results, we formulated some intriguing questions in mid-1991 which we expected our longitudinal research to help answer:

1. Should it be our goal to try to increase student thinking skills (preference and competence) in all four quadrants of the Ned Herrmann model?

2. Do engineers who have to function well in the 21st century need thinking skills in all four quadrants?

3. Is the HBDI profile of a first-year student a predictor of success in engineering?

4. How easily can a student's pattern be changed?

5. Do those students who think "differently" drop out?

6. Why do the most talented, creative students (including merit scholars) leave engineering at various stages in their program or immediately after graduation (see Appendix B)?*

7. How do we know our restructuring efforts work—are we making an impact on the students?

8. Will our efforts result in more right-brain (or whole-brain) students graduating from our program?

9. How are the four quadrants of thinking involved in learning?

The data which are now receiving provide some insight as well as quantitative answers to these questions; reporting on these findings is the main objective of this paper.

Why is having this data so important? We must look at the context of engineering education and the changes that are being demanded by industry.[7,8,9] Our customers are looking for engineers who can think holistically, who can innovate, who can work in teams, who can synthesize, who can do optimal designs, who integrate environmental and societal values and ethics into their work—all activities that demand right-brain thinking skills. These ways of thinking have been neglected in the heavily analytical and sequential approach to problem solving that is being taught in most K-12 curricula and continued in engineering education. Dr. Ellen T. Harris, Associate Provost for the Arts at MIT, affirms that "a number of American businesses have recognized the 'higher usefulness' to be derived from the study of art—how it serves as a spur to creative thinking, methodologies and solutions. These organizations have turned to artist residencies and art seminars to promote the values of individual risk-taking and institutional flexibility, as well as the shared overview that makes for creative teamwork."[10] Then, making a direct connection to education at MIT, Dr. Harris cites an example of how the arts have helped prepare MIT students. Of the 10 graduates recently hired by a large New York accounting firm, "four presented minors in the arts. The latter fact so significantly set these candidates apart from the others in terms of creative thinking, flexibility and presentation that the firm is now using the arts minor as a screening criterion." And finally, "beyond the parallels in creativity, the arts are also at home at MIT because the educational focus is on learning by doing... and because of the importance of design in engineering, architecture and science."[11]

Ned Herrmann, through his extensive work with corporations and businesses, has developed an illustration (Figure 3) about the paradigm shift that has occurred in the last decades in the area of thinking skills required for success. It is interesting to compare the profile shown in Figure 2 with those in Figure 3. Are we educating engineers for the 1970s, since the average profile of graduating seniors is a "clone" of that of their professors? Even though manufacturing technology, the tools available to engineers, and the thinking skills required for success all have changed significantly, the thinking skills that we are teaching and modeling for our students have changed little, if at all.

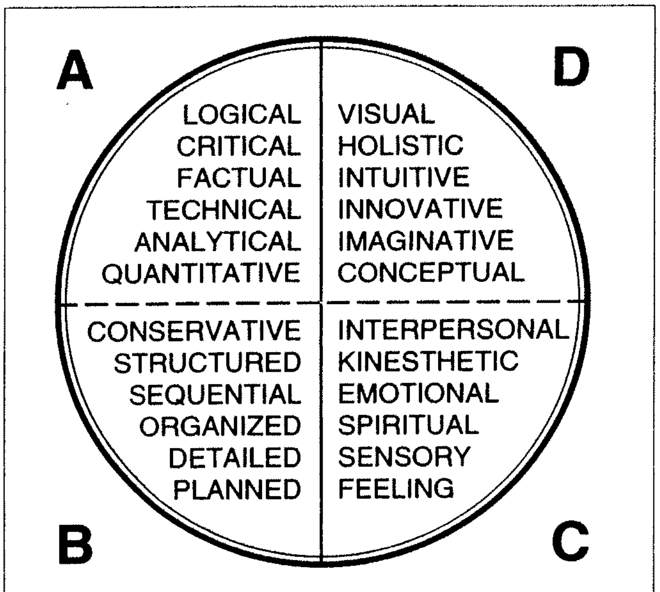

Figure 1. The four-quadrant brain model of thinking preferences developed by Ned Herrmann.

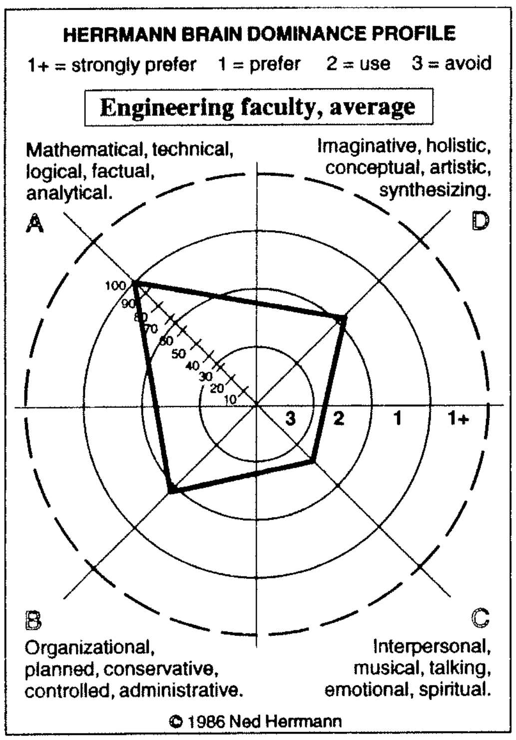

Figure 2. Average HBDI profile for engineering faculty at the University of Toledo, 1990.

*Of the students in the creative problem-solving honors class (where a large majority were National Merit Scholars), five right-brain students changed majors before the academic year was out. Only one left-brain student left engineering, and this student's strongest thinking preference was in quadrant D.

II. Data Analysis and Discussion of Results

Many of the students who were in our first group of freshmen engineering students completing an HBDI at Toledo in 1990 had become seniors by spring 1994. We asked these to complete another HBDI survey. Over 60 percent responded by answering the 120 questions. We will discuss the results from four different viewpoints: (a) the big picture and trends as depicted by group averages; (b) the changes in the distribution of generic profiles; (c) the changes in individual student profiles, and (d) a stratified analysis of three different groups of senior students. The results have serious implications for directing the restructuring of the engineering curriculum that cannot be ignored.

A. The Big Picture and Trends

In the following tables, the letters A, B, C, D refer to the respective quadrants in the Herrmann model of thinking preferences. In the discussion of profile scores, scores of 100 or more indicate a very strong preference (usually visible in behavior), scores of 67 to 99 a strong preference, and scores of 34 to 66 a lesser preference. Scores less than 34 signify a potential avoidance (which also tends to be visible to others). Most people have multiple primary thinking preferences. Since the focus on creativity was introduced to the faculty during 1990/91, this means that the last two classes of seniors (in Table 1) had more exposure to faculty beginning to do creative activities. The 1994 group of students was also the first group to have taken the creative problem solving course as freshmen (although a few seniors in the 1993 class participated in a pilot creative problem solving/engineering orientation course). N denotes the number of student profiles evaluated in each group. The 1994 group of seniors was small because it was restricted to students who took the HBDI during fall 1990 and had attained senior status by spring 1994.

The dominant thinking preference for the seniors in all four years is analytical thinking. However, a noticeable shift has occurred away from quadrant B (=> "plug-and-chug" problem solving) toward quadrant D (=> creative thinking). We believe that this shift resulted through three different means:

1. More faculty members are making an effort to appreciate and encourage creativity in their students, thus creating a more hospitable classroom environment for right-brain thinkers.
2. Some students are becoming more confident in expressing and using D quadrant thinking; they are finding that it is O.K. to be different; they take risks with learning; and they make connections with creative extra-curricular activities.
3. Creative activities and innovation in the College have been strongly supported by the Dean (from 1988 until he left in 1993).

