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A study of the thinking styles and academic performance of civil engineering students

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A worldwide industry-led paradigm shift is taking place in engineering education. Feedback from industry indicates that success in the working environment is related to 'non-technical or soft skills' such as communication and interpersonal skills. Engineering education needs a bias correction from a historical focus on technical training. These 'non-technical' skills are mostly associated with the right hemisphere of the well-known left/right brain model.

The Department of Civil and Biosystems Engineering of the University of Pretoria used the well-calibrated four quadrant whole brain theory and model developed by Ned Herrmann to measure the thinking preferences of first year civil engineering students. The study covered information gathered from student intakes in the period 1999–2001. The survey was also carried out among lecturing staff. The results confirmed a predominantly left brain bias among students and lecturing staff. Students' academic records were then correlated with their thinking preferences and this confirmed that right brain dominant students tend to perform academically below average and less well than left brain dominant students. The implications of the results are discussed with regard to curriculum changes, lecturing style and implications of admission criteria, as well as the needs expressed by industry for the incorporation of 'non-technical or softer skills'.

INTRODUCTION

A worldwide change in engineering education is taking place, driven by industry needs. Feedback from industry indicates that 'industry is increasingly looking for employees who can think holistically, who can innovate, who can work in teams, who can synthesise and who can integrate environmental and societal values and ethics in their work' (Lumsdaine & Lumsdaine 1995a). The Australian perspective is given by Beder (1998): 'Engineering is very much a social activity with political, ethical and economic dimensions. It is an art that requires a variety of skills, including visualisation and communication skills. It requires judgement and choices, and these have consequences for people that have to be considered and weighed up.'

Studies worldwide have revealed that employers believe that entry-level engineering employees are incompetent in the broader non-technical skills. Employers also feel that educational institutions need to place more emphasis on teaching the so-called softer skills (Busse 1992; FRD 1991; Nasree 2000; De Lange 2000). The trend to create a balance between technical and non-technical aspects in the training and education of engineers is evident in engineering education and curricula designs worldwide (ABET 1998; Lumsdaine *et al* 1995a; Beder 1998). These balanced education objectives, supported by the Engineering Council of South Africa (ECSA) (1998), initiated a review of the education and training of engineers in South Africa. Education is going through a major paradigm shift and restructuring in South Africa, too. The restructuring of education and training is being coordinated by the South African Qualifications Authority (SAQA) (1998).

The softer skills and 'non-technical' skills are invariably activities that demand right brain thinking skills and 'will be needed by the engineer of the future for survival in an age of instant communication and unsurpassed technological advance – an era where virtually all things are possible' (Dryden *et al* 1994). Unfortunately a bias persists towards the development of analytical and technical skills that requires mostly left brain oriented thinking at undergraduate level. The consequences of a curriculum that does not address the development of social, thinking and communication skills are far reaching (Horak 2000).

In order to facilitate the development of non-technical skills of first year civil engineering students, a teaching/learning facilitation strategy, based on an awareness of whole brain principles, was introduced in the Department of Civil and Biosystems Engineering at the University of Pretoria (UP) in 1999. This approach was based on the successes achieved with the introduction of Technological Innovation as a first year subject module in 1996 for the Department of Electrical, Electronic and Computer Engineering at UP (Cilliers 2000). Based on the success achieved in these departments with this new approach, Innovation was introduced as a subject module in the School of Engineering for all engineering disciplines as part of the new ECSA designed curricula from 2001. The Herrmann Brain Dominance Instrument (HBDI) was used to give civil engineering students insight into their own thinking preferences, foster awareness of the whole brain concept, and acknowledge the existence of diversity in thinking skills (Horak *et al* 2000). According to Herrmann (1995), every classroom represents a complete spectrum of learning style preferences. A diversity of thinking skills can be expected within a classroom sample. Herrmann also reported that the thinking preference profiles of engineers tend towards a predominance of thinking modes of the left hemisphere.

The HBDI was also used to determine the homogeneity/diversity of the group of students and to give lecturers insight not only into the distribution of their students' preferred modes of thinking, but also into their own (De Boer *et al* 2001; Horak *et al* 2000). This homogeneity/diversity has implications for teaching and learning style preferences, which pose challenges for all classroom practices (De Boer *et al* 2001; Horak 2000). By applying a four quadrant whole brain approach, the shortcoming in engineering education identified earlier may be rectified in this manner. There is, however, no simple instructional solution as to how students should acquire the functional skills associated with the non-technical skills engineering they need (Horak *et al* 2000).

SCOPE AND METHODOLOGY OF THE STUDY

The thinking preferences of 100 first year civil engineering students (24 female and 76 male) and 13 lecturers of the Department of Civil and Biosystems Engineering were assessed in a three-year study, using the Herrmann Brain Dominance Instrument (HBDI). This instrument quantifies a person's relative preference for thinking modes, which is based on the functioning of the physical brain (Horak *et al* 2000). Each year, starting in 1999, first year civil engineering students took the HBDI as part of the subject of Civil Engineering Practical Orientation (1999 and 2000) and the new subject, Innovation, which was introduced in 2001 in the Engineering School of the Faculty of Engineering, Built Environment and Information Technology (EBIT), to provide a database for comparison and analysis of trends. Finally, the academic results of the students were interpreted in terms of the HBDI, more specifically as related to left and right brain dominance.

