TEACHING VISUALISATION IN ENGINEERING GRAPHICS: METHODOLOGY AND IMPLICATIONS

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Abstract— *We have developed a teaching methodology for introducing students to the conventions of engineering graphics, which has been implemented both at our own university and in a number of other South African institutions of higher education. Our teaching model is based on Piagetian theory, and involves students in activities involving modelling, sketching and drawing as a basis for developing perception and mental imagery, as foundations for the higher level processes involved in visualisation, abstract thinking and problem-solving. Results of university students who have been exposed to our methodology would suggest the value of introducing students with difficulties in learning the conventions of engineering drawing to modelling and model-building, as well as activities involving sketching and drawing as the basis for developing perception and mental imagery. On the basis of positive gains in scores on tests of spatial ability, and increase in pass rates from 64% to 88% in our first year engineering graphics courses over the last fifteen years, we have published our materials, which focus on providing instruction in perception and use of mental imagery for the purposes of three dimensional graphic representation. These have been used as the basis for teaching graphics courses in otherSouthern African contexts, including technical colleges and a community college. We are currently planning a pilot project to introduce our teaching model in technical drawing courses at secondary school level, and have in.addition conducted two pilot studies using high imagery and revisualisation techniques with children who have learning difficulties affecting reading, writing and spelling with positive results. Tthe research designs used in the pilot studies, mvolving detailed case-by-case analyses, are being cross-validated at three research sites this year.*

Index Terms ¾ perception, mental imagery, visualisation, revisualisation, engineering graphics.

SPATIAL ABILITY

Within the literature, different theorists and research investigators have referred to spatial ability in different ways. Pickreign [30] highlights seven types of spatial ability, namely:

Eye-motor coordination – the ability to coordinate information yielded by the visual and motor systems and to undertake action using these two systems in combination.

Figure-ground perception-the ability to distinguish foreground from background.

Pe Perceptual Constancy-the recognition that of certain geometric figures presented in a variety of sizes, shapes, textures and positions and their discrimination from similar figures (this can been be seen as a mature version of Piaget’s object constancy).

Position in space perception- the ability to perceive the position of an object in relation to oneself or identifying congruent figures in complex drawings.

Perception of spatial relationships- the ability to see two or more objects in relation to oneself or in relation to each other.

Visual discrimination- the ability to identify the similarities and differences among objects independent of their position.

Visual memory- the ability to recall accurately visual stimuli that are removed from view.

The literature on spatial ability is thus a broad one. In addition, terms such as perception, spatial ability, spatial imagery, spatial intelligence, visual imagery, visual memory and visualisation have been differently defined and often loosely used. The term “spatial ability”, for example, has been used interchangeably with the notion of spatial visualisation as well as ‘spatial sense’ or spatial perception [44].

Gardner [8] refers to spatial intelligence as the ability to perceive the world accurately and recreate or transform aspects of the world. We follow Gardner in using the broad term “spatial ability” to refer to capacity to undertake mental manipulation and rotation of images of objects, as reflected in the tasks involved in learning engineering graphics.

PIAGET’S THEORIES OF MENTAL IMAGERY

Our model of teaching is based on Piagetian theory [17]-[29], which suggests that perception, mental imagery and language develop hierarchically, and form the bases of

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thought. According to Piaget, [18]-[20] [28] [29] perception and mental imagery share a common basis in activity. Piaget suggests that imitation is the fore-runner of mental symbolism. According to Piaget, mental imagery develops through action, and can be developed through activities which involve imitation. Perceptual development is based on activity, while imitation of things, particularly through drawing, is linked to the development of mental imagery. The visual image is based on internal imitation of the originally perceived object. Both copying and sketching thus form the basis for the development of visual imagery in children.

In his work on mental imagery [28], Piaget distinguished three forms of visual images, which he called static, kinetic and transformational images. In addition to static images representing objects which do not rotate or move, there are two other kinds of images which children normally develop. The first Piaget 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 transformation of a mental representation of the object, through a process involving mental manipulation of the visual image.

While his theories were based on extensive observation of children, Piaget suggests that perception, mental imagery and language develop over the whole life span of the individual, as separate processes which are used in thought. The ability to work with static, kinetic and transformational images and to manipulate these mentally is fundamental to various aspects of mathematics, and is also fundamental to the work of an engineer. In particular, these different forms of mental imagery are central to the design process, and form the basis of the ways in which engineers represent and communicate their ideas through sketching and drawing.

