# SPATIAL ABILITY, VISUAL IMAGERY AND ACADEMIC PERFORMANCE IN ENGINEERING GRAPHICS

*Charles Potter[1] and Errol van der Merwe[2]*

*Abstract* — *Our research has demonstrated that spatial ability and visual imagery influence academic performance in engineering, but can be increased through appropriate instruction. The instructional model we have developed is based on Piagetian principles, and confirms Piaget's theories with respect to the trainability of spatial ability in adulthood.*

*Prior to our intervention, the first year Engineering Graphics course at our university had a failure rate of 36% for all Engineering students, and failure rates of 80% for African students studying at our university. Similar high failure rates were found in Engineering Drawing and Design courses at other Southern African universities, and similar association between low scores on tests of spatial ability and academic performance in this area. These findings suggested the importance of early identification of students with difficulty, as well as the potential value of an intervention aimed at training visualisation and three dimensional modelling and representation of objects, in which students experiencing difficulties were apparently deficient.*

*Over the initial two years of the intervention, pass rates for the first year Engineering Graphics course improved from 64% to 76%. With further changes in teaching, and the training of senior students as tutors to support the lecturing and practicals provided in the course, the pass rates have risen to 88% annually, over a period in which the composition of the first year student body has represented increasing diversity in terms of cultural and educational background.*

*While spatial ability is trainable through the methods we have developed, our research also indicates that level of spatial ability at time of intake to university is an important influence on academic performance. This would suggest the value of courses at school level in this area, in addition to interventions aimed at improving spatial ability in those university and technikon courses for which visualisation and three dimensional representation are a requirement.*

*During 2000, the course materials we have developed were published in workbook form, and we have this year published a book on our teaching methodology. We are currently conducting evaluative research directed at fine-tuning the approach we use. We are focussing our research in particular at the needs of students who have low spatial ability at time of intake to the university, to establish how these students can be trained to use visual imagery to assist the learning process.*

*Index Terms* — *academic performance, engineering graphics, spatial ability, visual imagery*

## INTRODUCTION

The link between visualisation and engineering drawing and design is well established [9][10]. Not only do practising engineers report using visual images as an essential part of the design process, but many teachers of engineering graphics state that visualisation forms an integral part of the courses they teach[3][11][15]. Bertoline and his co-workers [3], for example, suggest that visualization ability is central to design, and that imagery provides a bridge between design ideas and their representation in sketching and drawing.

A number of researchers working in Southern Africa [6][7][13][14][43][44][46]have reported that students who score poorly on tests of three dimensional spatial perception are at risk as regards passing engineering drawing and design courses. We have also found [30]-[37] that students experiencing difficulties can be trained in perception and the use of mental imagery in drawing tasks. After receiving training, their performance on tests of three dimensional spatial perception improves. More importantly, the students also pass their engineering drawing and design courses. Similar results have been reported by Davies [4][5], working with overseas students at an airforce training college in Britain, and by Sorby and Baartmans [42], working with engineering students in the United States, suggesting that the research and instructional procedures we describe in this paper may have broader relevance.

## TRAINING SPATIAL ABILITY

Our model of teaching is based on Piagetian theory [16]-[28], which suggests that perception and imagery are figurative processes which can be trained throughout the human life-span, and that the processes involved in mental imagery apply both to children and to adults. Following the stages in development of perception and mental imagery suggested by

[1] Charles Potter, University of the Witwatersrand, Johannesburg, School of Human & Community Development, Centre for Psychology, PO WITS 2050, South Africa, 018pots@muse.wits.ac.za
[2] Errol van der Merwe, University of the Witwatersrand, Johannesburg, School of Mechanical Engineering, PO WITS 2050, South Africa, evan@hertz.mech.wits.ac.za

Piaget, our materials are organised hierarchically. Students identified as having weaknesses in three dimensional perception are provided with additional remedial activities involving modelling, copying, sketching and drawing. These activities are organised as a series of remedial loops involving additional exercises, which are undertaken by students experiencing difficulties with course assignments and class tests.

We have found, in line with Piagetian theory on perception and mental imagery, that students vary in their ability to use mental imagery, and may require training to do so. Those students with well developed abilities in using mental imagery for the purposes of visualisation are likely to experience few difficulties in learning the different methods of graphical illustration which engineers use in practice. In contrast, those students who lack visualisation ability experience difficulty in learning the conventions of engineering drawing, and applying these to the problems of design. These students can benefit from exercises which enable them to develop and use different forms of imagery as tools in thinking. We have developed teaching materials for training visual imagery and its associated spatial abilities [38][45], which are organised in a way that takes different student needs into account.