Guidelines given by the newly established EBIT Faculty Committee for Research Ethics and Integrity were followed to ensure that all the participants were informed and fully aware of the nature and objectives of the study, that they had the right to choose whether to participate, and that all information was to be handled in a confidential manner.

The study focused on two aspects:

- The interpretation of first year civil engineering students' HBDI results gathered over a three year period. The interpretation of HBDI results of lecturers at the Department of Civil and Biosystems Engineering was done in parallel.
- The implications of being right brain dominant in a left brain dominant curriculum was investigated by comparing the academic achievement of left brain dominant students with that of right brain dominant students.

THE FOUR QUADRANT WHOLE BRAIN METAPHORIC MODEL

The general concept of left and right brain dominance is well established. Analytical, logical, organised and structured thinking stems from the left brain area. People skills, conceptual and holistic thinking are associated with the right brain area. Herrmann (1995) developed the four quadrant whole brain model based on work by Sperry, as reported by Ornstein (1997) and Gazzaniga (1998). It is in essence a further refinement of the well-known left/right two hemisphere brain model and has its basis in the physiology of the brain. Today the four quadrant whole brain model, although originally thought of as a physiological map, is entirely a metaphor. This metaphorical model was derived not so much from a strict physiological interpretation as from documented observations of behaviours (Herrmann 1995). The physiological basis of the metaphor, architecture and application of this model are illustrated in figure 1.

The organising principle behind the model is four interconnected clusters of specialised mental processing modes that function together situationally and iteratively, making up a whole brain in which one or more parts become naturally dominant. The four clusters or quadrants of the circular graph are labelled counterclockwise from A to D, beginning with the upper left quadrant. Quadrants A and B represent the left part and quadrants C and D the right part of the brain, thus incorporating the well-known left brain/right brain theory (Ornstein 1997). Quadrants A and D and quadrants B and C represent the cerebral hemispheres and the limbic systems respectively.

THE HERRMANN BRAIN DOMINANCE INSTRUMENT

The Herrmann Brain Dominance Instrument (HBDI) is a survey of preferred thinking modes. This thinking style assessment tool consists of 120 questions, which can be answered without a time limit. The data collected does not measure intelligence or competence. The result is a graphical profile displayed on a metaphoric model of the brain and indicates thinking styles, showing the level and relative order of preferences. The HBDI is not a test and no profile is regarded as better or worse than any other. Quadrants are colour-coded for easy association. Quadrant A is blue, quadrant B green, quadrant C is red and quadrant D yellow. The scoring protocol results in a quantified measure of an individual's preference for each mental quadrant, which is then charted on a circular grid to make a personalised visual metaphor. Each quadrant score can range from less than 10 to more than 150. The typical profile of an engineering student is shown in figure 2, with the metaphoric thinking styles descriptors associated with each quadrant.