The focus of the faculty enhancement seminar in the two years following the introduction of creativity was on communications and teamwork. The results above show that these introductory efforts have not yet been widely accepted and implemented by the faculty to where they are improving the C quadrant thinking preferences of the students. Despite the strong demand from industry for engineers who can work in teams and communicate well, these are still areas that are being avoided by many engineering students and faculty. The results seem to indicate that a major, broad-based effort is required for change to happen, and this change must start with the faculty. The faculty average in C is only 48, less than that of the students, including the freshmen whose averaged data is shown in Table 2. We have found (not only at Toledo but more recently at Michigan Tech) that faculty who begin implementing collaborative learning strategies into their courses and those that become enthusiastic about teaching creative problem solving and are applying the process into their lives are able to create a "people-friendly" learning environment so that students develop their C-quadrant thinking modes instead of losing them as they progress through the curriculum.

For the incoming freshman classes as a whole, no definite trend can be discerned as to a change in the average of their thinking preferences. But if we looked at quadrant D in more detail, especially at the very high scores, would the conclusions be the same? How prevalent are these strong quadrant D innovative thinkers, and do they persist to the senior year? Table 3 provides data to answer these questions.

We can predict that as many as 10 percent of the entering engineering students typically will have a very strong thinking prefer-

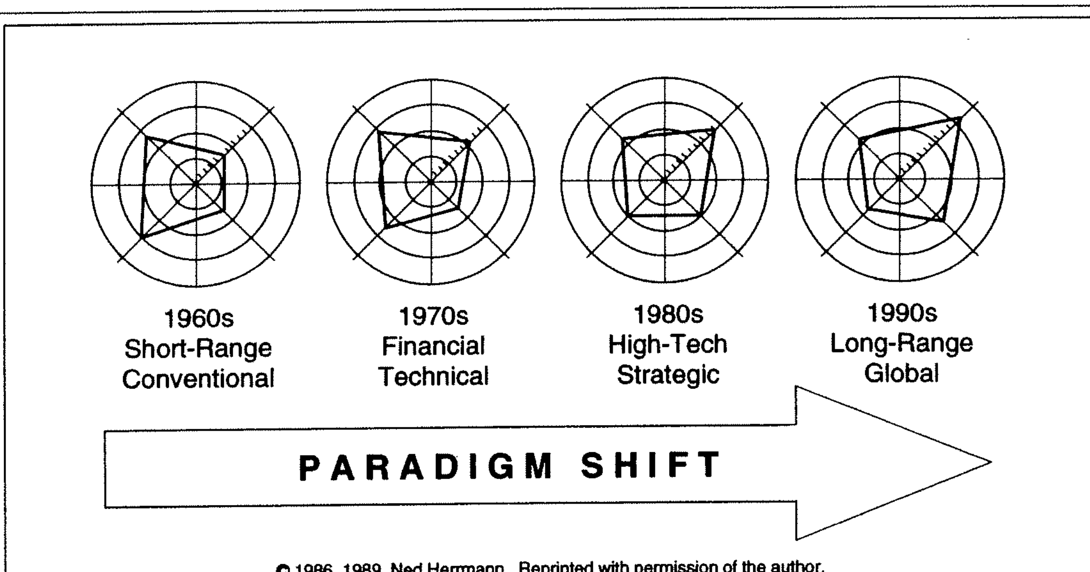

Figure 3. Paradigm shift in thinking skills required for success.

ence in quadrant D. But only rarely does a preference greater than 120 appear among the seniors. The unusual rise in the percentage of D>100 from the 1990 freshmen to the 1994 seniors seems to indicate that we are beginning to do a better job at retaining the thinking skills of these talented students. When analyzing the 30 seniors who have completed the 1994 HBDI, five of these students had quadrant D preferences as freshmen greater than 100 (one>120). Three students of the 30 maintained this preference; two students lost this preference, while two others developed this preference. We will discuss the reasons for this result in Sections 3 and 4 below. In our 1990 honors class of creative problem solving (N=34) alone, three students with D>100 (one>140), two students with strong preferences in both C and D, and a multi-talented minority student all changed to other majors at the end of the freshman year, because (as they told us) they felt very uncomfortable with the engineering peers and the curriculum.

B. Generic Profile Distribution

HBDI profiles are plotted along axes on a circular grid, as shown in the Appendix. In addition, they are also expressed as a generic profile in the form ABCD, where 1=strong thinking preference (scores>66), 2=lesser preference signifying comfortable usage when the situation requires it (scores 34 to 66), and 3=potential avoidance (scores<34), for the respective quadrants. Thus, a 1231 generic profile means that this person has strong thinking preferences in quadrants A and D, a usage in quadrant B, and an avoidance in quadrant C. Avoidances are relatively rare; however, among engineering students, a 3 in quadrant C appears with some frequency, particularly among males, indicating that these students tend to feel uncomfortable when they have to interact with others or work in teams. Seniors in the first two years of assessment had an average 1122 generic profile, seniors in the last two years an average 1121 generic profile, indicating that quadrant D thinking has developed into a stronger preference.

Which profiles are the most common (and the most successful) for engineering students? In Table 4, we have tabulated the results for our 1990 freshman class (N=332) and compared them with the 1994 senior class (N=30). The left-brain dominant 1122 profile remained the most prominent profile for these students. The 1121 profile became more prominent and moved from third to second in ranking for the seniors, showing that they have become more structured and sequential in their thinking. Ten percent of the students now have a 1211 profile (mostly in the shape tilted to the right which is preferred by industry); this is a welcome result. Of concern is the increase in the prevalence of the 1132 profile (and other pro-

	Profile Scores per Quadrant				Number of Students
Year	A	B	C	D	N
1991	91	80	52	66	91
1992	88	82	52	57	44
1993	86	78	54	72	57
1994	88	74	53	75	30

Table 1. HBDI average profile scores for senior engineering students, University of Toledo.

	Profile Scores per Quadrant				Number of Students
Year	A	B	C	D	N
1990	85	75	55	73	332
1991	84	75	56	70	442
1992	87	74	54	70	415
1993	86	75	55	72	440

Table 2. HBDI average profile scores for first-year engineering students, University of Toledo.

Freshman Year	D > 100	D > 120	Senior Year	D > 100	D > 120
1990	N = 29 or 9%	N = 5	1991	N = 5 or 5%	N = 0
1991	N = 38 or 9%	N = 6	1992	N = 1 or 2%	N = 1
1992	N = 30 or 7%	N = 7	1993	N = 6 or 6%	N = 1
1993	N = 45 or 10%	N = 3	1994	N = 5 or 17%	N = 0

Table 3. Occurence of high preference for D Quadrant thinking in engineering students.

Year	Generic Profiles 1122	1221	1121	2111	1222	1132	1112	1211	Others
Freshmen	23%	14%	12%	8%	6%	5%	4%	3%	18 for 25%
Seniors	29%	13%	**16%**	6%	0%	**16%**	0%	**10%**	4 for 10%

Table 4. Comparison of generic profiles for freshmen and senior engineering students.

files with an avoidance in the C mode). Overall, almost one quarter of the seniors show an avoidance for quadrant C thinking which bodes ill for their preparation to work well as a member of a multidisciplinary team in industry.

