Developmental theory-driven evaluation: Strategies for course development and improvement

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Abstract
This article focuses on the longitudinal evaluative strategies used in the development of a new teaching approach for a university course with high failure rates. The subject is compulsory for all first year engineering students at our university.

The evaluation has been conducted as part of a process of developmental action research, and has focused on the cognitive and implementation theories represented in the course’s instructional approach. It has been based on qualitative focus group, interview and questionnaire analyses, and quantitative pre-experimental, predictive and quasi-experimental studies.

The research has been conducted over a twenty five year period to validate the theory on which teaching has been based, to establish effects of the intervention and to identify ongoing needs for the type of instruction offered in the course. Based on improvement in both spatial ability and pass rates, the materials used in the course have been published in workbook form.
INTRODUCTION
This article focuses on the strategies we have adopted in implementing and evaluating an intervention designed to change existing teaching practices in the first year engineering graphics course at our university. This has involved developmental action research focused on developing a new form of teaching methodology designed to improve pass rates in the course, as well as throughput in terms of increased numbers of students entering subsequent years of study, and ultimately graduating as engineers.

As an integral part of this process we have also conducted a series of theory-driven evaluative studies from the early 1980’s to the present to:

- Identify factors predictive of the academic performance of first year engineering students, and the particular influence of spatial ability on the academic performance of first year engineering students;
- Establish whether our methodology of teaching develops spatial ability in university students;
- Establish whether the new form of instruction we have provided has been effective, and whether there is a continuing need for the type of instruction provided.

THEORY-DRIVEN EVALUATION AND ACTION RESEARCH
Chen and Rossi (1980; 1983) have suggested that underlying every programme there is a theory. Weiss (1998) describes a programme’s theory as a theory of change, which can be specified in two forms:

a. The programme’s implementation theory, as represented in the activities undertaken in a programme, curriculum or course.

b. The programme’s theory, as represented in the mechanisms of change which are envisaged through the programme’s activities.

Wholey (1979; 1987) states that a programme is not ready to be evaluated unless its theoretical basis has been developed and implemented. Without a theory-driven basis, programme evaluation becomes an atheoretical and method-driven exercise (Chen 1990; Lipsey 1985; Lipsey et al. 1987).

Given the emphasis placed in action research on evaluation (Cohen and Manion 1989; Uzzell, 1995), theory-driven evaluation has been used in our work as an integral part of the action research process. The programme’s theory of change has assisted in planning points for observation and data collection, and has also formed a framework for interpreting and reporting results of and benefits arising from the programme’s implementation (Rossi, Freeman and Lipsey 1999).

In the research described in this article, the development of a new form of instruction in our course was based on Piagetian theory, which provided a framework for conceptualising the mechanisms of change we envisaged in the cognitive abilities...
of the first year students with whom we were working. Piagetian theory also informed the sequence of instructional activities undertaken in the academic support provided for students.

The action research process involved developing and refining our instructional procedures to the stage where it was clear that our model of implementation was associated with the types of cognitive changes we envisaged. Theory-driven analyses were then undertaken in an attempt to identify longitudinal causal relationships between the variables involved in our intervention and its results, through ‘identifying the micro-mediating processes that causally connect a treatment to an outcome, usually through a process of theoretical specification, measurement and data analysis’ (Cook and Shadish 1994, 576).

THE CONTEXT OF THE COURSE

Our intervention commenced in the early 1980’s, as a response to high failure rates in the first year engineering graphics course at our university. Prior to our intervention, the course had a high failure rate, with 36 per cent of all first year engineering students and 80 per cent of African students failing or dropping out of the course. This contributed to a 45 per cent failure rate for first year engineering as a whole, affecting both throughput and graduation rates.

The lecturing staff believed that the high failure rates were due to difficulties with both visualisation and drawing ability. The Engineering Faculty thus commissioned two studies (Taylor 1980; 1981; Visser 1981), which indicated a link between three-dimensional spatial perception and academic performance in the course. This corroborated studies conducted by other researchers in Southern Africa (e.g. Behr 1980; 1982; Deregowski 1968; 1974; 1977; Mauvis 1979; Millroy and Rochford 1985), which also found that engineering students who scored poorly on tests of three-dimensional spatial perception were at risk as regards passing engineering graphics courses.