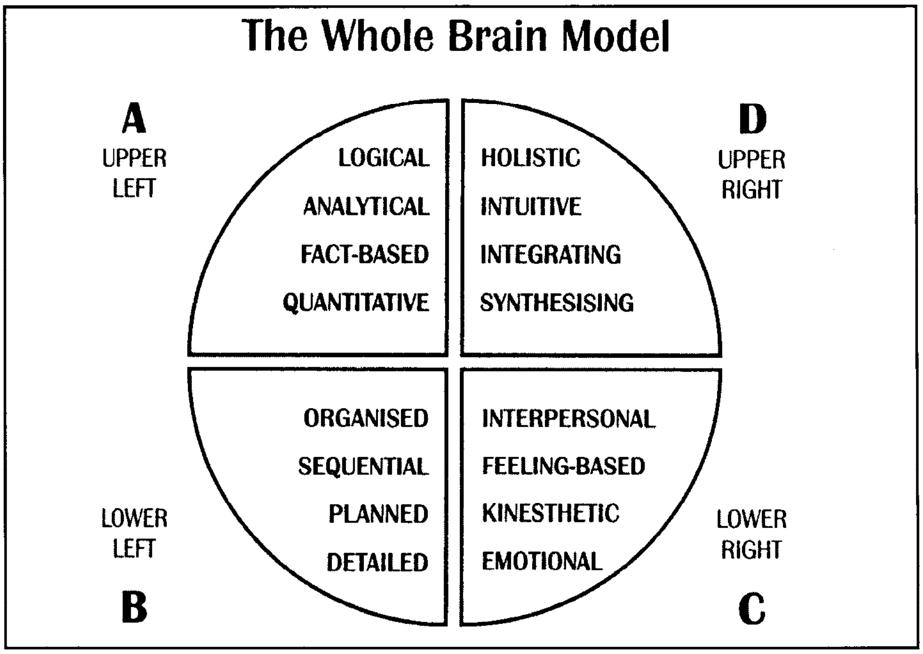

***Figure 1** Illustration of Herrmann's metaphorical whole brain model (Herrmann 1996)*

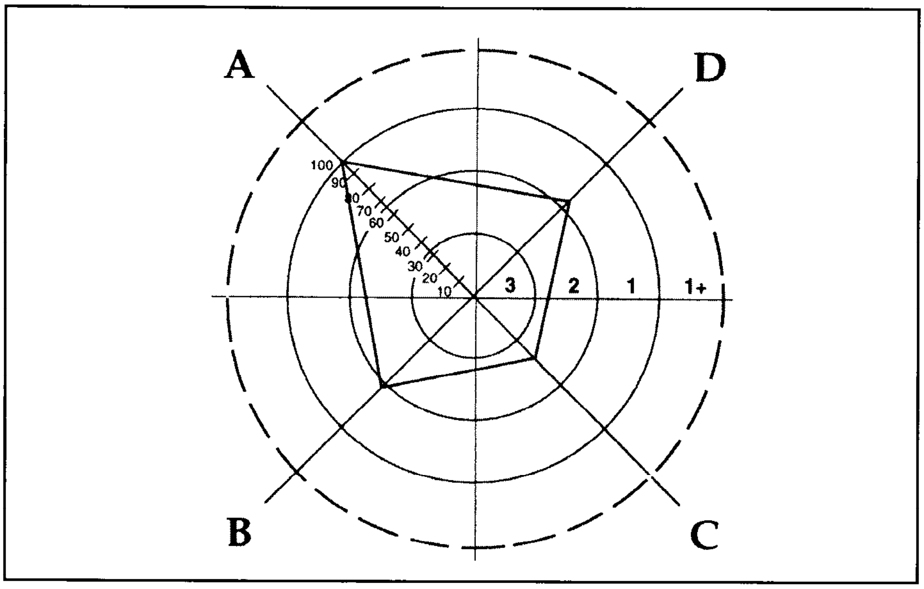

Figure 2 Typical HBDI profile of an engineering student (Lumsdaine & Lumsdaine 1995a)

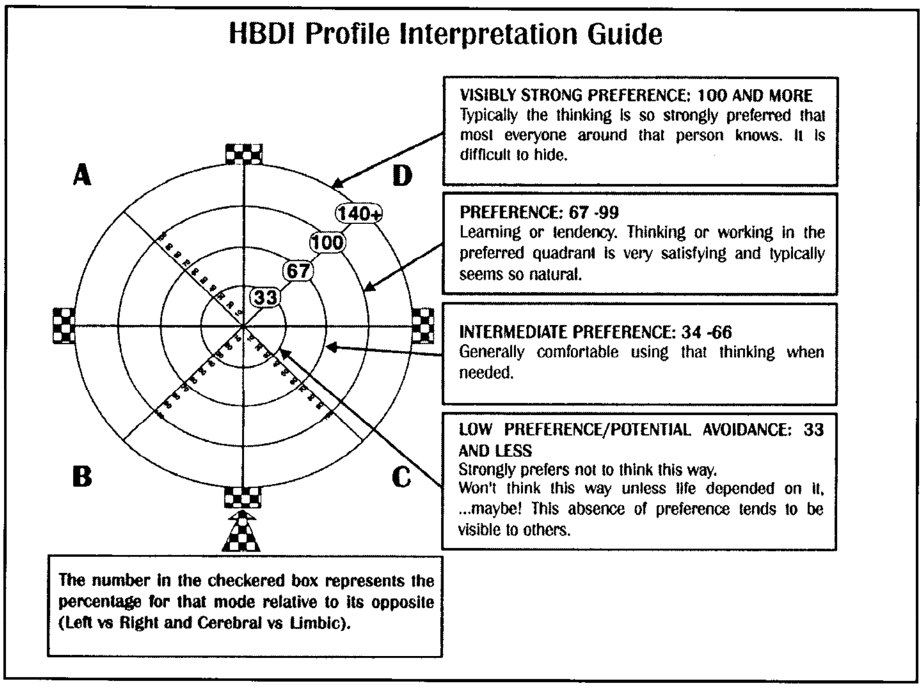

Figure 3 Graphical explanation of HBDI profile interpretation (Herrmann 1996)

In figure 3 the interpretation of an HBDI profile is described. It shows that a person's profile can be expressed in terms of bands or zones. A four digit numerical code describes the preference based in the score per quadrant in these zones.

A number is assigned to each quadrant, indicating the strength of preference for that quadrant as follows:

- A score of 67 or more points on any one preference is considered a primary or strong preference and is given a number 1 designation.
- A score of 34 to 66 is considered a secondary preference and is given a number 2 designation.
- A score of 0 to 33, designated by the number 3, is considered a tertiary preference and indicates an area of potential avoidance. This means that even if the person has somehow developed good skills for operating in this quadrant, the mental activity is likely to be very demanding, even intolerable.