We have noticed some differences among different programs. Although the samples are small and we must be careful not to generalize the results, the data provided by the College show that the Computer Science and Engineering Department (CSE) has sixty percent of seniors who took the HBDI with an avoidance in interpersonal thinking (another department with a high figure is Mechanical Engineering). We believe that classes which have many peers with this thinking pattern may provide an inhospitable environment for female students. This view is not only based on our own observation and experiences, but also on feedback from female students in many classes, and especially from feedback received from female engineering and science faculty, as for example in several sessions at the 1994 ASEE Annual Conference in Edmonton, Canada[12,13]. At present, no female student in our Toledo database is listed as a senior in CSE. Since the freshmen at Toledo during this study were enrolled in pre-engineering, we have no other retention data by departments or programs. Among the 1994 seniors, the 1132 profile was not only retained by several students—others developed this profile from different profiles, as they changed their thinking in response to curriculum and peer pressures.

C. Individual Student Profiles

As we began to evaluate the data, we were initially surprised to see the magnitude of changes that individual students have undergone.* Perhaps this change should not surprise us, since the engineering curriculum is very intense: some students spend up to 14 hours a day, six or seven days a week, in the classroom, in studying, or in working on engineering projects, thus engaging in mostly analytical and structured/sequential thinking modes. Because the brain is very plastic and undergoes change with each use, the outcome is that thinking preferences change—certain ways of thinking become preferred as we are rewarded for success in their use. Preferred modes require less energy in the brain and are usually more enjoyable. People with similar preferences form "tribes" who have similar vocabularies and ways of communicating—those that think differently are excluded from the tribe as outsiders. The encouraging news is that through positive feedback and consistent practice, it is possible to change, develop, and strengthen preferences in desired directions.

Let us now examine profile results from individual engineering students (Figures 4-1 to 4-4). The dashed line indicates the profile at the beginning of the freshman year (1990); the solid line shows the profile at the end of the senior year (1994). The profiles in Figure 4-1 and 4-3 are from students who have become more left-brained thinkers in response to the curriculum. The profiles in Figures 4-2 and 4-4 are from students who have moved to the right—students who have become more whole-brain or more right-brain thinkers despite the pressures of the curriculum and the thinking preferences of the faculty. What made the difference? The students on the right were involved in additional creative problem solving activities: they worked as undergraduate class assistants in several creativity classes, or they helped in Saturday Academy where we taught creative problem solving to middle school students and their parents. Without exception, students who received additional exposure to creative teaching exhibited a shift to the right.

We also found that a few students were able to remain right-brained without this additional exposure. When we interviewed these students or someone who knew them well, we found that these students have provided opportunities for right-mode thinking for themselves: they spend much of their leisure time in sports or in performing or listening to music; they actively seek out group living, group activities, and group study arrangements with creative peers; they get much enjoyment out of the senior synthesis project; they have part-time work that involves visual thinking; or they developed a strong sense of self-worth and independence despite their being labeled as "different" by family and peers.

D. Stratified Analysis of Seniors

The 30 students of the 1994 senior year can be divided into two distinct subgroups: 18 "traditional" students and 12 "different" students. The different students in turn can be divided into two equal groups—those who exhibit unusual results in their 1994 HBDI and those who helped with creative problem solving activities. The averaged profiles of each of these groups are shown graphically (Figures 5-1 to 5-3) and numerically (Table 5).

For the traditionally educated group of 18 students, the drop in quadrant C thinking (with a corresponding increase in quadrant B thinking) is of deep concern. As freshmen, this group of 18 as a whole had a rather high preference for interpersonal thinking (C = 60). They dropped to a low of 46 (slightly below the faculty's score) by the time they became seniors. Their creative thinking preference (quadrant D) also dropped, while their left-brain scores increased, often spectacularly.

The six creativity assistants without exception have profiles which moved to the right. If they were left-brained as freshmen, they dramatically increased creative or interpersonal thinking to be-

*According to Ned Herrmann, longitudinal studies of hundreds of HBDI participants indicate that change can take place if there is a reason for it (such as a person's desire to change, a significant change in life's circumstances, or as a result of important emotional events). However, if individuals continue to do the same things they have always done and do those things in the same way, then the profile will remain stable. This reliability is based on the four-quadrant design of the Instrument and the multiple questions being asked in each quadrant.