THEORETICAL BASIS OF OUR INTERVENTION

Our initial literature review suggested a link between visualisation ability and success in engineering graphics (Arnheim 1969; Davies 1973; 1976; Ferguson 1977; 1992; McKim 1980). We also surveyed the methods commonly used to teach engineering graphics in other tertiary institutions in South Africa, as well as in overseas tertiary institutions working with students from developing countries.

While researchers in Southern Africa reported lack of success (e.g. Fish 1980; Grant 1980; Rolfe 1980), positive results in training visualisation ability were reported by Davies (1973; 1976), working with overseas students at an air force training college in Britain. Davies provided a number of types of practical procedures which he had pioneered, which were apparently successful when used with small groups of students.
Davies’ methods appeared to us to be based on the theoretical position advocated by the developmental psychologist Jean Piaget (Piaget 1953; 1964; 1969a; 1969b; 1970; 1971 1977; Piaget and Inhelder 1971; 1973). Piaget suggested that perception and mental imagery develop as life-long processes, which are trainable both in children and in adulthood. Piaget further suggested that perception derives from activity, and that mental symbolism derives from activity.

We thus based our model of instruction on Piagetian theory, for the reason that Piaget suggested 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 Piaget, we organised our teaching approach and our materials hierarchically. Students identified as having weaknesses in three-dimensional spatial perception were provided with additional remedial activities involving modelling, copying, sketching and drawing. These activities were organised as a series of remedial loops involving additional exercises, which were undertaken by students experiencing difficulties with course assignments and class tests (Potter and Van der Merwe 1982; 1983; Van der Merwe 1982; 2001; Van der Merwe and Potter 2000; 2001).

**IMPLEMENTING THE INTERVENTION**

**Initial pilot studies with pre-university students**

The first stage of the intervention involved two pilot studies undertaken with two small groups of African students who had been selected to undertake a pre-university year in engineering. The purpose of this stage in the action research process was to establish whether the type of teaching approach we were developing was effective in preparing the students for their university studies, and whether it led to increase in spatial ability.

In terms of these aims, the progress of each of these groups of students was monitored closely over a two-year period, using questionnaires, interviews, course progress tests and psychometric tests. The results of the questionnaires and interviews indicated that the students believed they had learned in the programme, and were able to cope with university-level assignments. In addition, analysis of post-test scores in both groups indicated that spatial ability (as measured by a number of psychometric tests) 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).

The students’ progress was then tracked when they subsequently went to university. All students in the first group, with the exception of one, passed the engineering graphics course. All students in the second group passed, indicating that our approach had not only improved the students’ spatial ability, but had also enabled them to pass at university.
Pilot intervention with first year Engineering students

Thirty-five first year engineering students who had been experiencing difficulties with mastering engineering drawing were then provided with a special course based on our model of instruction, in which tuition was provided using materials developed with the specific aim of developing spatial ability. The sample included both white and African students who had failed their course tests over the first quarter of the academic year. All students in the sample had low scores on tests of spatial ability at time of university entry.

After six months of instruction using our instructional procedures, the academic performance of these students was compared with two matched samples of students in the first year course who had not been exposed to our teaching methods (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 exposed to our teaching methodology with other African students who had not (t = .45 (16), ns). In addition we compared their academic performance with the two groups of African students who taken part in our pilot studies during their pre-university year (Group 1, t = 2.45 (12), p < .05; Group 2, t = 2.72 (13), p < .05).

Overall, these analyses (Potter and van der Merwe 1982; 1983; 1984) indicated that students could overcome their difficulties given appropriate instruction. For optimal results, the instruction provided 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 (refer also Epstein 1984).

Implementing a new instructional programme with all first year Engineering students

Based on the above indications, the teaching approach we had developed was integrated into the first year engineering graphics programme in the following year. In order to establish students who needed additional teaching or remedial intervention, analysis of psychometric test scores and results of university progress tests was undertaken for all students, to identify those persons having difficulties with the course. Additional instruction using our teaching approach was then provided to these students.

We also undertook materials development, linked to a series of evaluative studies in which we observed and analysed the work of students with difficulties with the course. We related these analyses to a predictive investigation of the relationship of a variety of variables to the academic performance of students taking the course. Those variables most highly predictive of first year academic performance were established using regression analysis. The data were also factor analysed (Potter 1990; 1991a; 1991b; Potter and Van der Merwe 1992a; 1992b; 1993; 1994).