For example, the code 1-2-3-1 means the person has primary preference in quadrants A and D, secondary preference in B, and tertiary preference in C. The designation of a typical engineer thinking preference profile shown in figure 2 would be 1-1-2-1. Regarding the instrument and the interpretation of the results Herrmann (1995) points out that the 'HBDI is not a test for competencies and intellectual abilities but an indication of preferences and potential competencies. Profiles are neither good nor bad, right nor wrong; the instrument measures preference for mental activity, which is entirely different from competence in performing it and profiles tend to remain constant, but they can, and do, change'.

According to Herrmann (1995) preference for the A quadrant (the left cerebral mode) means that a person favours activities that involve logical, analytical and fact-based information. A preference for the B quadrant (processes of the left limbic mode) implies a linear approach to activities. Individuals with a B quadrant preference favour organised, sequential, planned and detailed information. They are conservative in their actions and like to keep things as they are. A preference for the C quadrant (processes of the right limbic mode) indicates favouring information that is interpersonal, feeling based and involves emotion. A preference for the D quadrant (processes of the right cerebral mode) is characterised mainly by a holistic and conceptual approach in thinking. These preferences are summarised in figure 2.

The HBDI has been scientifically validated in three separate studies (Herrmann 1995). More than sixty doctoral dissertations based on the HBDI and the whole brain concept have enhanced the validity of the instrument. To date, more than one million HBDI profiles have been carried out worldwide (Lumsdaine, Lumsdaine & Shellnut 1999). One such study, conducted by Dr C Victor Bunderson in 1988, concluded that 'the HBDI provides a valid, reliable measure of human mental preferences when applied in a professional way, interpreted in conformity with the four-quadrant model, and scored with the approved scoring method' (Herrmann 1995).

ASSESSMENT OF THINKING STYLES USING THE HBDI

First year civil engineering students were informed about the HBDI as part of the course material for Innovation and the subject module it replaced, Civil Engineering Practical Orientation. It was emphasised that the instrument is not a test and cannot measure intellectual abilities. The students completed the HBDI survey during a scheduled lecture period. Students who experienced problems with the terminology were assisted, enabling them to fully understand the questions and to ensure that all the questionnaires were completed correctly. The completed questionnaires were sent to the HBDI-Africa branch in Pretoria for processing. Only certified HBDI practitioners trained by Herrmann International are allowed to do this. After processing each student received an HBDI results package, consisting of a coloured profile transparency, customised profile explanation and data sheets, and an explanatory booklet. The results were discussed with the students, focusing on the identifying aspects of the profiles and revisiting the four quadrant whole brain concept.

A summary of the HBDI results of the three-year groups ranging from 1999 to 2001 is given in figures 4–7. The results of