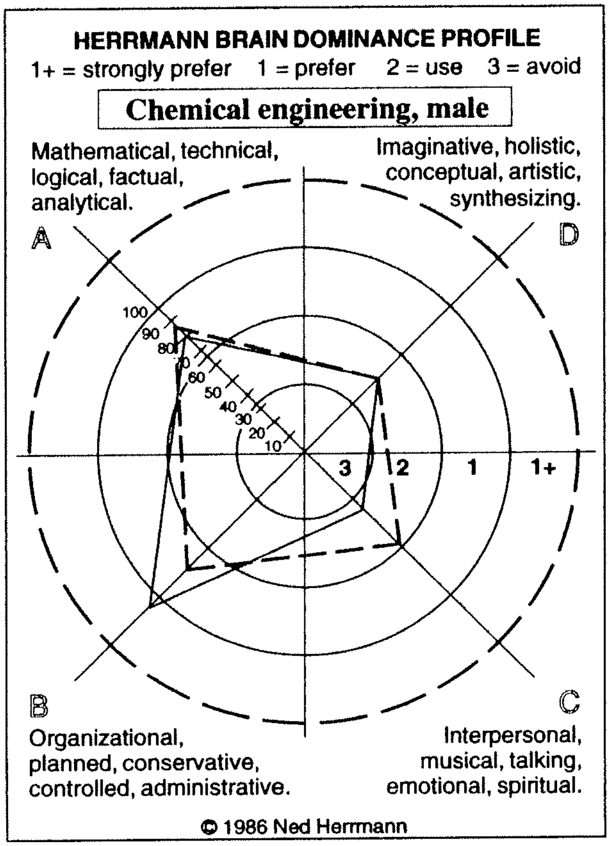

Fig. 4-1

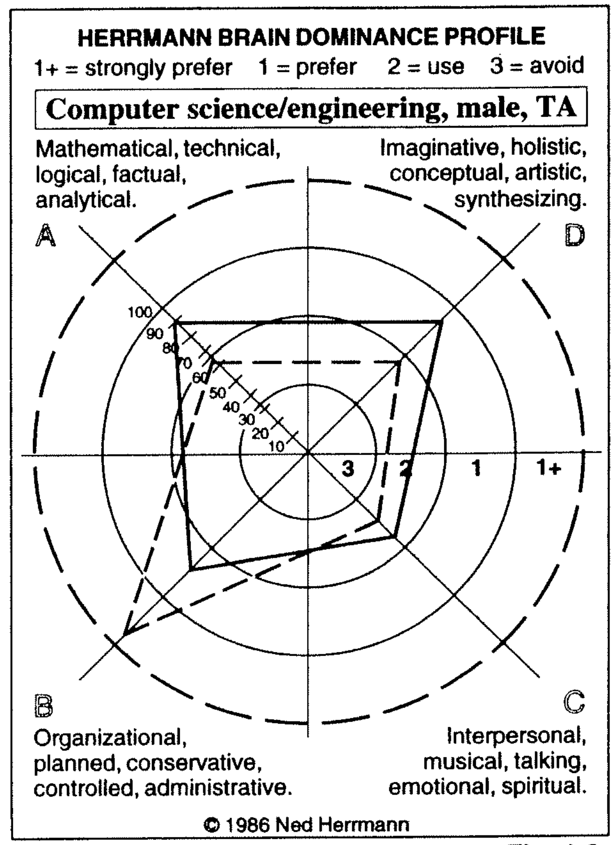

Fig. 4-3

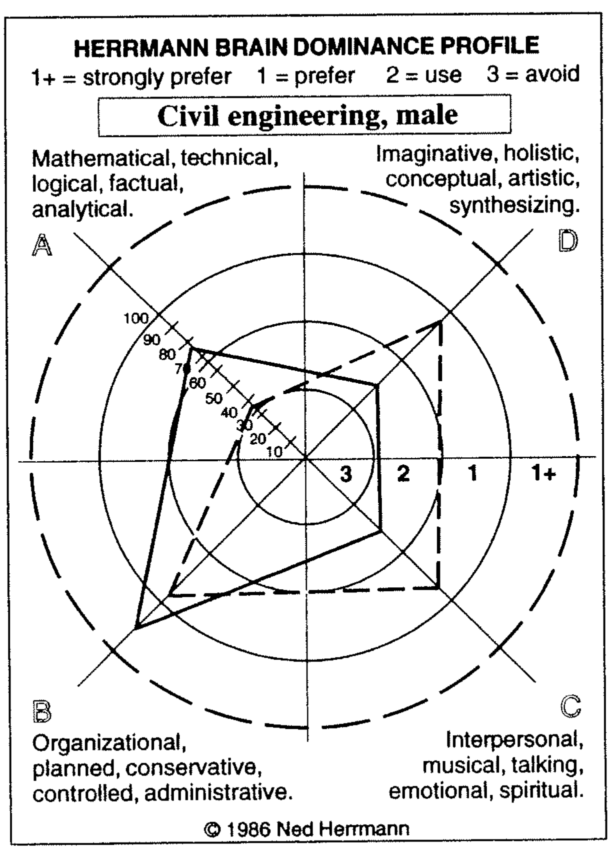

Fig. 4-2

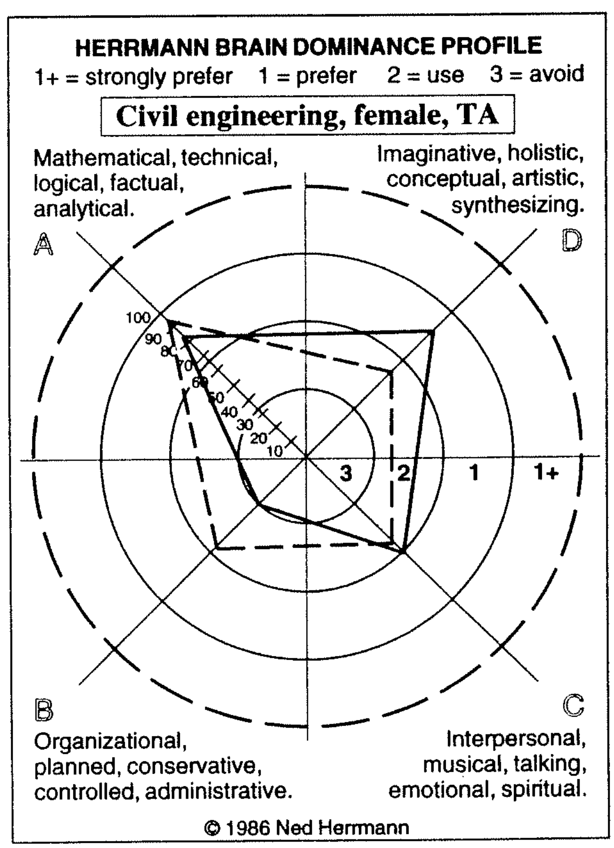

Fig. 4-4

Figures 4-1 to 4-4. Changes in the HBDI profiles of engineering students at the University of Toledo from 1990 (dashed line) to 1994 (solid line).

come more whole-brained; if they were right-brained already, they strengthened or maintained these preferences. They were the only subgroup that increased in the quadrant C mode (not unexpected in people who are involved in student-centered teaching activities and collaborative learning). They increased their creative thinking average from 78 to 90.

The six "unusual" students as a group were unusual in the sense that they strengthened their already high preference for quadrant D thinking, achieving this result on their own with little support from within the College, with the possible exception of the first-year creative problem solving course which validated their independent outlook.

From this stratified analysis, we conclude that the rise of the average profile to 75 for quadrant D is due solely to the retention of the unusual students and to the involvement of students as creativity assistants—not all students benefited from the improving climate for creativity. This result again points out shortcomings in the curriculum and problems in the way it is delivered which must be addressed by the faculty. From feedback received in a number of sessions at the 1994 ASEE Conference in Edmonton, Canada, it is becoming clear that creativity and teamwork act synergistically—both have to be developed systematically and simultaneously for students to achieve improved learning and problem-solving outcomes.

III. Conclusions, Implications, and Recommendations

A. Usefulness of the HBDI:

We believe that these early results of the longitudinal study con-

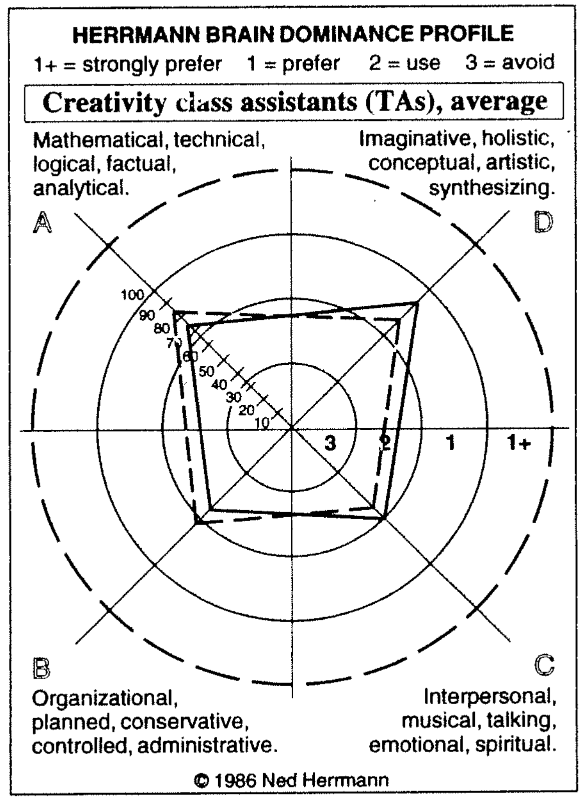

Figure 5-2. Changes in the average HBDI profile of six creativity class assistants.

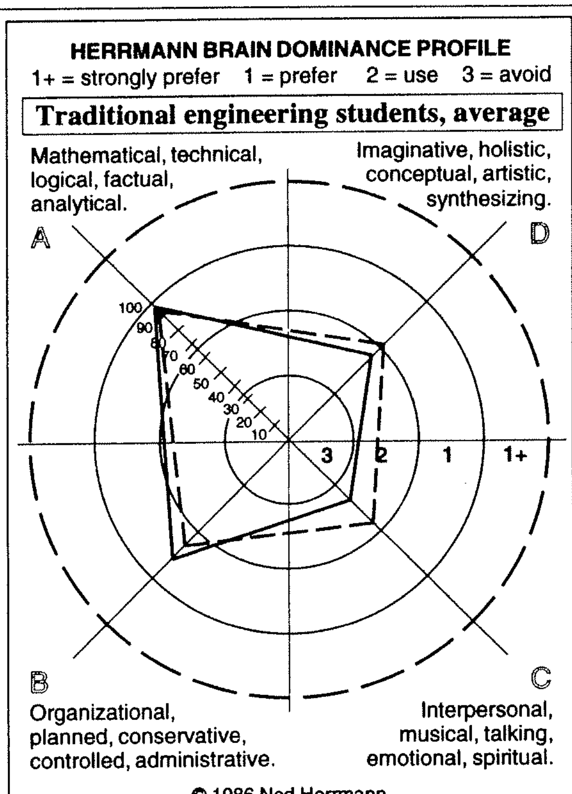

Figure 5-1. Changes in the average HBDI profile of 18 "traditional students.