The results of students who have been exposed to our teaching model would suggest that the processes involved in developing and using perception and mental imagery are trainable. This would suggest, in line with the theories of Jean Piaget, that perception and imagery are processes which can be developed both in children and in adults, and can be trained throughout the human life-span. The implementation of our research has taken place in four stages, which will be summarised in the rest of this paper.

## STAGE ONE: THE PILOT INVESTIGATION

Prior to our intervention, the first year engineering graphics course was taught by a single lecturer to large groups of engineering students. Given previous indications concerning the relationship between spatial perception and academic performance at our university [43][44][46] and the evidence that 36% of all first year engineering students failed the first year engineerng graphics course, we believed that differences in spatial ability were affecting all students.

Analysis of first year pass rates also indicated that 80% of African students were failing the course. It was likely that there were a number of factors which were placing African students at a disadvantage. Due to the policies of apartheid, there were segregated schools under the South African system of education, in terms of which African students were taught in separate areas and in largely inferior and underfunded schools. In addition, African students had to spend a year doing a general B.Sc at a tribal university and then transfer to a university which taught engineering. We thus believed that adaptation factors in addition to spatial ability were affecting the academic performance of African students in particular.

In terms of these assumptions, it would be important not only to establish whether spatial ability was trainable with all students, but also to establish a system of instruction which could benefit African students in particular. Stage One of the research thus involved pilot work undertaken to establish whether spatial ability was trainable. In terms of a literature in which terms such as perception, spatial ability, spatial perception, visual imagery, visual memory and visualisation have often been differently defined and loosely used [38], we based our definition of spatial ability on the work of Piaget [17]-[19][27][28], who developed a comprehensive theory concerning the development of perception, mental imagery and language, and the relationship of these processes to cognition.

Piaget suggested that perception derives from activity, and that mental symbolism derives from activity. Based on extensive observation of the development of children, Piaget concluded that imitation of things is the fore-runner of mental symbolism, and is linked to the development of mental imagery. The internal abbreviated imitation of the perceptual activity constitutes the visual image, the visual image being based on the internal imitation of the originally perceived object. According to Piaget, mental imagery thus develops through action, and can be developed through activities which involve imitation. Both copying and sketching form the basis for the development of visual imagery in children. In addition to static images, based on objects which do not rotate or move, there are two other kinds of images which children normally develop. The first he called kinetic images, which are images based on the experience of an object's movement. The second he called transformational images, in which as an object is viewed it changes shape of form rather than position. This requires the trnasformation of a mental representation of the object, through a process involving mental manipulation of the visual image.

In summary, Piaget suggested that perception, mental imagery and language develop over the whole life-span of the individual, as separate process which are used in thought. In terms of Piaget's theories, the ability to work with static, kinetic and transformational images and to manipulate these mentally is fundamental to the work of an engineer. In particular, these different forms of mental imagery are central to the design process, and also form the basis of the ways in which engineers represent and communicate their ideas through sketching and drawing.

Based on this theoretical framework, our instructional programme included experience in modelling, copying and sketching. Where students were unable to use mental imagery and to visualise objects, we developed a series of remedial activities which aimed to develop the type of static, kinetic and transformational imagery which engineers use in design [40][41].

This programme was initially undertaken with three small groups of African students who were selected over a three year period to undertake a pre-university year in engineering. The progress of the students was monitored closely by questionnaires, interviews and course progress tests. Psychometric tests were also conducted with the first two groups. The results of the psychometric tests were of particular interest in yielding indications that three dimensional spatial perception increased significantly after experience and training was provided in modelling, sketching, visualisation and three dimensional representation using the conventions of engineering drawing (Pre- and Post-test Comparisons: Group 1, $p < ,05$; Group 2, $p < ,05$).

An additional pilot study was then conducted with 35 first year engineering students who had been identified as having difficulties with mastering engineering drawing. These students had low scores on tests of three dimensional spatial perception at time of university entry, and also failed their course tests over the first quarter of the academic year. The sample included both white and African students, who were provided with a special course, in which tuition was provided using materials developed with the specific aim of developing spatial ability. The academic performance of students taking this course was then compared with two matched samples of white students in the first year course who had not been exposed to the intervention (t Group 1 = 3,40 (42), $p < ,01$; t Group 2 = 3,87 (42), $p < ,001$).