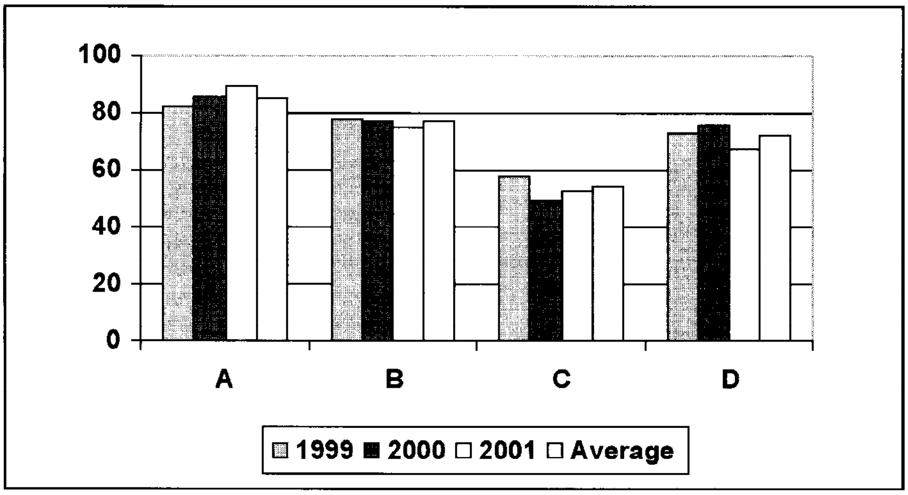

Figure 4 Average HBDI quadrant scores for first year civil engineering students

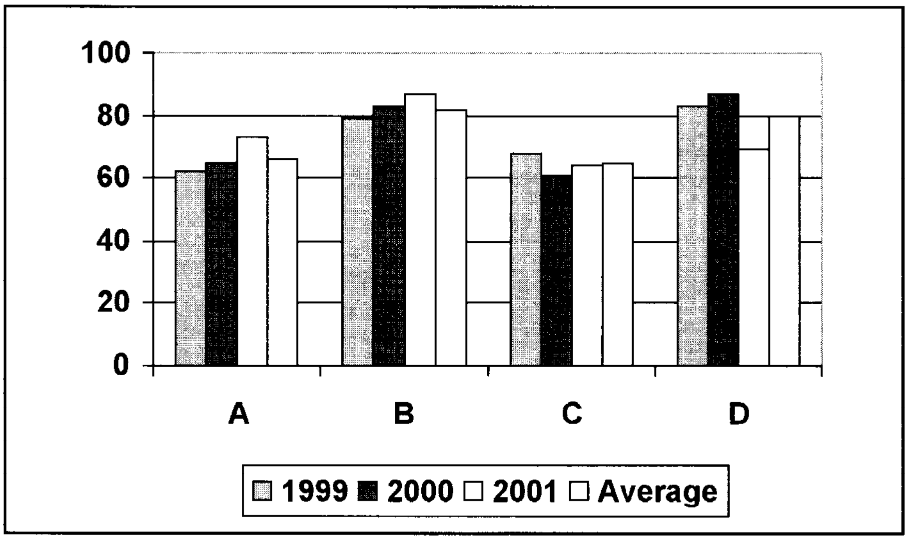

Figure 5 Average HBDI quadrant scores for female first year civil engineering students

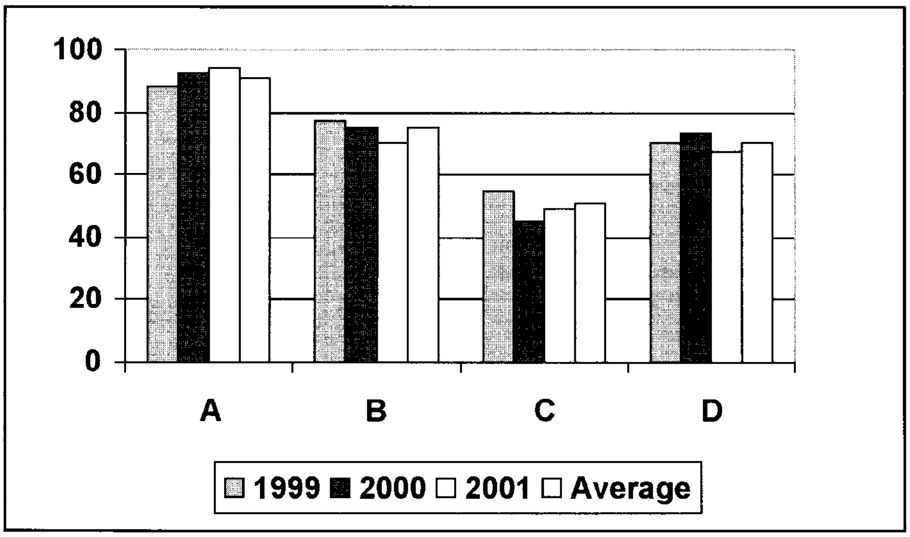

Figure 6 Average HBDI quadrant scores for male first year civil engineering students

the lecturers in the Department of Civil and Biosystems Engineering who participated in the study are also included.

The average profile of each year group is given in figure 4. This includes all female and male students in one group as a whole. Note that the average of the total group was calculated by using the quadrant scores of all 100 participants and not by taking the average of the three groups' averages. By calculating the average in this way, one group cannot carry a larger weight than another and all the results contribute equally. The results from all three years confirm that the left brain dominance associated with engineering students (Lumsdaine & Lumsdaine 1995a) is consistent for these civil engineering students, too. The tendency to be close to the avoidance level in the C quadrant (interpersonal, emotional and feeling) for all year groups is also consistent with the typical engineering student profile. It is the results for this quadrant in particular that indicate that these students are in need of 'soft or non-technical skills'. The D quadrant (holistic, conceptual, etc) preferences for all year groups are marginally lower than their preferences in the A and B quadrants. The combination of A and D quadrant preferences indicates cerebral hemisphere dominance versus the limbic system (quadrants B and C preferences).

Figure 5 is a summary of the average HBDI quadrant scores for first year female civil engineering students. The B and D quadrants were consistently more or less equally preferred or dominant for the female students for all year groups. The C quadrant preference has increased consistently for all female year groups and is not tending towards the avoidance level, as shown for the whole group in figure 4. The A quadrant preference has also moved from the first preference position for the whole group to the third position for the female group.

The average quadrant scores of first year male civil engineering students are given in figure 6. Their profiles and preferences are consistent with those of the whole group shown in figure 4. It is interesting to note that the dominance of the A quadrant preference of the male students consistently increased at the expense of the C quadrant preference. The C quadrant preference for the male students is consistently tending towards the avoidance level and may be a cause for concern with regard to development of soft skills in general. The tendency for the male students is to be consistently left brain oriented, while the female students consistently showed a balanced preference for the left and right hemispheres.

The HBDI quadrant scores of 13 lecturers in the Department of Civil and Biosystems Engineering who volunteered to participate in the study are given in figure 7. The quadrant scores in figure 7 are the average scores of the number (N) of participants. Note that the total group is differentiated into female (N = 2) and male (N = 11) participants. Admittedly the sample is small, but it is nevertheless regarded as indicative and not conclusive. The tendency is towards a cerebral or upper hemisphere dominance with the preferences consistently for the A quadrant and secondly the D quadrant preference. The lecturer groups have a left brain hemisphere bias owing to the strong A quadrant preference, though. It is significant that the group consistently have the lowest preference for the C quadrant. The results indicate a potential for left hemisphere lecturing styles and a potential strengthening of the left hemisphere bias observed in the student profiles.