Our own work has been based on the assumption that, in line with the theories of Piaget, perception and mental imagery are figurative processes which can be trained throughout the human life-span, and that the processes involved in developing perception and mental imagery apply both to children and to adults. In order to test this assumption, we have conducted action research with university students studying engineering graphics, which requires increasingly complex perception and representation of three-dimensional visual images on paper and on the computer screen, as well as their more abstract manipulation in design and problem-solving [32] [33] [40].

Following the stages in development of perception and mental imagery suggested by 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. In addition to working through exercises, students are tutored by senior students who have taken the course in previous years, using the course materials as a basis for mediation of the concepts and skills involved in using engineering graphics as an integral part of the design process.

TEACHING METHODOLOGY

The first stage in our programme involves use of freehand sketching, which is done after the students have made a model of a given object. This object (usually an engineering artefact or component) can be made with plasticine or straws or whatever material (eg clay; wire; anti-waste material) is available. The completed object is then drawn as a two-dimensional object showing two or more views. Once the student has the concept of viewing the object from different sides, he is then introduced to the conventions commonly used in drawing the object in first angle orthographic- and third angle orthographic projection.

The process involves using two-dimensional drawings to enable the student to visualise and sketch three-dimensional drawings. If the student has difficulty in visualising three-dimensional drawings, he is again provided with the opportunity to build models of the objects represented in the drawings. This is done to help him interpret the two-dimensional clues in the sketch or drawing, and establish their relationship both with the object being drawn and its representation in different views.

The majority of students do not have serious problems with interpreting this type of exercise, and can proceed with the exercises in our workbook, which consists both of a core of exercises, as well as supplementary and remedial exercises which are covered by the students working at their own pace. When the students are able to accurately represent a solid model in orthographic representation, they are then required to interpret a pictorial drawing as a 2D orthographic view, supplying sufficient views to completely describe the required object. The concept of auxiliary or extra views is introduced at this point. Emphasis is placed at this stage on using mental imagery more flexibly, with students being encouraged to manipulate and rotate the object mentally through ninety degrees, to allow any side or facet of the object to be visualised. Where students have difficulty in making the transition to this type of mental imaging, additional exercises are given to facilitate this process.

The materials are organised hierarchically in a way which enables the student to select additional exercises as and when necessary to reinforce the concepts covered in lectures. Emphasis is placed both on using pictorial sketches and drawings to communicate ideas to others, as well as to visualise and understand the ideas of others. The aim is to develop both representational and communicative abilities, the representation of a pictorial sketch or drawing allowing the student to visualise objects and design situations in 3D. Once the student has mastered this skill, he or she is normally able to interpret most given drawings whether in 2D or 3D.

The next step in the development of visualisation ability is the development of the student's ability to interpret Descriptive Geometry problems, which require more abstract thought. This step is taken once students have developed the ability to mentally manipulate visual information. At this point, they are introduced to the principle that descriptive geometry provides the means of understanding the way in which points, lines and planes combine in forming any given shape, and offers mathematical principles for solving problems involving geometric shapes.

As the basic shape of many structures is rectangular, straight lines and plane surfaces can represent the majority of applied engineering problems. The principles can also be related to solids with curved edges, or to solids, which have warped surfaces. The principles relating to the projection of points, lines, surfaces and solids can therefore assist in the graphic representation of structures of every possible shape

Descriptive geometry is grounded on a number of mathematical principles, and at this stage the students are introduced to these. The aim is to provide the student with several geometric procedures, which can be applied in constructing engineering drawings based on the same principles as orthographic projection. Because of the relationship of descriptive geometry to orthographic auxiliary and revolved views, it requires students to have mastered the skills involved in interpreting 2D and 3D drawings, and to apply these skills conceptually.

INCREASED PASS RATES IN ENGINEERING GRAPHICS

Our assumptions in teaching the course in this way are that the ability to work with different visual images of an object forms the basis for the development of visualisation, which can be defined as the ability to form a mental picture of things which are invisible, absent, or abstract. The processes of perception and mental imagery underpin the ability to mentally manipulate visual information, which is essential in solving engineering graphical problems. We have found that the majority of students who have worked through the process of modelling, sketching and drawing as given above, are able to interpret most 2D and 3D engineering graphic problems.