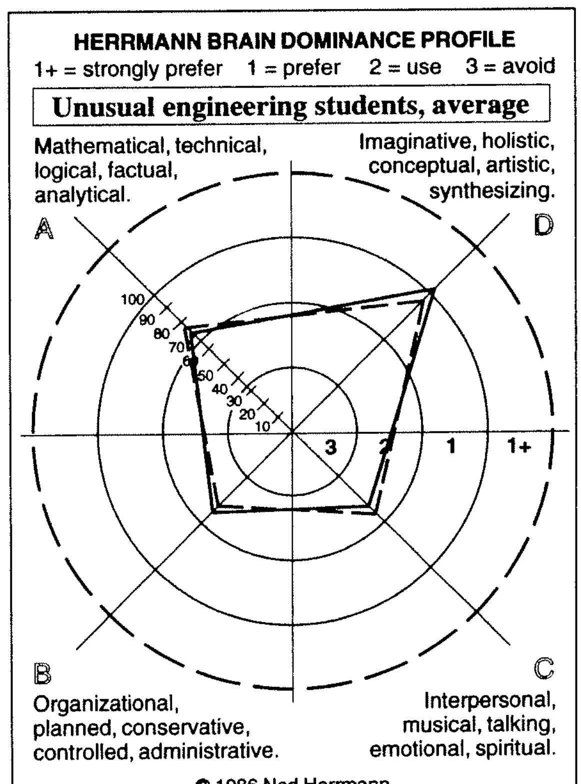

Figure 5-3. Changes in the average HBDI profile of six "unusual" students.

Group	1990—Freshman HBDI A	B	C	D	1994 —Senior HBDI A	B	C	D
Traditional	93	74	**60**	69	97	84	**46**	61
Creativity Asst.	84	70	58	78	75	59	**68**	**90**
Unusual	77	55	59	95	74	58	56	**103**
Average	88	68	59	76	88	74	53	75

Table 5. Comparison of averaged HBDI scores for subgroups of engineering seniors.

firm the usefulness and advantages of the HBDI as an assessment tool:

1. Students gain insight into their thinking styles and are able to formulate successful learning strategies. For example, students showing a high preference for C-quadrant thinking realize that they can benefit from group study and thus will seek out such opportunities; students with right-brain thinking preferences become more understanding and accepting of left-brain instructors—they have learned to cope with different environments.

2. The results are very useful to the class instructor—student questions, comments, and answers can be appreciated and understood much better in the context of the students' thinking preferences. Instructors who understand the power of the Herrmann model and its implications can expand their teaching strategies to meet the thinking styles of all students in their classes.

3. We have used the results to help students form whole-brain teams for optimum problem solving. The students have gained an increased understanding about communicating and working with people who are "different" and who can contribute special skills to particular tasks. These are not just formal technical skills but synergistic interactions that are facilitated by a knowledge of other people's thinking and learning styles.

4. The HBDI can assess the influence on student thinking skills (individually and collectively) of curriculum changes. This could be crucially important to the large efforts of the engineering coalitions being supported by the National Science Foundation.

5. We use the HBDI when conducting workshops and seminars, including in-college staff development. Many faculty members with right-brain preferences gain insight into why they have been feeling isolated and "different" from their peers.

B. Male-female differences:

We have found that the average profile for male engineering students and female engineering students differs little in quadrants A,B, and D; the only difference is in quadrant C where women on the average score significantly higher. With very few exceptions, women do not show an avoidance in quadrant C thinking. In particular, the 1132 generic profile prevalent in male engineering students is extremely rare in female students. Some professional women who do score low in quadrant C will admit, when interviewed, that they have had to suppress those thinking modes in order to succeed in a male-dominated organizational environment, and we have seen a complete switch from left-brain to right-brain dominance in the HBDI profiles of females, once they found that it is acceptable or safe to express their true selves* (Figure 6).

C. Implications for teaching:

In our group of 30 seniors, 40 percent of the students are right-brain thinkers, based on the HBDI results (refer to the Appendix for the calculation and definition). This is not an unusual result; our freshmen honors class in 1990 had this same distribution (for N = 34). Thus engineering professors can expect to have many students in their classes who have right-brain thinking and learning preferences. For this reason, important concepts must be taught to all four quadrants for optimum learning and to create an environment that provides opportunities for all students to strengthen all four thinking modes. We can no longer assume that engineering students have the typical faculty profile or that this is the profile that will succeed in the future. We must take special care not to weed out the more right-brain profiles and not to pull whole-brain profiles to the left. Whole-brain thinkers—people who have thinking preferences in all four quadrants—are especially in demand in organizations because they can communicate with and act as "translators" on teams for people who are very different from each other in brain dominance.

D. Implications for curriculum restructuring:

Industry needs engineers who can think globally and work in teams; society needs engineer-entrepreneurs who can start their own companies and create jobs. Thus it is essential that we develop students who have whole-brain thinking skills and who have metacognitive abilities—they can think about thinking, not just plug into formulas. These characteristics can be built into each subject. Integrated courses are an exciting option. For example, an integrated biology-English composition course is being pioneered at Michigan Tech and will serve as a model for integrating engineering courses with humanities courses. Our proforma HBDI analysis of a typical mechanical engineering curriculum found that the curriculum is even more skewed to the left than the faculty average (see Figure 7)[6]; thus many innovative ideas can be applied to achieve a better balance.

However, the good news for faculty is perhaps that not the entire curriculum has to be restructured; we can keep the best of the

*It has only been within the last year that we have begun to be aware of this phenomenon among our workshop attendees and through conversations with female students. We are planning to investigate this aspect in more detail in the future.

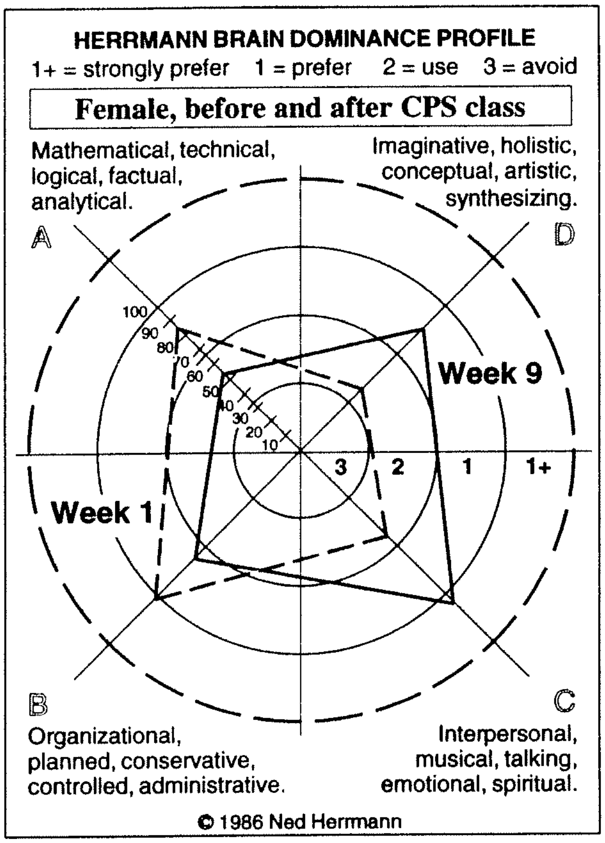

Figure 6. Changed HBDI profile of a female student in creative problem solving, resurveyed during the ninth week because her strong quadrant C behavior contradicted her earlier profile.