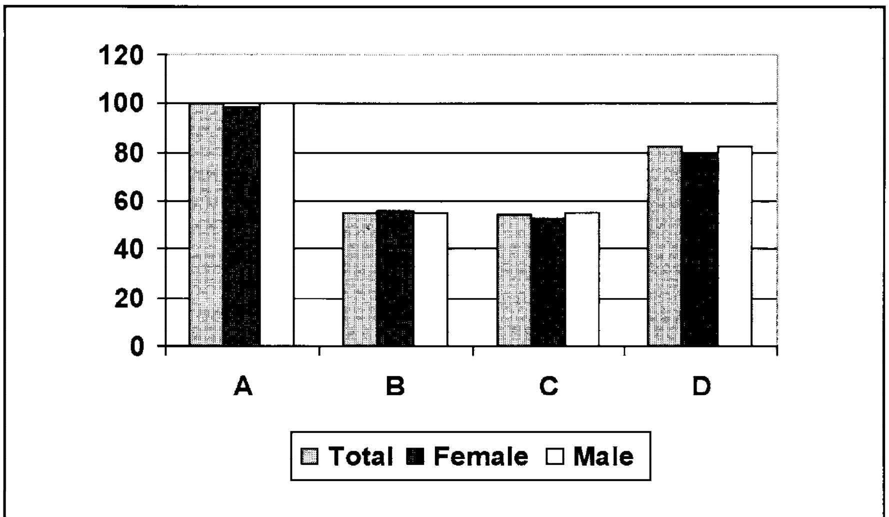

Figure 7 Average HBDI quadrant scores for lecturers in the Department of Civil and Biosystems Engineering

Table 1 Minimum and maximum quadrant scores for students

	A quadrant		B quadrant		C quadrant		D quadrant	
Group	Min	Max	Min	Max	Min	Max	Min	Max
1999	29	114	30	113	17	117	41	108
2000	30	116	54	114	27	101	53	116
2001	54	135	41	125	23	96	33	102

Table 2 A summary of left brain / right brain dominance of students

	Total			Females			Males		
Group	Left	Right	N	Left	Right	N	Left	Right	N
1999	55	45	49	48	52	11	57	43	38
2000	57	43	24	50	50	6	59	41	18
2001	58	42	27	55	45	7	59	41	20
Average	56	44	100	51	49	24	58	42	76

The minimum and maximum quadrant scores that resulted from the HBDI, for each civil engineering student year group, are given in table 1. As previously explained, a score in any quadrant of 67 or more is considered a primary or strong preference, while a score below 34 is defined as an area of potential avoidance. It is clear from table 1 that within this grouping of individual scores there is avoidance as well as a preference in each quadrant. It is in the C quadrant, however, that there are consistently very low scores as minimums recorded below 34, indicating avoidance potential.

The classification of a student as a left or a right brain dominant learner is carried out in accordance with the HBDI results. For a preference profile of A = 44, B = 69, C = 53 and D = 129, for example, the total of the four quadrants is 295. Of these 295 points, 113 are in quadrants A and B, and 182 are in quadrants C and D. This results in a 38/62 percentage split between the left and right modes. According to Herrmann (1995) a mode represents the combined mental processes of two adjoining quadrants, in this case A + B and C + D. The same process can be followed to calculate the split between the upper/cerebral (A + D) and lower/limbic (B + C) mode.

Brain dominance of the students in terms of the left and right hemispheres of the brain is given in table 2. The data that resulted from the HBDI are not only grouped into the total year groups, but are also divided into female and male students. The data is the average of the total number (N) of individual participants' preference of the left and right modes respectively.

The primary and secondary quadrant preference scores were used to determine left and right brain hemisphere dominance for the total group. The groups tend to be more left brain oriented than right, with a 56/44 percentage split between the left and right hemispheres respectively. This can also be seen graphically in the histograms in figure 3. It is noteworthy that female students show no clear dominance for a specific hemisphere (51/49) (being close to 50/50), unlike the male students, who show a clearer tendency of dominance (58/42) of the left hemisphere. These observations are consistent with the histograms of these two groups shown in figures 5 and 6.

FINDINGS AND CONCLUSIONS ON THINKING STYLES

The individual thinking preferences of the students, interpreted according to Herrmann's four quadrant whole brain concept, are diverse. The composite profile of the group of 100 students represents thinking style preferences in all four quadrants. This finding is in accordance with research that 'every classroom represents a complete spectrum of learning style preferences' (Herrmann 1996). 'It displays a composite whole of the diverse individual profiles representing thinking preferences in all four quadrants' (De Boer *et al* 2001).

Students noted that learning style preferences are distributed across the whole brain model. Not only the preferences, but also the avoidances were pointed out to them. They were reassured that no profile is wrong or bad and that students must be proud of their profiles. This reassurance, together with the discovery of their own profiles, led to a certain 'liberation' of the students' fear of being different. Communication and follow-up individual discussions with the students indicated that the self-esteem of some of these 'different' students also improved. This was confirmed by anecdotal statements through a survey carried out on the first group of civil engineering students of 1999, eighteen months after entering university.