We identified through these analyses that matric results were as good or better predictors of academic performance in first year engineering as scholastic and aptitudinal tests, but that tests of spatial ability (and particularly tests of three
dimensional spatial perception) were the best predictors of academic performance in our course. The progress tests we set early in the academic year were also highly predictive of overall academic performance in our course, and loaded highly on the spatial ability factor.

With respect to course development, our results thus indicated that either progress tests or scores on tests of three dimensional spatial perception could be used for identifying students at risk with respects to passing our course. Gains made on tests of three dimensional spatial perception provided the best way of monitoring gains made in response to instruction provided in the course. As the various tests of three dimensional spatial perception were highly intercorrelated, any of the tests measuring three dimensional spatial perception could be used for this purpose.

The trainability of spatial ability: A comparative evaluation using gain scores in three dimensional spatial perception

Pre- and post-testing of Science and Engineering students

Our model of instruction at this stage involved both mainstream teaching in the form of lectures and practical drawing sessions, as well as additional instruction, which was provided to students having difficulties with course content. Our additional instructional procedures involved exposure of the students during their vacations to materials and activities designed to train students in how to visualize, and how to use mental imagery in solving design problems.

In order to establish whether the instruction we were providing was effective in training spatial ability, we undertook pre- and post-testing of samples of the first year Engineering students over a two-year period. This indicated that gains in spatial ability had taken place in both years (Sample 1: N = 263, t = 15,00, p < .001; Sample 2: N = 138, t = 9,23, p < .001). A comparison was also made in the second year of the study with the pre- and post-test scores of a sample of first year Science students (N’s at beginning of academic year = 175; 165 respectively). The two samples of students were matched by courses taken in Maths, Applied Maths, Physics and Chemistry, with the Engineering students also taking our course in engineering graphics.

The results indicated that gains in three dimensional spatial perception took place in both samples after elapse of six months (Engineering sample N = 138; t = 9,23, p < .001; Science sample N = 126, t = 3,90, p < .001). The Engineering students, however, gained more than the Science students (two-tailed T Test: t = 2,19, p < .05; one-tailed F test F = 1,90, p < .001) over a comparative period of six months between pre-and post-testing. Analysis of co-variance was thus also conducted, holding initial level of three dimensional spatial perception constant (Potter 1991a).

The results of this analysis 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. What this implied for course design was as follows:

• It was evident that the instructional procedures we were providing in our course were effective, but were most effective with those students who already had
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well developed three dimensional spatial perception at the time they entered university.

- It was thus important to identify students at risk as early as possible in the academic year, with a view to exposing these students to training in use of visualisation and mental imagery at as early as stage in the course as possible.

**Modifications to our model of intervention**

Over the initial two years of our intervention, pass rates for the course improved from 65 per cent to 77 per cent. This will be evident from the following analysis of pass rates pre and post our intervention, presented in Table 1.

**Table 1:** First year results in Engineering Graphics (1976–1983)

<table>
<thead>
<tr>
<th>Period</th>
<th>Total number of registrations</th>
<th>Total number of students writing final examinations</th>
<th>Total number of passes</th>
<th>Total number of failures</th>
<th>Total number of dropouts</th>
<th>Total number of failures and dropouts</th>
<th>Percentage of failures</th>
<th>Percentage of failures and dropouts</th>
</tr>
</thead>
<tbody>
<tr>
<td>1976–1980 (Prior to remedial tuition)</td>
<td>2 165</td>
<td>2 028</td>
<td>1 378</td>
<td>630</td>
<td>157</td>
<td>787</td>
<td>31.07</td>
<td>36.35</td>
</tr>
<tr>
<td>1981 (Concurrent eight month remedial course)</td>
<td>608</td>
<td>484</td>
<td>447</td>
<td>37</td>
<td>124</td>
<td>161</td>
<td>7.64</td>
<td>24.48</td>
</tr>
<tr>
<td>1982–1983 (July vacation remedial courses with additional instruction integrated into course structure)</td>
<td>931</td>
<td>797</td>
<td>704</td>
<td>83</td>
<td>134</td>
<td>217</td>
<td>10.41</td>
<td>23.31</td>
</tr>
</tbody>
</table>

Given indications from our analyses that students with well-developed three dimensional spatial perception were at an advantage relative to other first year students at time of intake to the university, we modified our model of intervention as follows.
a. Use of Assignments and Progress Tests for Early Identification of Students in Need of Academic Support

Our analyses had established that low marks over the first quarter of the academic year were highly predictive of academic performance, indicating that students’ marks on their assignments and progress tests could be used to identify students experiencing difficulties. In terms of our predictive model, this could be done early in the academic year. Academic support could then be provided.