In addition, comparisons were made between the academic performance of African students taking the course with other African students who had not been exposed to the intervention (t = ,45 (16), ns), as well as the first year academic performance of African students who had taken the pre-university year. Here the results indicated a significant difference between the pre-university students and both the first year African student samples (Group 1,
t = 2,45 (12), $p < ,05$; Group 2, t = 2,72 (13), $p < ,05$), indicating that the African students who had received training in spatial ability over an extended period of time prior to university entry were advantaged relative to African students who had entered the university straight from school, or via a tribal university.

Overall, the results [33][34] indicated that students could overcome their difficulties given appropriate instruction. Such instruction, however, needed to be of extensive duration, suggesting that quality of education received prior to university entry was an important influence on first year academic performance [8][30]. The results of the pre-university students were of particular interest, in yielding indications that spatial ability increased significantly after extensive training in visualisation and three dimensional spatial perception had been provided, and that all students receiving this training subsequently passed the first year engineering graphics course. African students who had not had the pre-university year did not fare as well, suggesting that there were additional factors affecting their adaptation to the demands of the course, probably relating to previous educational disadvantage.

## STAGE TWO: SPATIAL ABILITY AS PREDICTOR OF FIRST YEAR ACADEMIC PERFORMANCE IN ENGINEERING GRAPHICS

The pilot studies were followed by psychometric testing of all students in the Faculty of Engineering over a two year period, using a number of instruments. These included psychometric tests, as well as a biographical inventory. Various tests of spatial ability were administered to the students and the tests most highly predictive of first year academic performance were established using regression analysis. The data were factor analysed and then subsetted in different ways, to yield indications concerning the predictive influence of a variety of factors on the academic performance of the engineering student body as a whole, as well as samples of educationally disadvantaged students [40][41].

The results of the various analyses were as follows [30][31][35]-[37]. With respect to academic performance over the academic year, school performance and matric results were the best predictors, accounting for roughly 30% of the variance in academic performance in each first year subject, except in the Engineering Graphics course, where tests of three dimensional spatial perception were better predictors, accounting for about 24% of the variance. Overall, the Science and Maths Matric matric accounted for approximately 41% of the variance in the first year aggregate mark obtained by students. In addition, between 30% and 40% of variance in academic performance in the first year final examinations in the individual subjects was accounted for by university progress tests. Psychometric tests taken at entry point to the university added little to prediction in the majority of first year subjects.

An exception to this trend occurred in the Engineering Analysis and Design course, where a test of three dimensional ability taken at entry point made a small contribution to prediction of final year mark in the subject (about 4% of the variance). In other subjects, scores on the same test of spatial ability taken later in the year also made a small contribution to prediction of final year marks(about 3% of the variance),

suggesting that change in spatial ability over the year was a factor to investigate in more depth.
Our own predictive analyses thus confirmed the results of previous research in which tests of spatial ability highly saturated with a three dimensional spatial perception factor had been found to have the firmest predictive relationship with academic performance in the course[43][44][46]. Given the consistency of these findings with broader evidence that three dimensional spatial perception predicted success in engineering graphics at other Southern African universities [1][2][7][13][14], it was logical to use scores on tests of three dimensional spatial perception as a means of identifying students at risk with respects to passing the course.

Given the high predictive value of university progress tests with respect to academic performance in all first year subjects, low marks over the first quarter of the academic year could also be used to identify students with difficulties in mastering the first year content. Academic support could then be provided and evaluated, in terms of a model in which measurement, self-report and academic performance were used to identify students requiring special tuition, as well as to monitor improvement in spatial ability and academic performance [30][31].

## STAGE THREE: COMPARATIVE RESEARCH INVOLVING SCIENCE AND ENGINEERING STUDENTS

The results of the predictive studies reported in the previous section established a firm link between spatial ability (and in particular three dimensional spatial perception) and academic performance, but did not establish whether spatial ability was the only influence on academic performance which was operating. In terms of our model, it was likely that other factors relating to teaching and previous instruction were also influencing the academic performance of the groups studied.