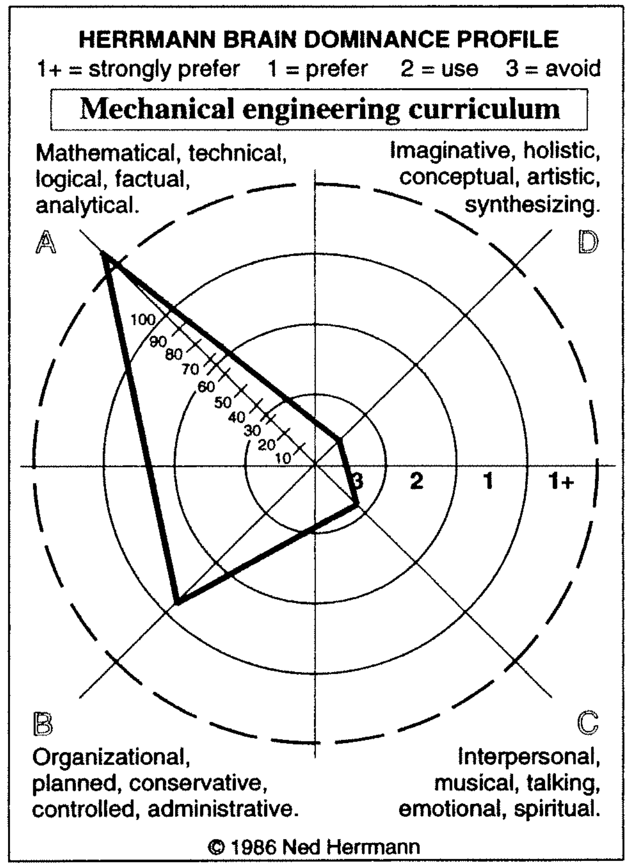

Figure 7. Proforma (approximate) analysis of a 1991 mechanical engineering curriculum using the Herrmann brain dominance model.

strong, analytical instruction of the fundamentals. We need to start with changing maybe 20 to 30 percent of the courses or course content toward whole-brain teaching and evaluate the outcome over the next four years, using the HBDI. It would also be very interesting to evaluate the outcomes of the NSF engineering coalitions in terms of student thinking preferences. Also, since there seems to be some correlation between the presence of certain profiles and the retention of women students, this connection could be further investigated at institutions that have a sufficiently large engineering student population.

Our data show that it is possible to significantly change the thinking preferences of individual students and consequently the outcome for an entire college. We also believe, based on our findings, that the effort required does not demand a radical change for all courses; at this time we feel that good results can be obtained if students had one course per term that would incorporate and emphasize all four thinking modes. Then it is up to the faculty in each department to cooperatively redesign the curriculum so that it will meet these new thinking requirements in a way that makes holistic connections within and outside of engineering.[9] We highly recommend that attention be paid to using cooperative learning strategies and that teamwork be required in many courses, with these efforts being supported with positive feedback within the classroom, by faculty peers, and by the administration. Thinking preference can lead to competence—this is another goal that demands careful thought for implementation, so that we will provide our students with competence in all thinking modes. We will continue to collect HBDI data from Toledo seniors for another two or three years, and we are planning to follow-up the 1994 seniors after they have been in industry for two years. The focus of our work has now shifted to Michigan Tech; we are initiating new HBDI studies in engineering as well as biology. With Electrical Engineering in the process of requiring creative problem solving as a three-credit hour course for their freshmen starting in 1995, we will have a new group of students and faculty for evaluating the effects of curriculum change. We are also investigating the correlation between thinking preferences (HBDI), creative problem solving, and developing critical thinking skills.

E. Answers to the Nine Questions:

Based on our data and discussion, how would we answer the questions listed at the beginning of the paper?

1. *Should it be our goal to try to increase student thinking skills (preference and competence) in all four quadrants of the Ned Herrmann model?* By all means!

2. *Do engineers who have to function well in the 21st century need thinking skills in all four quadrants?* Definitely yes.

3. *Is the HBDI profile of a first-year student a predictor of success in engineering?* With a few exceptions, no. Only scores less than 40 in A, coupled with a low B, seem to characterize students who will quickly leave engineering for more creative or people-oriented fields. Since both the learning climate and student thinking preferences can be changed, we cannot make categorical recommendations on career choices based on the HBDI; the profile is best used to gain insight on how to match a student's thinking preference with learning strategies

for success. People with strong preferences in any of the quadrants have been successful in engineering, but career opportunities in the area of teaching/training and innovation in industry are wide-open for quadrant C and quadrant D thinkers.

4. How easily can a student's pattern be changed? More easily than previously thought. Students can "discover" their creativity and affirm their different thinking styles, especially as they find that right-brain modes are legitimate and useful. On the other hand, students can also be squeezed into a left-brain mindset—a skewed curriculum can suppress their creativity and interpersonal skills.

5. Do those students who think "differently" drop out? About half do; others change, and some persist despite their "different" mindset. Overall, we are losing a valuable resource. Figure 8 shows the "tilt" of thinking preferences of honor students, most of them national merit scholars, and all but four from our fall 1990 honors creative problem solving class, with the solid circles for those students who dropped out of engineering. With the exception of one left-brain student who left the university for personal reasons (double circle), it is striking that all students who opted out of engineering had strong or very strong quadrant D preferences as shown by the location of the respective dots on the grid above the A-C axis (except for one of the three strong C-quadrant thinkers who also changed to other majors as well).

6. Why were the most talented, creative students leaving engineering? Lack of challenge and support for their right-brain thinking modes; lack of creativity; lack of teamwork; lack of synthesis and connections with real life; lack of holistic learning strategies in the curriculum. A study tracking the entering students of 1984 at New Mexico State University found "one rather disturbing point that a significant number of students with high (> 26) ACT scores left engineering..."[14] Excerpts from a top student's eloquent essay as to the reasons why he is leaving engineering after getting his degree are given in Appendix B.

7. How do we know our restructuring efforts work—are we making an impact on the students? If the HBDI profiles begin to change toward the desired directions (because these thinking skills are being taught in the curriculum)—this will show that the effort is having results, both individually and collectively. Yes, we are making an impact on our students. In the words of one engineering professor, when we teach, we are "messing" with our students' brains: either we can let this happen accidentally, or we can direct and optimize the process, and we can let the students actively participate in choosing the desired directions.

8. Will our efforts result in more right-brain (or whole-brain) students graduating from our program? If a large proportion of the faculty participates and supports the restructuring effort, we can guarantee that they will graduate "different" students—students who will be capable of dealing with change, who will be innovative, who will have what it takes to succeed and contribute value to the global community.

9. How are the four quadrants of thinking involved in learning? We are just beginning to explore and exploit these strategies in the teaching of engineering courses and the development of textbooks and integrated software.[5,6,7] For example, visual and sensory thinking (quadrants C and D) are key to memory and synthesizing ideas in the subconscious mind. Hands-on team projects and application to a real-life design problem (quadrants B, C, D) enhance learning. Also, we require customer surveys (quadrants C, A), patent searches (quadrants A, D), verbal and written presentations (primarily quadrant C), and the use of interactive software for solution optimization and asking what-if questions (quadrant D) within the context of creative problem solving (which in itself is a whole-brain process using all four quadrants iteratively).