We thus used analysis of student progress for identifying students in need of academic support, in terms of a predictive model in which assignments and progress tests and academic performance were used early in the academic year to identify students requiring special tuition. Measurement gains in three dimensional spatial perception ability was then used as an indicator of improvement in the cognitive abilities required to pass the course.

b. Use of a number of strategies and procedures for academic support

We had by now established a sequence of instructional procedures which had been implemented with both small and large groups. Course evaluations from the student body were positive. The evidence from our analyses also indicated that the instruction we had provided in mainstream lectures and in remedial courses in the university vacations was effective in training three dimensional spatial perception. In addition, gains in three dimensional spatial perception were associated with increase in pass rates.

However, given the indications from our analyses that academic support of extended duration was necessary, we were not satisfied that the remedial courses we were providing in the university vacations were sufficient. We thus established procedures for matching particular senior students with particular groups of first year students. We also provided training to senior students in tutoring, to enable better support in the practical sessions in the drawing halls. This enabled students with difficulties to be identified as early as possible in the academic year. Additional instruction could then be provided during the term, and supplemented by remedial courses run during vacations.

c. Use of quantitative indicators to establish effects of the intervention

Up to this point our quantitative studies had involved use of a number of psychometric tests in the evaluation of the programme. We had identified through factor analysis that the tests of spatial ability we had used were highly intercorrelated, and that many of the tests measured a similar spatial ability factor which was associated with pass rates in the course.

We thus at this point took the decision to cut down the amount of tests we were using to measure the spatial abilities associated with academic success in our course. The instrument chosen for use in our subsequent research was the H Test. This test was
reliable (Taylor, 1980; 1981; Delacour, 2004) highly saturated on the spatial ability factor we had identified, and was also the most highly predictive indicator of first year academic performance in the course. It could also be administered in a short time. We used this one measure to provide three quantitative indicators relating to the development of spatial ability in the course:

- Initial level of three dimensional spatial perception at time of intake to the university
- Level of three dimensional spatial perception post-instruction
- Gain scores in three dimensional spatial perception as reflecting amount of change in spatial ability over the academic year.

These indicators were used longitudinally as quantitative variables in a number of studies which we describe later in this article, as a way of establishing the effects of our intervention.

d. Use of qualitative indicators to establish student needs

We also conducted a number of qualitative studies which focused on student response to our mainstream teaching programme, as well on student response to the materials we had developed for use in the remedial courses run during vacations (Van der Merwe 1983; Potter, Van der Merwe and Kemp 1984; 1987; Potter 1991a). Given socio-political changes occurring across South Africa, we took the decision to undertake an assessment of the study habits and attitudes of engineering students, and the potential influence of adaptational and contextual factors on pass rates in our course.

Our aim was to establish a number of qualitative indicators of student needs, which could then be used as a framework for developing instructional and evaluating our instructional materials (Potter 1991a; Van der Merwe and Potter 2000). They could also be used as a basis for interpreting subsequent results with respect to academic performance, student retention and pass rates (Potter and Van der Merwe 2000; Kaufman 2000; 2003; Delacour 2004; Mokone 2008).

LONGITUDINAL EVALUATION OF THE INTERVENTION

Development of indicators relating to retention

To develop indicators relating to retention, we undertook cohort analyses of the academic performance of five successive intakes of first year engineering students. This involved tracking the academic performance of all first year engineering students over a period of five years, in order to establish trends in the Faculty of Engineering with respect to pass rates, retention and graduation.

As part of this investigation, tracer studies were also conducted of five cohorts of African students who undertook a pre-university year prior to entering the Engineering Faculty. These students were firstly tracked through to first year, to establish how
they studied, and whether their pre-university tuition had enhanced their academic performance at university (Potter and Van der Merwe 1983; 1984).

These students were then subsequently tracked over a number of years of university study through to graduation. They were also interviewed as part of a larger analysis undertaken to establish the types of academic support which were necessary at levels in the engineering curriculum beyond first year (Potter, Meyer, Scott and da Silva 1984; Potter 1991a; 1991b).