The results of pre- and post-testing of samples of the first year Engineering students over a two year period [30] indicated that gains in spatial ability had taken place in both years (Sample 1: $t = 15,00$ (262), $p < ,001$; Sample 2: $t = 9,23$ (137), $p < ,001$). A comparison was thus made in the second year of the study with the pre- and post-test scores of a sample of first year Science students, using the test of three dimensional spatial perception which had correlated most highly with first year academic performance in the previous predictive analyses. Both the Engineering and the Science students were matched by courses taken (N's at beginning of academic year = 175; 165 respectively), and were registered for different variants of the BSc degree.

Substantial attenuation due to drop-out took place in both samples (21,1% of the Engineering sample; 23,6% of the Science sample). For those students who remained, the results indicated that gains in spatial ability took place in both samples after elapse of six months (Engineering sample $t = 9,23$ (137), $p < ,001$; Science sample $t = 3,90$ (125), $p < ,001$). The Engineering students, however, gained more that the Science students ($F = 1,90$ (137, 108), $p < ,001$) over a comparative period of six months between pre-and post-testing.

The finding that three dimensional spatial perception increased in both groups suggested that perception and mental imagery were not fixed abilities, but involved processes which were changeable in adulthood. The results indicated that changes in spatial ability had occurred within both groups, and suggested in particular that the instruction received at university by both science and engineering students had influenced their three dimensional spatial perception positively. The differences between groups indicated that the Engineering students had gained more than the Science students. As both samples had been matched by courses taken in the BSc degree, with the exception of the Engineering Analysis and Design course taken by the Engineering students, one possible explanation was that the instruction provided in our course, which had focussed on training perception and use of mental imagery in drawing and design tasks, had influenced the results obtained.

However, there was also the possibility that aptitudinal factors had influenced the results. Despite the fact that the two samples had been matched by courses taken at university, the Engineering students had commenced the year with significantly greater scores in spatial ability than the Science students ($t = 6,53$ (337), $p < ,001$). In addition, the exploratory analyses conducted in previous years had also indicated that spatial ability changed in response to instruction, but that certain students gained more than others. This raised the issue of how initial level of spatial ability at time of intake to the university had influenced the results of both the Engineering and Science students.

Analysis of variance and co-variance was thus conducted, holding initial level of spatial ability (as measured by the test of three dimensional spatial perception) constant. The results of the within-groups comparisons indicated that spatial ability changed significantly in both Science and Engineering students over the year, while the between-groups comparisons indicated that Engineering students gained more than Science students ($F = 4,79$ (1, 245), $p < ,05$). In addition, when initial level of spatial ability was held constant, it was apparent that level of spatial ability at entry point to the university was an important influence on subsequent academic performance ($F = 38,43$ (3, 243), $p < ,001$). Overall, the results of the analyses indicated that initial level of spatial ability at time of intake to the university had been a significant influence on the results of both groups, and had been a greater influence on academic performance than type of degree taken while at university. [30][37].

Viewed in relation to the previous predictive research undertaken with the first year engineering student body, it was thus possible to conclude not only that spatial ability was an important predictor of subsequent academic performance in engineering graphics, but that instruction in engineering graphics improved spatial ability. This conclusion was reinforced by the findings of our previous predictive studies, indicated clearly that students with low levels of spatial ability (and in particular low levels of three-dimensional spatial perception) at time of intake to the university were at risk, and would be unlikely to pass the first year Engineering Graphics course without remedial intervention.

## STAGE FOUR: USING EARLY IDENTIFICATION TO IMPROVE PASS RATES IN ENGINEERING GRAPHICS

The fourth stage of our research focussed on intervention, involving early identification of students experiencing difficulties with the engineering graphics course, and on provision of tutorial support. In the initial years of the intervention, scores on tests of three-dimensional spatial perception were used in conjunction with academic performance to identify students with difficulties in mastering the first year content. Academic support was then provided, with tests being used to monitor improvement in spatial perceptual ability and academic performance.

Over the initial two years of the intervention, pass rates for course improved from 64% to 76%. In more recent years, given evidence that instructional variables contribute the majority of variance in final year examinations [30], we have utilised psychometric tests less, and self-report and response to instruction more, as ways of identifying students experiencing difficulties with the course. With further changes in teaching involving the training of senior students as tutors to support the lecturing and practicals provided in the course, pass rates in the course have risen to 88% annually, over a period in which the composition of the first year student body has represented increasing diversity in terms of cultural and educational background.