The average civil engineering student profile code is 1121 (A = 85, B = 77, C = 54 and D = 72). As stated previously, this profile is consistent with the typical profile Herrmann associates with engineers. The only area of concern is the tendency to approach avoidance in the C quadrant (the area of interpersonal, emotional, feeling and spiritual skills). This is precisely the area that needs development in the training and education of civil engineers to meet the industry needs for well-rounded people who can communicate, conceptualise and express themselves competently in a changing sociopolitical environment.

ACADEMIC RESULTS IN TERMS OF LEFT AND RIGHT BRAIN DOMINANCE

Engineering curricula are known for their large technical content and high degree of difficulty. A subjective analysis and interpretation of the subject content descriptions of the curriculum for civil engineering at UP as described by Horak, De Boer *et al* (2001) indicated the following regarding course content: 36% in the A quadrant, 35% in the B quadrant, 8% in the C quadrant and 21% in the D quadrant of the Herrmann whole brain model. This results in the curriculum being predominantly left brain oriented, coinciding with the classical preference

Table 3 A data summary of second and third year students' left and right modes and academic results

	Group	Males		Females	
	Total	Left	Right	Left	Right
Third-years (tested in 1999)					
% Left	80	84	-	67	-
% Right	20	-	16	-	33
1999 Academic average (%)	61,8	61,7	59,1	65,6	58,7
N participants	25	16	3	4	2
Second-years (tested in 2000)					
% Left	62	69	-	50	-
% Right	38	-	31	-	50
2000 Academic average (%)	61,5	62,7	58,9	60,9	62,6
N participants	37	20	9	4	4

Table 4 Academic performance of students in terms of the group average

	Performing above average	Performing below average	Performing above average	Performing below average
	N	N	%	%
SECOND-YEARS				
Left brain oriented	8	16	33	67
Right brain oriented	2	11	15	85
THIRD-YEARS	N	N	%	%
Left brain oriented	8	12	40	60
Right brain oriented	1	4	20	80

profile of an engineer. Even though this analysis is not objective, it is regarded as indicative of trends, confirming that the curriculum content is biased towards the A quadrant and B quadrant.

It was found in the first part of this study that diverse thinking styles exist among the civil engineering students at UP. The curriculum analysis showed a tendency towards left hemisphere orientation. Learners who are right brain oriented, with avoidance for quadrants A and B, would probably experience an environment that is less supportive. 'Learning avoidances are even more significant than learning preferences because they turn people off. A turned-off learner is a waste of educational time and effort' (Herrmann 1996). If this statement is valid, 'right brain' students will potentially be below average achievers compared with students who are 'left brain' oriented. The attrition rate of engineering students at the School of Engineering at UP being as high as 25% over a number of years is serious cause for concern. Avoidance preferences may be linked to the potential for attrition. Not enough information is available yet to investigate this possible link, though.

The academic history of every student who participated in the HBDI survey was analysed and the average mark for all subjects passed in one year was calculated. The average for each year group was then calculated by adding all the averages and dividing by the number of participants. Because the academic results used for this investigation spanned a one-year period, the results of the first year students of 2001 were not taken into account.

The data is summarised in tables 3 and 4. These tables deal primarily with the available data of the two different year groups (1999 and 2000). From table 3 it can be concluded that the second-year group (tested in 2000) consists of 80% left brain oriented students and 20% right brain oriented students (see table 2). The average mode split between the left and right hemispheres is 57% and 43%, respectively. In total, 84% of the male students are left brain oriented, while 67% female students share the same preferred hemisphere. That leaves 16% males and 33% females who differ from what the 'left brain hemisphere oriented system' expects of them. Of these four groups, the left brain oriented females are top of their class with an academic average of 65,6%, followed by the left brain oriented males almost equalling the group average of 61,8% with their performance of 61,7%. Both the male and the female students with a preference for the right mode perform somewhat below the group average. The right brain oriented males scored an average of 59,1% in their first year of study with the females managing only an average of 58,7%.

The group tested with the HBDI in 1999 consists of 62% left brain oriented students with the rest (38%) being right brain oriented. The poorer academic achievers in this group, with a group average of 61,5%, are the 31% right brain oriented males, with an average of 58,9%. The performance of the left brain oriented females, scoring 60,9%, is lower than the right brain oriented females' performance of 62,6%. The small sample makes this result dubious and no conclusion can be drawn from this apparent reversal. The 69% left brain oriented males managed to average 62,7% and the 31% right brain oriented males achieved a 58,9% average.

Table 4 shows that 33% of the second year students classified as being left brain oriented achieved an average higher than the whole group. This percentage may appear to be low, but compared to the 15% right brain oriented students who were also able to top the group average, it can actually be considered comparatively high. This implies that 85% of the right brain oriented students in the second-year group were poorer academic achievers compared to the group average in the first year of study. This disturbing finding continues to prevail in the third-year group, where 80% of the right brain oriented students were unable to achieve an academic average better that that of the whole group. Eight left brain oriented students (40%) did manage to outperform the average, leaving behind the remaining twelve students with the same mode preference with the tag of being poorer academic achievers.