**Development of qualitative indicators relating to academic performance**

To establish factors in the university environment which were contributing to failure and dropout rates in our course, an evaluative study was undertaken a stratified sample of one hundred and sixty engineering students in five disciplines (electrical, chemical, metallurgical, mechanical and civil engineering). Quota samples were drawn of students with differing levels of academic performance in all four years of study, who participated in a series of twenty focus groups (Potter, Meyer, Scott and da Silva 1984).

These students first completed questionnaires, which were based on a series of open-ended questions relating to study habits, strategies and difficulties. The students’ responses were then analysed so as to match their verbal responses to the grades they had received in their previous year of study.

The analysis indicated that there were a number of qualitative indicators which discriminated successful as opposed to unsuccessful engineering students. One of these was participation in a highly developed informal student network which was used by the majority of engineering students at all levels of study in overcoming their study difficulties. This network included a ‘buddy’ system operating among students in the same year of study, as well as students in higher years of study at university.

Another was the student’s ability to identify his or her particular study needs, as well as the ability to find a ‘buddy’ (i.e. another engineering student of similar level of academic performance) in a subject or area in which difficulty was experienced. These two factors were crucial to getting over a study problem, for the reason that there was a lack of academic counseling and support for first year engineering students, as well a lack of orientation of the relationship between what they were learning and the demands of engineering as a career. Besides spatial ability, the development of adequate foundations in mathematics was crucial and a problem for many first year engineering students. At higher levels in the engineering curriculum, mathematical ability and the development of engineering problem-solving abilities were crucial to academic success.

Motivational and non-cognitive attributes (such as perseverance and self-discipline) were also fundamental to success in all years of study. The ability to interact and communicate effectively with others was also important, not only for the obtaining of help with study problems in the courses taken by a student, but
also for adequate development of problem-solving abilities at higher levels in the engineering curriculum.

The abilities to identify personal study problems and to network with others in solving academic problems were identified as the most important qualitative indicators of successful academic performance as an engineering student. Tutorials were rated as the most effective support system offered by the Faculty. Student peers were the most common and effective support system operating. Lecturers were consulted infrequently, and attitudes to lecturers appeared ambivalent. Across the Faculty as a whole, poor standard of lecturing appeared to be contributory to this attitude.

**Longitudinal analysis of pass rates**

With respect to the development of our course, longitudinal analysis of pass rates was undertaken in conjunction with course evaluation data to establish whether the forms of instruction and academic support we were providing were effective (Potter and Van der Merwe 1992a; 1992b; Kaufman 2000, 2003). The data on pass rates indicated an initial gain to 80 per cent, and then further gains to an average pass rate of 88 per cent annually. Course evaluations also indicated positive student ratings of the instruction they received, over a period in which the composition of the first year student body has represented increasing diversity in terms of cultural and educational background.

With the move to modularization of the curriculum after the country’s first democratic elections in 1994, a number of changes took place within the course structure, with certain disciplines (e.g. Electrical, Chemical and Metallurgical) taking a one semester variant of the course, while others (e.g. Mechanical and Civil) continued to take the two semester long course on which our previous research had been based.

Our longitudinal data with respect to pass rates on both variants of the course are summarised in Table 2.

The data from Table 2 provided evidence that, despite contextual changes both externally in the country as well as within the university in terms of curriculum and course revision, high pass rates for the course were maintained. These pertained to both the one and two semester variants of the course.

Comments made by the external reviewers during the five-yearly accreditation reviews of the course also provided indications that both courses were taught at a consistently high level, as rated against international standards (Potter and Van der Merwe 2000; 2001; 2003). Based on these positive indications and the improvements in pass rates in the course, there has been both national and international interest in our teaching methodology, our approach to course evaluation as well as the materials we have developed (Potter and Van der Merwe 2000; 2003; Potter, Van der Merwe, Kaufman and Delacour 2006a; 2006b), which are available in workbook form (Van der Merwe and Potter 2000; 2003).
Table 2: Student Pass Rates in Engineering Graphics (1986–2001)