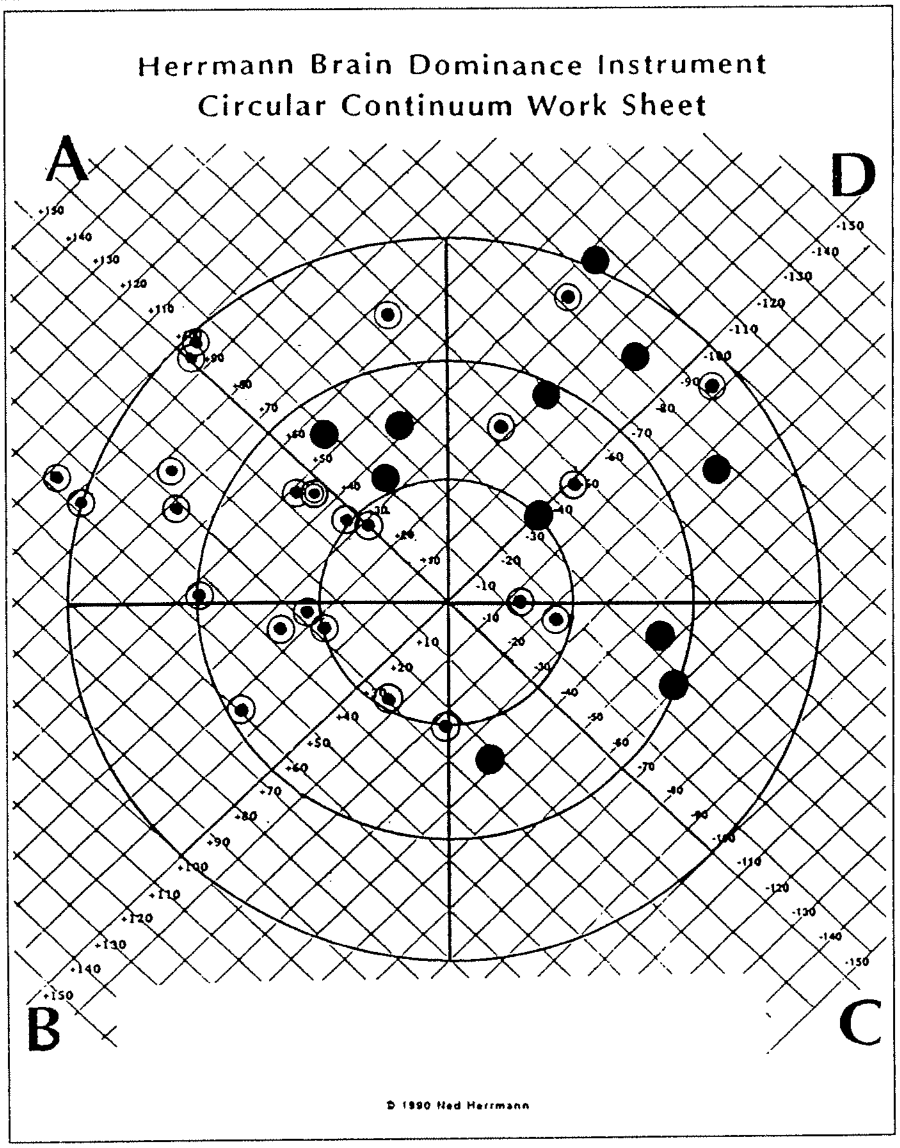

Figure 8. Distribution of thinking preference "tilt" for the honors creative problem solving class and the top engineering senior, fall 1990. Dark dots indicate students who have dropped out of engineering.

ACKNOWLEDGEMENT

We gratefully acknowledge the help of Dr. J.D. Gupta, civil engineering, and Mrs. Sylvia Pinkerman, counselor in pre-engineering, for their assistance in collecting the 1993 freshman and 1994 senior HBDI data at the University of Toledo. We want to thank Mr. Ned Herrmann for his support of the longitudinal study and his staff members for their patience; they were always ready to help and answer questions on the use of the pc-based HBDI scoring program.

REFERENCES

1. Edward Lumsdaine, "Six-Year, Six-Topic Engineering Faculty Enhancement Program," *Proceedings, ASEE Annual Conference*, New Orleans, June 1991, Vol. 1, pp. 59-64.

2. Ned Herrmann, *The Creative Brain*, Brain Books, Lake Lure, North Carolina, 1990.

3. Edward Lumsdaine and Monika Lumsdaine, "Full Implementation of Freshman Course in Creativity and Problem Solving", *Proceedings, ASEE Annual Conference*, New Orleans, June 1991, Vol. 2, pp. 1572-1577.

4. Edward Lumsdaine and Monika Lumsdaine, *Creative Problem Solving: Thinking Skills for a Changing World*, McGraw-Hill, New York, 1995.

5. Edward Lumsdaine and Jennifer Voitle, "Contextual Problem Solving in Heat Transfer and Fluid Mechanics," *AIChE Symposium Series, Heat Transfer*—Atlanta 1993, Volume 89, pp. 540-548.

6. Edward Lumsdaine and Jennifer Voitle, "Introducing Creativity and Design into Traditional Engineering Analysis Courses," *Proceedings, ASEE Annual Conference*, Urbana, Illinois, June 1993, pp. 843-847.

7. Edward Lumsdaine and Wen J. Wu, "Interactive Computer Software for Teaching Heat Transfer," *Proceedings, ASEE Annual Conference*, Urbana, Illinois, June 1993, pp. 102-107.

8. R.H. Todd, C.D. Sorensen, and S.P. Magleby, "Designing a Senior Capstone Course to Satisfy Industrial Customers," *Journal of Engineering Education*, Vol. 82, No. 2, pp. 92-100.

9. Joseph Bordogna, Eli Fromm, and Edward W. Ernst, "Engineering Education: Innovation Through Integration," *Journal of Engineering Education*, Vol. 82, No. 1, pp. 3-8.

10. Ellen T. Harris, "Why Study the Arts—Along With Math and Science?" *The Aspen Institute Quarterly*, Vol. 4, No. 1, Winter 1992, pp. 95-96.

11. Ref. 10, pp. 100-102.

12. J.B. O'Neal, Jr., "Engineering Education as an Ordeal and its Relationship to Women in Engineering," *Proceedings, ASEE Annual Conference*, Edmonton, Canada, June 1994, Vol. 1, pp. 1008-1011.

13. Richard M. Felder, Gary N. Felder, Meredith Maney, Charles K. Hanrin, Jr., and E. Jacquelin Dietz, "Women in Engineering: Falling into the Gender Gap," *Proceedings, ASEE Annual Conference*, Edmonton, Canada, June 1994, Vol. 1, pp. 1253-1256.

14. C. Quentin Ford, J. Eldon Steelman, Jody Jordan, and Jeremy Wood, "The Progress of the 1984 Engineering Cohort," College of Engineering, New Mexico State University, Las Cruces, NM 88003.

APPENDIX

A. Herrmann Brain Dominance Profile

Completed HBDI forms are forwarded to the Ned Herrmann group (or a person certified by Ned Herrmann in the administration, application, and interpretation of the instrument). The data is entered in the HBDI scoring program and then transmitted by modem to Ned Herrmann's headquarters in North Carolina for scoring. Numerical results are returned by the computer and can then be entered on the profile data sheet manually or with a graphing program (Figure 9). On this profile sheet, the numerical scores from the survey show that this person has primary preferences in quadrants A and D, a secondary preference in quadrant C, and an avoidance in quadrant B. This is also indicated by the generic profile code 1321 (which is sketched in the small figure on the left) and entered on the first line in the data box.