FINDINGS AND CONCLUSIONS ON ACADEMIC PERFORMANCE

The data and analysis indicate that the majority of students are left brain oriented and that these students tend to achieve higher averages than those who are right brain oriented. Right brain oriented students tend to be poorer academic achievers compared to the group averages. It was assumed that there is no definite difference in the students' capability of achieving high marks, because all students selected have a minimum C symbol for both Grade 12 Mathematics and Science in the higher grade.

Many other factors contribute to the academic success or failure of civil engineering students. In the context of the thinking preferences presented here, this tendency is attributed to the fact that the right brain oriented students have a stronger potential to become so-called turned-off learners in a curriculum that is biased towards the left mode. These students may be 'turned off' because the key mental preferences of intuitive and perceptive thinking, as well as their idealistic, expressive and open approach, do not fit that of the curriculum or that of their classmates. The implication of potentially being classified as 'different' and even 'weird' is a reality, too. The majority of students who are 'normal' in terms of the present system cannot always understand these students' different approach.

Students who fit the glove of the left brain biased curriculum prefer concise, efficient processes with realistic, disciplined and orderly approaches. The lecturers tend to function more strongly in this mode, too.

FINAL CONCLUSIONS AND RECOMMENDATIONS

Although diversity exists in profiles, on average these profiles tended to be triple dominant with the primaries in quadrants A, B and D and the secondary in C.

Like studies at the University of Toledo in America (Lumsdaine & Lumsdaine 1995b), this study revealed that more than one fifth of male students studying engineering tend to avoid the C quadrant. These students will have difficulty functioning as members of multidisciplinary teams in industry.

Lecturers at the Department of Civil and Biosystems Engineering also revealed a 1-1-2-1 profile, indicating structured and sequential thinking. The typical profile of the students and lecturers is the same as the one that Herrmann used to describe a typical engineer.

Learners and lecturers need to develop non-technical skills through the implementation of a four quadrant whole brain facilitation framework. Facilitators need to accommodate the diverse spectrum of learners with a variety of delivery styles in a balanced way to avoid 'turned off' learners. Lumsdaine *et al* (1995a) report that they achieved a significant rise in average D quadrant thinking preference with engineering students from first year to final year. They ascribe this mostly to greater sensitivity towards and retention of their 'creative' and 'different' students. Students who think 'differently' can be identified with the HBDI and given special encouragement, mentoring, and support to persist to graduation.

To summarise: up to 80% of the group were found to be left brain oriented, with a left/right mode split of close to 60/40. Right brain oriented students had a tendency to achieve slightly below average marks. These 'different' learners need to be accommodated in the system to harness the full potential that arises from the diversity.

The study indicates that the Department of Civil and Biosystems Engineering still needs to change and experience a further paradigm shift as industry demands. The industry needs the 'new engineer', as described by Beder (1998). This study spans the changeover from the old curriculum to the new one (introduced in 2001). The effect of the new curriculum will therefore only be seen in due course. Nevertheless, the implications of the department potentially being 'stuck' in the typical left brain dominant profile typical of the 1960s to 1970s are far reaching and probably typical of civil engineering departments at South African universities. Such departments are in danger of training students via a 'dated' or 'biased' curriculum, still focused on hardcore technical and analytical aspects, resulting in engineers who are potentially badly equipped for the current demands of the industry.

The focus of this study was not on the curriculum changes. This warrants a separate study. Nevertheless, the potential of using the HBDI to evaluate curriculum changes is evident. Lumsdaine *et al* (1995) found that the HBDI is a very useful tool for evaluating the effect of curriculum changes. Addressing the left brain bias of the engineering curriculum will be more complicated than merely making an adjustment to the right brain modes (Horak 2000). The ECSA quotas for discretionary subjects and non-technical subjects are based on the ABET (1998) quotas, and sticking to the minimum requirements of complementary studies or discretionary studies will not achieve this shift. A holistic change approach is needed. The curricula should be changed to reflect the necessary shift towards right brain thinking, or rather whole brain thinking, and the following complementary activities will also need urgent attention:

- the need for innovation and change in the education modes and style of application and teaching
- the need for diversity in the lecturing corps to ensure that different role models and diversity are experienced by the learners
- the need to revisit the admission criteria, which tend to pre-select predominantly left brain oriented people.
- ongoing revision and research into a whole brain basis for the curricula in civil engineering along the lines of Lumsdaine *et al* (1995).
- sensitising left brain oriented learners to the need to develop their right brain skills by preparing them for lifelong learning that includes 'soft skills' learning.

The four quadrant whole brain model is a facilitating tool to spark the much-needed and long-awaited revolution in engineering education in South Africa. The whole brain concept, once understood, becomes irresistible (Herrmann 1996), and indeed, its time has come.

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