## CURRENT DIRECTIONS

When we started our investigation twenty years ago, the engineering graphics course was taught over two semesters to all first year engineering students. With modularisation in recent years , there have been changes in teaching as well as changes in the way the course is implemented. Certain students now take a one semester, and others a two semester variant of the course. One of the engineering disciplines has also opted for another form of the course taught on a different model to ours. In addition, a number of students are now placed on a slow stream, based on their academic performance over the first quarter of the year.

Given these changes, the course is now very different to the two semester course on which our original research was based. Despite these changes, the principles adopted in teaching the students remain largely unchanged. We have developed and published our course materials materials we have developed in workbook and teaching manual form so that they are mediated and easily available to students taking either one semester or two semester variants of the course [45]. We have also recently published a book on our teaching methodology, and its link with Piagetian theory [38]. This consists of a section on how our teaching methodology supports Piaget's theories of perception and mental imagery, a section on our early research, and a section in which we summarise our research findings. We have drawn on this latter section in constructing this paper.

We have reported our findings at various stages during the investigation, with the result that there has been interest from teachers of engineering graphics at universities, technikons, technical colleges, technical schools and community colleges in the methodologies we have used in training spatial ability as an integral part of the teaching of engineering graphics. We are currently conducting research focused on evaluating how different groups of students respond to the various forms of instruction provided in the different variants of the course as it is taught at first year level in our university, as well as research to establish whether spatial ability is still as important a predictor of academic performance in engineering graphics as it was twenty years ago [39].

From our current work, it is apparent that many students still find difficulty with engineering graphics at the outset of the course, and that spatial ability still improves in both engineering and science students over the course of their first year at university [12]. However, the differences between the gain scores on tests of three-dimensional spatial perception shown by engineering and science students appear to be no longer significant. This may be a feature of changes in the student body, a shorter length of time spent in instruction as a result of semesterisation, or of improvements in the initial levels of spatial ability of students generally. We are currently conducting longitudinal analysis of the scores of engineering and students on tests of spatial ability as well as interviews and focus groups with students, to establish possible reasons for this change and its implications for the way the course is taught. We are also exploring ways of developing mental imagery in female students, many of whom experience difficulties with the course content.

SUMMARY

In our research, we have combined correlational studies with pre-experimental and quasi-experimental comparisons in a longitudinal research design. In terms of a progressively focussed evaluation, we have also used exploratory and qualitative studies involving questionnaires, observation and interview to investigate the relationship between spatial ability and academic performance.

Our findings to date would suggest that

a. Students vary in spatial ability. Those students with low scores on tests of spatial ability (and in particular three dimensional spatial perception) are at risk as regards passing engineering graphics courses.

b. Students with low scores on tests of spatial ability can be trained to use both perception and mental imagery, but may require extended exposure to exercises involving modelling and sketching, as well as exercises which link three dimensional models to the different views used in multiview sketching and drawing. This implies that foundational work done in introducing engineering graphics may need to be introduced gradually, extended over time, and supplemented by additional sketching and modelling exercises.

c. We have found in this respect, in line with indications from the pioneering work in teaching engineering drawing conducted by Davies in Britain [4][5], that modelling engineering components with plastiscene and clay, construction of line models with plastic straws, work with three dimensional spectacles and stereoscopes, work with mirrors and work with see-through perspex models provides students with additional concrete experience on which they can base their perception of objects. These perceptual foundations can then be used as the basis for working with mental images of objects, as well as the mental imagery necessary to relate the graphically drawn images used in multiview drawing to the objects and components which these views represent.

d. Following Piaget, we assume that there is an active process involved in moving between perception, mental imagery and its use in problem-solving. At foundational and intermediate stages in our instructional programme, this process needs to be based on activities which involve the student working from the object to static images, and from static images back to the object. At higher levels in our instructional programme, the process is then extended to working with kinetic images of objects as they are imagined in movement or with the viewer in movement, and transformational images which change or distort their shape according to the laws of perspective, or transformational images which change or distort their shape as they are worked with in the processes of manufacturing and assembly. Once proficiency in these different forms of imagery has been established, the focus of the programme shifts to using perception and imagery as tools of thought.

Our research in course improvement is ongoing. Our current studies focus on the relationship of perception and imagery to academic performance in engineering graphics, as well as on ways of developing mental imagery in students experiencing difficulties with course content.