The second line lists the scores for one particular section in the survey (showing how a person's thinking preferences may change when under pressure). The third line indicates the scores for each of the four quadrants—this data is then plotted on the circular graph and connected with straight lines, yielding a characteristic profile. The four boxes around the graph designate the percentage distribution of left-brain (quadrants A + B) versus right-brain thinking (quadrants C + D) and cerebral (quadrants A + D) versus limbic thinking (quadrants B + C). This is the data that we have used in the paper to determine if students are left-brain or right-brain dominant. The individual in the example has a strong preference for cerebral, cognitive processing (as opposed to the less preferred limbic modes), but is equally balanced between left-brain and right-brain thinking, at 50 percent each.

This sample profile shows primaries in both quadrant A and quadrant D, where analytical, logical, technical-mathematical thinking modes as well as innovative, creative, conceptualizing, and imaginative thinking are preferred (as indicated by the individual's responses to the survey questions). This individual has a secondary preference in quadrant C (the interpersonal, emotional and musical modes) but would tend to avoid the structured, administrative, detailed modes of quadrant B. Occupations typical of this profile include researchers, physicists, design engineers, and many in top executive positions in technical or financial fields where future-oriented strategic thinking is required.

B. Excerpts from an Ethics Essay by an Engineering Honors Student—"Impressions of Engineering"

> **"... I looked forward to entering an engineering program [developing new and creative ideas to solve problems of manifold nature] and taxing my mind and hands ... The overwhelming factor in my decision to enter an engineering program was the advice of my father, a mechanical engineer: "Engineering will teach you how to think."**
>
> **...Three terms of reading the classics [in the honors seminar] indeed inflamed a desire to think and to learn. My honors calculus classes thrilled me with an almost deterministic view of the world. Seemingly anything could be dealt with through mathematical techniques. The differential equation in particular seemed to me the pinnacle of beauty and form.**
>
> **Then, I finally began getting to my engineering courses. ... At first, I was a bit disappointed. The classes seemed dry and "mechanical." There was no talk of either beauty or applicability, merely equations (and even so, the mathematics and the physics behind the equations were played down). The impression was handed down through a number of professors that it was not important to understand why the equations are, merely what they are.**

> Upon reaching [fluid dynamics], I observed a new phenomenon. I had read and observed enough about fluids to become alarmed by what was taught in class. No mention of what a fluid actually is, no sense of what the Reynolds number represents (ratio of inertial to viscous forces), simple "rho-vee-dee-over-mu."
>
> ... The design sequence was the end of my career in engineering. Equation upon equation, rule on rule on rule. No sense of where it all came from or what it means. If I just copy down the right formula out of the book and do my addition and multiplication correctly, I get my "A."
>
> ... Through outside reading on my own, I have seen the beauty of Hamiltonian mechanics, tensor calculus, partial differential equations, and non-linear analysis. All of these have tremendous application to the engineering realm, yet they are never mentioned. Furthermore, I have been penalized in certain classes for thinking independently and applying "non-standard" methods to problems. ...Laboratory experiences, far from exposing me to experimental techniques, have given me great practice in reading the lab manual and following the step-by-step instructions without having to think about what I am doing. It would be hyperbole to use the term "brainwash," but the word nonetheless comes to mind.
>
> ... My experience has been by no means exclusively negative. Two professors and one TA have inspired me and challenged me to true education. I am not so bitter as I am concerned about the now substantial flux of National Merit Scholars entering the engineering program. Even now, my experience is not unique, and I strongly believe that without action it shall be the beginning of "things to come." I do not despise engineering, and I have a feeling my impressions of the engineering program would not have been universally similar at all schools. Nevertheless, I (and others in the honors engineering program) are resolved to graduate and do practically anything but engineering!"

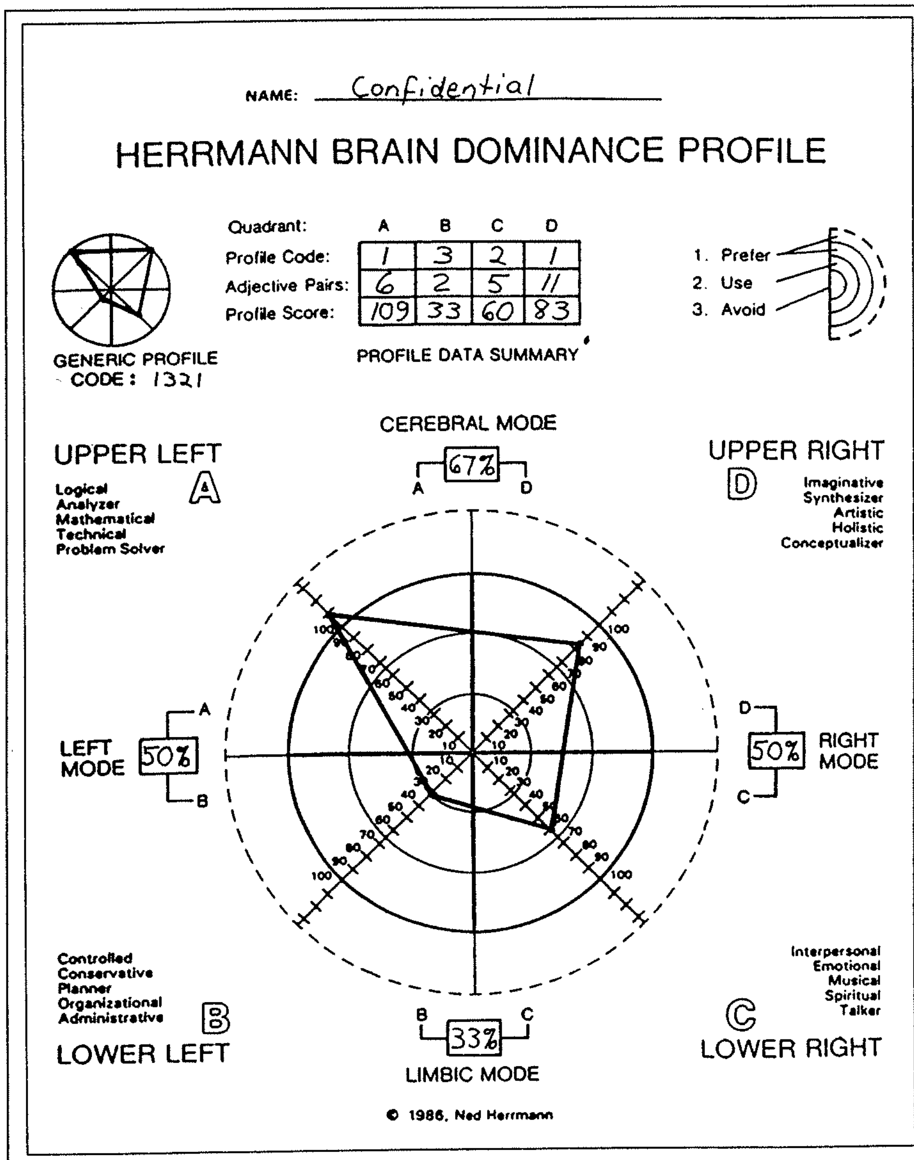

Figure 9. Format of an actual HBDI profile, with data summary.

This student sent us a copy of the essay to let us know how he felt. When we subsequently saw his HBDI profile, his reaction to the engineering curriculum and especially the way it was taught was no surprise to us. This is a student who graduated at the top of his class. Would it surprise you to hear that this student's younger brother was equally talented but decided to opt out of engineering even before completing the freshman year? But we also know a student with similar abilities, background, and HBDI profile who loves engineering—the only difference that we can discern is that this student went through a program that included a collaborative learning environment and a stronger emphasis on creative activities in the engineering curriculum.