An advantage of the approach we have adopted is that students who have problems with modelling and pictorial representation in the initial stages of the programme can be identified at the beginning of the academic year. These students are allocated a tutor, who is a senior student who has been through the course before. The tutor spends extra time with the student, working individually or in small groups. Work is done on both core and supplementary exercises from our materials, which have been published in workbook form. There are also additional exercises in the teacher's manual to allow the student to do more exercises if necessary. The aim is to provide individual and small-group tutoring, and additional exercises, at each stage of the development of the student's visualisation ability.

The results of students taught through this methodology improved over the first three years after the introduction of our new teaching methodology from a 36% to a 23% failure and dropout rate, while currently the pass rates average 88%. Students in the course have reported [9] that mental imagery is an important facet when drawing three- dimensional sketches and also report that their inability to form these images affects their academic performance in engineering graphics. Many students comment that if they are not able to visualise an object, they cannot draw it. Both students and tutors also report that those students with previous experience in drawing (eg technical drawing taken at school level) are at an advantage in dealing with the course material.

INCREASE IN SPATIAL ABILITY

In addition to increase in pass rates, analyses of psychometric test scores at different points over a period of twenty years indicate that our teaching methodology has been associated with gains in spatial ability. Initially, we used psychometric tests as an integral part of a process of action research [32] through which our course materials were developed, implemented and then evaluated, working with small groups of students. We then used psychometric test data as a means of establishing gains in spatial ability made in the large groups of students in which our materials were implemented as an integral part of the mainstream teaching programme in Enginering graphics. We have also used psychometric tests data comparatively at different points over the past twenty years, to compare gains in spatial ability made by Engineering and Science students studying at our university.

ACTION RESEARCH: THE PILOT STUDIES

Our instructional 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 [32] [42] [43]. In terms of our action research model, 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 the students' performance on tests measuring 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 = 0,45 (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 [35] [36] 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 [32] [7]. 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.

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 tests of mental alertness, deductive reasoning, spatial ability, mathematical achievement, as well as a biographical inventory. Various tests were administered to the students at the beginning of the academic year in February and again in August, and the tests most highly predictive of first year academic performance were established using regression analysis. The data were also 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 [31] [32] [37]-[39] [42] [43].

The results of the various analyses were as follows: 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, Science and Maths matric marks 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 first year Engineering graphics 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.

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 research model, it was likely that a variety of factors relating to both our intervention (ie current teaching) as well as previous instruction and background were influencing the academic performance of the groups with whom the programme was being implemented.

The results of pre- and post-testing of samples of the first year Engineering students over a two year period (Potter, 1991a) 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), $p < {,}001$). Whether similar gains would also found in other samples of students, or were specific to Engineering students, was not clear. A comparison was thus undertaken 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 three dimensional spatial perception 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 within-groups comparisons indicated that changes in spatial ability had occurred in both groups. The between groups differences 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 hypothesis was that the instruction provided in the Engineering Graphics 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 or maturational 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 three dimensional spatial perception than the Science students ($t = 6{,}53$ (337), $p < {,}001$). In addition, the exploratory analyses conducted in previous years had also indicated that three dimensional spatial perception changed in response to instruction, but that certain students gained more than others. This raised the issue of how level of three dimensional spatial perception at time of intake to the university had influenced the results of both the Engineering and Science students.

Analysis of co-variance was therefore undertaken, 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 three dimensional spatial perception 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, it was apparent that initial level level of three dimensional spatial perception 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 thus 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 [32] [39]. Viewed in relation to the previous predictive research undertaken with the first year engineering student body, we concluded that:

a. There was consistent evidence that spatial ability was an important predictor of subsequent academic performance in engineering graphics;
b. Spatial ability was not fixed, but changed over the first year at university in both Science and Engineering students;
c. Level of spatial ability at time of intake to the university was an important influence on the gains in spatial ability made by both Science and Engineering students; and
d. Engineering students who had instruction in visualisation and in three-dimensional representation improved in spatial ability more than Science students matched by year of study and courses taken at university, suggesting that type of instruction received had influenced gains in spatial ability.