## REFERENCES

1. Behr, D. "The Prediction of Academic Performance of First Year Engineering Students: Interim Report." *Durban: University of Durban-Westville*, 1980.
2. Behr, D. "The Prediction of Academic Performance of First Year Engineering Students." *South African Journal of Education*, 2, 1982, 89-95.
3. Bertoline, G.R., Wiebe, E.N., Miller, C.L. & Nasman, L.O. "Engineering Graphics Communication". *Chicago: Irwin*, 1995.
4. Davies, T.N.. "Visual Perception of Engineering Drawings." *Engineering Designer*, 4, 1973, 22-31.
5. Davies, T.N. "The Span of Visual Perception in Engineering Drawing." *The Communicator of Scientific and Technical Information*, 4, 1976, 2-11.
6. Deregowski, J.B. "Teaching African Children Pictorial Depth Perception: In Search of a Method." *Perception*, 3, 1974, 309-312..
7. Deregowski, J.B. "A Report on a Preliminary Investigation of the Difficulties experienced by the First Year Students in Engineering Drawing." *Harare: University of Zimbabwe, Department of Psychology*, 1977.
8. Epstein, B. "An Evaluation of the Special EAD Course in 1981." *Johannesburg: University of the Witwatersrand, Centre for Continuing Education, Cadet Scheme Working Paper 18.52*, 1984.
9. Ferguson, E.S.. "The Mind's Eye: Non-Verbal Thought in Technology." *Science*, 1977, 827-836.
10. Ferguson, E.S. "Engineering and the Mind's Eye." *Cambridge, MA: MIT Press*, 1992.
11. Hammond, R.H., Buck, C.P., Rogers, W.B., Walsh, G.W. & Ackert, H.P. "Engineering Graphics: Design, Analysis and Communication." *New York: Ronald Press*, 1971.
12. Kaufmann, W. "Student Perceptions of the Role of Mental Imagery in Academic Performance in First Year Engineering Graphics: An Exploratory Study." *Johannesburg: University of the Witwatersrand, Department of Psychology, unpublished Honours thesis*, 2000.
13. Mauvis, V. "A Study of Perceptual Difficulties Experienced by Engineering Students at University of Rhodesia." *Harare: University of Zimbabwe, Department of Psychology, unpublished Masters thesis*, 1979.
14. Millroy, W. & Rochford, K. "The Early Prediction of Failure in Engineering Drawing among First Year University Students." *International Journal of Applied Engineering Education*, 1 (6), 1985, 439-445.
15. Pare, E.G., Loving, R.O., Hill, I.L. & Pare, R.C. "Descriptive Geometry." *New York: MacMillan*, 8th ed, 1987.
16. Piaget, J. "The Origins of Intelligence in Children." *London: Routledge & Kegan Paul*, 1953.
17. Piaget, J. "The Development of Mental Imagery." *In R.E. Ripple & V.E Rockcastle (Eds.), Piaget Rediscovered: A Report of the Conference on Cognitive Studies and Curriculum Development. Ithaca NY: Cornell University, School of Education*, 1964.
18. Piaget, J. "The Mechanisms of Perception." *London: Routledge & Kegan Paul*, 1969a..
19. Piaget, J. "The Language and Thought of the Child." *Cleveland OH: The World Publishing Company, Meridian Books*, 1969b.
20. Piaget, J. "Genetic Epistemology." *New York: Columbia University Press*, 1970.
21. Piaget, J. "The Theory of Stages of Cognitive Development." *In D. Ross-Green et al. (Ed.), Measurement and Piaget: Proceedings of the CTB/McGraw-Hill Conference on Ordinal Scales of Cognitive Development. New York: McGraw-Hill*, 1971a.

22. Piaget, J. “The Child’s Conception of Time.” *New York Ballantine Books*, 1971b.
23. Piaget, J. “The Child’s Conception of Movement and Speed.” *New York Ballantine Books*, 1971c.