<table>
<thead>
<tr>
<th>Year</th>
<th>Registered</th>
<th>Cancelled Registration</th>
<th>%</th>
<th>Group</th>
<th>Wrote Exam</th>
<th>% Pass</th>
</tr>
</thead>
<tbody>
<tr>
<td>1986</td>
<td>522</td>
<td>58</td>
<td>11</td>
<td>A</td>
<td>440</td>
<td>82</td>
</tr>
<tr>
<td>1987</td>
<td>515</td>
<td>75</td>
<td>15</td>
<td>A</td>
<td>410</td>
<td>79</td>
</tr>
<tr>
<td>1988</td>
<td>496</td>
<td>83</td>
<td>17</td>
<td>A</td>
<td>409</td>
<td>91</td>
</tr>
<tr>
<td>1989</td>
<td>491</td>
<td>68</td>
<td>14</td>
<td>A</td>
<td>406</td>
<td>89</td>
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<tr>
<td>1990</td>
<td>557</td>
<td>86</td>
<td>15</td>
<td>A</td>
<td>457</td>
<td>91</td>
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<tr>
<td>1991</td>
<td>379</td>
<td>35</td>
<td>9</td>
<td>A</td>
<td>328</td>
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<tr>
<td>1992</td>
<td>263</td>
<td>13</td>
<td>5</td>
<td>A</td>
<td>239</td>
<td>89</td>
</tr>
<tr>
<td>1993</td>
<td>253</td>
<td>29</td>
<td>11</td>
<td>A</td>
<td>212</td>
<td>83</td>
</tr>
<tr>
<td>1994</td>
<td>289</td>
<td>45</td>
<td>15</td>
<td>A</td>
<td>136</td>
<td>90</td>
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<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>A, B</td>
<td>103</td>
<td>91</td>
</tr>
<tr>
<td>1995</td>
<td>250</td>
<td>35</td>
<td>14</td>
<td>A</td>
<td>105</td>
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<td></td>
<td></td>
<td>A, B</td>
<td>106</td>
<td>83</td>
</tr>
<tr>
<td>1996</td>
<td>225</td>
<td>54</td>
<td>24</td>
<td>A</td>
<td>78</td>
<td>89</td>
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<tr>
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<td></td>
<td></td>
<td></td>
<td>A, B</td>
<td>78</td>
<td>87</td>
</tr>
<tr>
<td>1997</td>
<td>299</td>
<td>32</td>
<td>11</td>
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<td>110</td>
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</tr>
<tr>
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<td></td>
<td></td>
<td></td>
<td>A, B</td>
<td>148</td>
<td>92</td>
</tr>
<tr>
<td>1998</td>
<td>264</td>
<td>29</td>
<td>10</td>
<td>A</td>
<td>117</td>
<td>87</td>
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<td>1999</td>
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<td>A, B</td>
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<td>2001</td>
<td>348</td>
<td>70</td>
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<td>A</td>
<td>99</td>
<td>93</td>
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<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>A, B</td>
<td>275</td>
<td>92</td>
</tr>
</tbody>
</table>

Group A = Engineering Graphics and Design (a full year course)
Group B = Engineering Graphics (a six month course)
Average annual pass rate 1986–2001 = 88%

Longitudinal analysis of changes in the three dimensional spatial perception of engineering students

In order to establish whether three dimensional spatial perception was a continuing influence on academic performance of students taking the course, two cross-validation
studies have been undertaken (Kaufman 2000; 2003). In addition, we undertook a longitudinal analysis of the value of three dimensional spatial perception in predicting first year academic performance in engineering (Delacour 2004).

The results of these studies indicated that the three dimensional spatial perception of Engineering students was significantly higher than matched samples of Science students both at time of entry into the university as well as post-instruction six months later (2000 pretest difference t (237)= 9.111, p < .005; 2000 post-test difference t (159)= 5.502, p < .005; 2001 pretest difference F (289)= 55.79, p < .005; 2001 post-test difference F (289)= 29.38, p < .005). The findings were similar to our earlier results (Potter 1991a), in indicating that both Engineering and Science students improved significantly in three dimensional spatial perception over the academic year (Engineering students 2001 pretest/post-test difference t (149, 1)= 7.17, p < .005; Science students 2001 pretest/post-test difference t (148, 1)= 9.65, p < .005), but indicated fluctuation in level of spatial ability in both groups relative to our earlier studies.