More recent research using a similar design involving pre- and post-testing of both first year Engineering and first year Science students over a two year period is currently being conducted. The first stage of the research has been reported by Kaufman [9] and demonstrates that both Engineering and Science students showed improvement in spatial ability over a period of six months after their intake into the university in the year 2000. There was a significant difference between both the pretest ($t = 9.111$ ((237), $p<{,}001$) and post-test ($t =$

5,502 (159), p<,001) results favouring the Engineering students.

There was, however, substantial attrition in both groups over the year, and univariate analysis of variance was done in order to determine whether the differences found between the groups could have been influenced by differences between those students who only completed the pretest and those who completed both pretest and post-test. The group main effects revealed significant differences between the Engineering and Science groups under both conditions (F = 73,587, p < .0001; F = 11.01, p < .001). There was, no significant interaction effect, indicating that the differences between the groups could not be attributed toi a difference between those who wrote the pretest and those who complted both pretest and post-test.

An additional interesting finding of this study was that greater gains between pre- and post-test scores were made by the Science students, suggesting that the spatial ability of the Science students had improved more over the first year of their studies than the the spatial ability of the Engineering students. However, the Engineering students' initial level of spatial ability far exceeded that of the Science students, suggesting, in line with the theories of Gardner [8] and our own earlier conclusions [32, p. 367] that those students with well-developed spatial intelligence , as indicated by greater spatial ability at time of university entry, were attracted to engineering as opposed to science as a field of study. Engineering students might thus have made less gain for the simple reason that they were already spatially competent at the outset of the study.

There is also the possibility that the spatial abilities of Engineering students are higher at this point in time than at the time we commenced our innovation more than twenty years ago. Our observation has been that many more first year engineering students have had experience with drawing at school level than previously, raising the possibility that changes in the South African school system have contributed to these results. We are currently conducting cross-validation of this research to establish whether the trends noted in Kaufman's study are found in subsequent intakes of Engineering students, and also longitudinal studies to establish whether the current spatial abilities of Engineering students are higher at this point in time than over the years when our initial studies were conducted [41].

IMPLICATIONS WITH RESPECT TO OTHER AREAS OF EDUCATION

We have established through our research that university students with low scores on tests of spatial ability are at risk as regards passing engineering graphics courses. We have also found that students with low scores on tests of three dimensional spatial perception can be trained to use 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 the foundational work done in introducing engineering graphics may need to be introduced gradually, extended over time, and supplemented by additional sketching and modelling exercises.

Our findings have a number of implications with respect to technical education. We have found, in line with indications from the pioneering work in teaching engineering drawing conducted by Davies in Britain [3] [4], 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 perceptions 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.

The skills involved in engineering graphics are fundamental to design problem-solving, and our work thus has a number of wider implications with respect to teaching and learning and education more generally. Following Piaget's theories, we assume that there is an active process involved in moving between perception, mental imagery, language and thought, and the integaration of these facets of cognition in problem-solving. At foundational and intermediate stages in our instructional programme, the process of teaching and learning 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.

While these teaching principles have been evolved from work with university students in South Africa, there are indications that similar principles apply with other student samples and in other areas of teaching and learning. Davies [3] [4], for example, applied similar principles to good effect in teaching technical dawing to overseas students at an airforce training college in Britain, while in North America, McKim [15] has developed a number of innovative strategies for promoting what he termed “visual thinking” in courses involving design problem-solving. Also in North America, Sorby and Baartmans have been working from similar assumptions, concluding that although some students are very good visualisers, other students who are “low visualisers” can significantly improve their spatial ability through ‘appropriate activities and guided instruction’ [44]. Convergent indications have also been yielded by the work of Gorska in Poland, and Leopold in Germany [45].

In Southern Africa, there is a body of literature [1] [2] [5]-[7] [13] [16] [46] [47] [49] which has highlighted the difficulties many students experience in learning the conventions of engineering drawing, and the association of low scores on tests of three-dimensional apatial perception with academic performance in engineering graphics courses. Our own teaching approach has been based on an apparently wide-spread perception of the need to establish instructional techniques which could increase pass rates in engineering graphics in students from different cultural and educational backgrounds [31]-[33] [42] [43]. We have found in the process that improvements in spatial ability occur in those students who have been exposed to our teaching methodology and materials.