26. Piaget, J. “The Role of Action in the Development of Thinking.” *In W.F. Overton & J.M Gallagher (Eds.), Advances in Research and Theory. New York: Plenum Press*, 1977.
27. Piaget, J. & Inhelder, B. “Mental Imagery in the Child: A Study of the Development of Imaginal Representation.” *London: Rouledge & Kegan Paul*, 1971.
28. Piaget, J. & Inhelder, B. “Memory and Intelligence.” *London: Routledge & Kegan Paul*, 1973.
29. Potter, C.S. “Prediction of Academic Performance in Engineering: The Case of Educationally Disadvantaged Students.” *In D. ADEY & T. MALAN (Eds.), Enterprise in Higher Education - Breaking the Mould: Proceedings of the Seventh Congress of the South African Association for Research and Development in Higher Education. Pretoria: University of Pretoria, South African Journal of Higher Education Limited Congress Edition*, 1990.
30. Potter, C.S. “An Analytical Case Study of a Pre-University Project.” *Johannesburg: University of the Witwatersrand, unpublished PhD thesis*, 1991a.
31. Potter, C.S. “Charting Progress in Large-scale Innovation: Two Case Studies - Part One: A Longitudinal Evaluation of Curriculum Development in a Pre-University Project.” *Journal of Educational Evaluation*, 1, 1, Spring, 1991b. 30-59.
33. Potter, C.S. & Van der Merwe, E. “Report and Summary Report on a Special EAD Course undertaken by the Faculty of Engineering during 1981.” *Johannesburg: University of the Witwatersrand, Centre for Continuing Education, Cadet Scheme Working Paper 12.2*, 1982.
34. Potter, C.S. & Van der Merwe, E. “The Identification and Support of Students with Weaknesses in Engineering Drawing at University Level.” *Johannesburg: University of the Witwatersrand, Centre for Continuing Education, Discussion Paper Series in Adult and Continuing Education No 4*, 1983.
35. Potter, C.S. & Van der Merwe, E. “Initiating Curriculum Change in an Engineering Faculty: Doorways from the Old to the New.” *Port Elizabeth: PE Technikon, Proceedings of the 1992 SAAAD Conference*, 1992.
36. Potter, C.S. & Van der Merwe, E.“Academic Performance in Engineering.” *South African Journal of Higher Education*, 7, 1, 1993, 33-46.
37. Potter, C.S. & Van der Merwe, E. “Academic Performance in Engineering.” *South African Journal of Higher Education*, 8, 1, 1994, 193-210.
38. Potter, C.S. & Van der Merwe, E. “Perception and Imagery in Engineering Graphics: A Piagetian Approach.” *Johannesburg: Open Learning Systems Education Trust*, 2001.
39. Potter, C.S., Van der Merwe, E. & Kaufmann, W. “Changes in Three-Dimensional Spatial Perception in Science and Engineering Students over a Twenty Year Period.” *Journal article* (in preparation).
40. Potter, C.S., Van der Merwe, E. & Kemp, A.R. “The Development of an Approach to Identifying and Remediating Weaknesses in Engineering Analysis and Design at First Year University Level.” *Pretoria: Committee of University Principals, Proceedings of Conference on Teaching and Learning in Southern Africa*, 1984.
41. Potter, C.S., Van der Merwe, E. & Kemp, A.R. “Increasing Pass Rates in an Engineering Analysis and Design Course.” *South African Journal of Higher Education*, 1, 1, 1987, 91-98.
42. Sorby, S.A. & Baartmans, B.J. “Teaching College Freshmen 3-D Spatial Visualization.” http://www.ntu.edu/1/atmp/ff96051401.html, 1996.
43. Taylor, J.M. “Factors Associated with Success in an Engineering Drawing and Design Course.” *Johannesburg: National Institute for Personnel Research, CSIR Special Report PERS 314*, 1980.
44. Taylor, J.M. “Factors Affecting Results in an Engineering Drawing and Design Course: Part Two.” *Johannesburg: National Institute for Personnel Research, CSIR Special Report PERS 314*, 1981.
45. Van der Merwe, E. & Potter, C.S. “Introduction to Engineering Graphics: A Workbook.” *Johannesburg: University of the Witwatersrand Press*, 2000.
46. Visser, S. “A Short-term Evaluation of the Effectiveness of Various NIPR Tests in Predicting Success in Engineering Analysis and Design.” *Johannesburg: National Institute for Personnel Research, CSIR Special Report PERS 317*, 1981.
24. Piaget, J. “The Construction of Reality in the Child.” *New York Ballantine Books*, 1971d.
25. Piaget, J. “Development and Learning.” *In Lavatelli, C.S. & Stendler, F. (Eds.)., Readings in Child Behaviour and Development. New York: Harcourt Brace Jovanovich*, 1972.