We thus also undertook a longitudinal analysis of the stability of the relationship between three dimensional spatial perception and our intervention over the twenty year period from 1982 to 2001 (Delacour 2004). This indicated a significant main effect of the intervention, based on a firm and ongoing relationship between three dimensional perception both at time of intake to the university and after six months instruction, and examination results (in the year 2001 three dimensional spatial perception ability accounted for between 38 per cent and 40 per cent of the variance in first year results in both engineering graphics as well as other first year engineering subjects).

However, there was also a significant interaction indicating that the relationship between these variables was a complex one. Overall, despite fluctuations within the data collected in our course over a twenty year period, three dimensional spatial perception remained a firm predictor of academic performance. The analyses also indicated that the relationship between three dimensional spatial perception and academic performance had increased as the student body had diversified (Potter, Van der Merwe, Kaufman and Delacour 2005; 2006a).

CONCLUSIONS

Continuing needs for the intervention

Overall, our longitudinal analyses indicate that despite evidence of contextual variables (e.g. changes in demographics) affecting the results obtained by the students, there is an ongoing need for our intervention. Gains made in three dimensional spatial perception, as well improved pass rates for our course, would also suggest that the type of instruction we have provided longitudinally in the first year engineering graphics course has been effective (Potter, Van der Merwe, Kaufman and Delacour 2005; 2006a; Potter Van der Merwe and Kemp 1984; 1987). These conclusions are supported by evidence from positive course evaluations, as well as qualitative analyses using interviews, questionnaires and focus groups with students (Kaufman 2000; 2003)
Instructional needs of African engineering students

Compared to the situation prevailing under apartheid education, our recent data would suggest that a substantial number of African students currently register for degrees in engineering. These students no longer have to live in segregated residences, and are thus in a position to participate in the student network and ‘buddy’ system which continue to be important to successful academic performance in engineering (Kaufman 2003).

Many African engineering students now take technical drawing at school level (Kaufman 2000; 2003). These students cope well with the demands of our course. Those African students who have not had adequate educational opportunity in this respect, continue to be disadvantaged at time of university entry.

Instructional needs of female engineering students

Relative to the results of previous studies (Jawitz and Case 1998; Jawitz, Case and Tshabalala 2000; Martineau 1997; Royer 1995) which have highlighted low numbers of female students studying engineering, our analyses (Kaufman 2003; Mokone 2008) indicate that many of the female engineering students taking engineering graphics have experienced difficulties with the course content, and use a variety of strategies to get over their problems. Those female students who have not taken technical drawing at school level, and female students who do not network with other engineering students are likely to be those at a disadvantage.

Our analyses also indicate that social factors such as stereotype threat lower the likelihood that female students will attempt to enter engineering as a field of study (Kaufman 2003; Mokone 2008). In addition, personal factors such as low self-efficacy of female students relative to the tasks they are required to do in their engineering courses militate against their successful adaptation to university. Poorly developed three dimensional spatial perception ability at time of university entry presents one such barrier to successful first year study (Mokone 2008).

Theoretical implications

Our analyses have yielded clear evidence that three dimensional spatial perception is a barrier to learning for many first year engineering students, but is trainable. The teaching methodologies we have developed would suggest the value of using the theories of the development of perception and mental imagery suggested by Piaget and his co-workers (Piaget 1953; 1964; 1969a; 1969b; 1970; 1971; 1977; Piaget and Inhelder 1971; 1973) as a basis for planning instruction in engineering graphics courses. Given earlier indications of similar benefits from the hands-on instructional techniques pioneered by Davies (1973; 1976) in working with overseas students in Britain, it may also be the case that the particular teaching approaches we have described and the materials we have published (Van der Merwe and Potter 2000) can be used in other contexts, as they apparently relate to similar needs in the teaching
of engineering graphics described by others internationally (e.g. Davies 1973; 1976; Sorby 2001).

**Indications for further research**

Our work in training spatial ability has indicated the value of an action research-based instructional approach directed at identifying and overcoming student difficulties in learning engineering graphics. Our longitudinal analyses indicate that three dimensional spatial perception is still highly predictive of academic performance in our course. Educational disadvantage also still remains a major issue. Overall, our analyses also suggest the need for ongoing research on issues relating to culture, gender and diversity, and the complex connections between cognitive and social factors, and academic performance. While the socio-political, economic and educational effects of apartheid remain, intervention will continue to be needed focusing on providing support to students with difficulties.

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