Also of interest is the fact that we have also found that improvements in spatial ability occur in the samples of first year Science students we have studied. This would suggest that our teaching approach is one of a variety of ways in which improvement in spatial ability can be achieved, and further that improvement in spatial ability may occur in response to the type of teaching received by students in university science courses (eg in a course such as chemistry, in which visualisation of atomic structures is required). Overall, our results would support the idea of spatial ability as being trainable over the whole of the human life-span as Piaget suggests [17]-[21], rather than a fixed ability, an ability which develops at critical periods, or one which is dependent on particular childhood experiences.

With respect to our own teaching approach, we can claim that our methodology for teaching engineering graphics is flexible enough to successfully accommodate students from a variety of different educational and cultural backgrounds, and to lead to improvements in pass rates, both in students who have had the benefit of good schooling prior to university entry, as well in educationally disadvantaged students. The improvement in pass rates in all students has been from 64% prior to our intervention to 88%, while the corresponding improvement in pass rates for educationally disadvantaged students has been from 20% to 80%. The regular five year external evaluations of our first year engineering graphics course indicate that the improvements in pass rates have been achieved without a drop in standards of teaching, marking or examining.

In terms of wider application, our methodology has been implemented to good effect both in technical college as well as in community college courses in technical drawing, and the materials in our workbook are currently being used in a number of other institutions of higher education .in South Africa. There is also interest from researchers working in related fields (eg architecture) in implementing the high imagery techniques on which our teaching approach is based, suggesting, in line with Gardner’s theories, that we may be working with facets of cognition and intelligence which have wide applicability not only in other areas of technical education, but also in education more generally.

BROADER APPLICATIONS

Pickereign [30] suggests that children who do not progress beyond Piaget’s concrete operational stage, will be dependent upon spatial representations. Pickereign also makes the observation that much in our everyday environments is of a spatial nature. Spatial representations may thus be particularly important for disadvantaged children or children who have grown up in underprivileged communities, and can be used as a basis for learning of higher order concepts. They may also be important for children who have learning disabilities, and can be used as a basis for remediation.

We are currently applying high imagery techniques is in working with children with a history of severe learning difficulties who have not learned to read, write and spell using conventional teaching techniques. We have been using mental imagery in multi-sensory teaching, to train the competencies in visual/spatial representations and memory involved in reading, writing and spelling. In the process, we have developed a teaching procedure called the “Targeted Revisualisation Approach”, which involves the teacher, therapist or tutor in mediating the form and structure of words through a process in which the multi-sensory associations and memories required to reproduce the form and structure of words are developed. These competencies are then used as a basis for the development of the higher-level competencies involved in using written language sequentially and integratively.

The approach assumes that memory is of different types, relating to the primary sensory modalities as well as their more complex integration in activities involving perception, mental imagery, language and thought. The Targeted Revisualisation approach uses similar high imagery techniques to those we have found helpful in teaching engineering graphics, and follows Piagetian theory in using the processes of perception, mental imagery, language and thought as the basis for establishing reading and spelling competence. The Targeted Revisualisation approach involves the teacher and child in targeting the vowel and syllabic structure of words, which are learned through processes involving analysis and colour coding. Mental imagery is used as a means of holding the word in mind and storing it in memory. Mental imagery is also used in the process of revisualisation of the word, which is encoded into output both orally and in writing.

The literature on mental imagery indicates that, while many children are able to use visual and eidetic images in this process, others are not. Thus the term "visualisation" may in fact be a misnomer. Another term, such as the term "spatial imagery" used by Gardner [8], might in fact be a better one. As used in the Targeted Revisualisation approach, the term "visualisation" implies use of mental imagery in the process of learning the form and structure of words (ie storing the form and structure of the mental image of individual words and sequences of words into memory), while "revisualisation" implies the process of drawing the stored image out of memory as an integral part of the proeesses involved in coding written output.

The methodologies which we have found effective in developing word, sentence and paragraph revisualisation abilities involve written language exercises as well as typing, colour coding of the vowel and syllabic structure of words, and use of high imagery techniques in developing short-term memory, revisualisation and sequentialisation abilities in both reading and writing. This particular combination of activities appears to be novel, and is not documented in the literature on approaches to teaching children with learning difficulties (though there are other teaching approaches which use imagery, and other teaching approaches in which typing and computers are used to develop word analysis and spelling competencies). The evidence from achievement tests conducted with those children with whom we have worked is that increased spelling and sentence and paragraph writing competencies are achieved, as well as transfer leading to increased fluency in creative writing tasks.

One of the reasons for this may be that our teaching methodology involves a number of ways of mediating cross-modalisation (linking language and visuo-spatial modalities on receptive, integrative and expressive levels through developing oral and visual communication abilities), as well as mediating discrete and sequential memory integrities through graded reading and written language activities. Focus on developing these integrities may promote improvement not only of written language functions but also the hierarchical neurological integrities and integration which underpin automaticity in reading and writing [10]-[12].

Whether or not this is the case is the focus of some of our current research with the methodology, which has been effectively applied with children with difficulties in learning to read write and spell by teachers, parents and university students working as tutors. Pilot studies conducted in 2001 indicated functional advantage of a number of children taught using high imagery techniques relative both to their previous progress as well as relative to the progress made by other children using conventional remedial teaching approaches [14] [34] [50].

Based on positive clinical evidence involving one-to-one work between therapists, parents, tutors and children, we have nine researchers involved this year in conducting studies with groups of children at three different sites. This stage of the research will be completed by the end of this year, and it is our intention from these data to build up a series of fifty in-depth case-by-case analyses, based on work conducted with the approach to date.

SUMMARY

This paper describes a process of action research conducted from the early 1980's through to the present, aimed at improving pass rates in engineering graphics at our university. Predictive research prior to our intervention demonstrated the relationship between tests of spatial ability and academic performance in the first year Engineering Graphics course at our university. The course had a failure rate of 36% for all Engineering students, and failure rates of 80% for African students transferring into our university. Similar failure rates were found in Engineering Graphics courses at other Southern African universities, and similar association between low scores on tests of spatial ability and academic performance, indicating the need for an intervention in this area.

At the outset of our intervention, we used psychometric testing to provide a base-line against which to establish change. Scores on tests of spatial ability were also used diagnostically in conjunction with academic performance to identify students with difficulties in mastering the first year content. Academic support was then provided, using an instructional approach based on Piaget's theories of perception and mental imagery and their relation to thought, with psychometric tests and pass rates for the course being used to monitor improvement in spatial ability and academic performance.

Over the initial two years of the intervention, pass rates for course improved from 64% to 76%. We were able to establish that spatial ability improved over the first year at university, apparently in response to instruction aimed at developing the abilities to visualise and represent objects in three dimensions. Level of spatial ability at time of intake to the university emerged as an important influence on academic performance at the first year level, both in students taking the Engineering graphics course, as well as in a comparison group of Science students. With further changes in teaching, and the training of senior students as tutors to support lecturing and practicals, pass rates in the

Engineering graphics 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.

Our intervention has been based on an approach to programme development and evaluation in which psychometric testing has been used for diagnostic, predictive and comparative purposes. Our research has demonstrated that spatial ability influences academic performance in Engineering and that pass rates in Engineering graphics can be increased through appropriate instruction. We have used both pre-experimental and quasi-experimental strategies to establish that spatial ability develops over the first year at university, supporting the Piagetian view that perception and mental imagery are trainable in adulthood. We have also established that level of spatial ability at time of intake to university is an important influence on academic performance, suggesting the value of instructional techniques designed to increase spatial ability at school level, 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.

The principles used in developing our teaching approach are also being implemented elsewhere in South Africa. Our teaching methodology has been implemented with students in community college as well as technical college courses in technical drawing. The workbook containing a selection of our teaching materials is in its second print run, and is currently being used by students at a number of South African institutions of higher education. Based on the indications from studies conducted by other researchers and our own research, that level of spatial ability at time of intake to the university is a good predictor of subsequent academic success in courses in engineering graphics, we are currently planning a pilot project to introduce our teaching model in technical drawing courses at high school level. This will involve adapting the procedures we have used in teaching engineering graphics at tertiary level, to secondary level teaching in schools

In addition to the developmental research we have conducted in technical education, we have also been working in other areas of education in which mental imagery can be utilised to effect improvement. We have over the past two years conducted two pilot studies using high imagery and revisualisation approaches with children who have learning difficulties affecting reading, writing and spelling, and are in the process of cross-validating this research with a larger number of subjects.

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