Academic support for under-prepared first year engineering students – does it pay off?

Tobia Steyn

School of Engineering, University of Pretoria, South Africa

Abstract

First year engineering students enrolled for an extended study program in the School of Engineering at the University of Pretoria have passed the University's admission tests assessing their ability to succeed at engineering studies. However, some of these students are academically still at risk because of shortcomings in their educational background. Diversity in these students' level of understanding and comprehension require careful consideration in planning and designing the curriculum of the extended study program so that the students can comply with the exit level outcomes for engineering graduates set by the Engineering Council of South Africa. Faculty is faced with the challenge to redress and enhance the under-prepared students' understanding of the fundamentals underpinning a study in calculus, to develop their personal, academic and communication skills and to introduce them to basic skills in information technology.

To meet this challenge and address these aspects, a developmental course, Professional Orientation, is presented during the first year of study. The main pedagogical approach in the Professional Orientation course is to develop the academic potential of the under prepared students. Therefore, the focus in this course is not only on the learning content but also on the learning process. In 2000 the current structure and content followed in the Professional Orientation course were introduced. Assessment of the real effect of academic support on freshmen level (as in the Professional Orientation course), requires following up on students until completion of their studies. Preliminary results of the freshmen engineering students who enrolled in 2000 indicate that the academic performance of the at-risk students on the extended study program, who took the Professional Orientation course, compares favorably with that of the students on the standard study program.

This paper overviews the curriculum design and instructional strategy followed in the Professional Orientation course in the School of Engineering. The paper reports on a longitudinal study of academic performance of first entrant engineering students who enrolled at the University of Pretoria in 2000 and compares performance of the under-prepared students with that of other first year engineering students.

Five Year Study Program

The standard university engineering program in South Africa requires four years of full time study as regulated by the Engineering Council of South Africa (ECSA). In 1994 the Five Year Study Program (5YSP)[1] was introduced in the School of Engineering at the University of Pretoria (UP). This program is structured in such a way that the academic courses of the first two years of the standard four year study program (4YSP) are spread over the first three years of the 5YSP.

The 5YSP is fully integrated into the mainstream program in the sense that all students on the 5YSP attend the same classes, have the same time-table, textbooks and lecturers and write the same tests and exam papers as the mainstream students. This contributes to increased credibility of the extended program and prevents stigmatising students as being 'at risk'. Faculty thus take ownership of the extended program and do not view it merely as an 'add-on'.

The purpose of the 5YSP is to create opportunities for students who have the potential to become engineers but who do not meet the entrance requirements for the 4YSP and/or are academically at risk because of their educational background. Students on the 5YSP are given additional academic support in their first year engineering courses through tutoring given by senior (engineering) students.

The Professional Orientation Course

In spite of the additional academic support through tutoring, some of the students on the 5YSP are academically still at risk of not succeeding at engineering study. Factors that contribute to the diverse needs of students upon entering higher education in South Africa originate from a system where there are differences in the quality of the education, in the levels of understanding and comprehension, and a lack of exposure and access to technology. These factors are indicators for selection of students into a developmental course, Professional Orientation, offered during the first year of study. It follows that not all students who are admitted into the 5YSP qualify for selection into the Professional Orientation course.

The Professional Orientation course is a credit-bearing course and comprises two semester modules. Contact time in the first semester is six hours per week and seven hours in the second semester. The modules focus on conceptual mathematical skills, communication, technological and personal skills. Figure 1 gives an overview of the contents of the module in the first semester and Figure 2 shows the content of the module in the second semester.

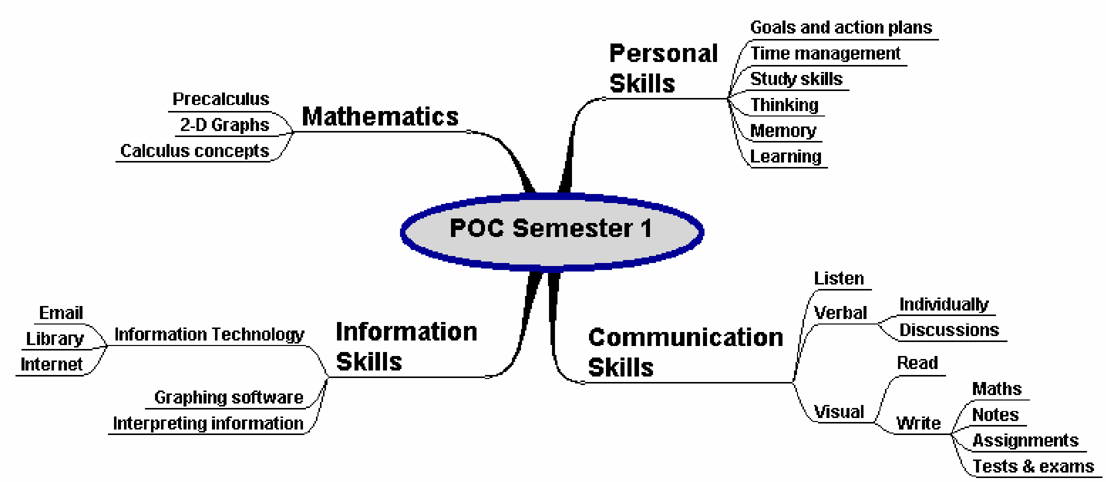

Figure 1 Overview of the content of the first semester Professional Orientation course (POC) module

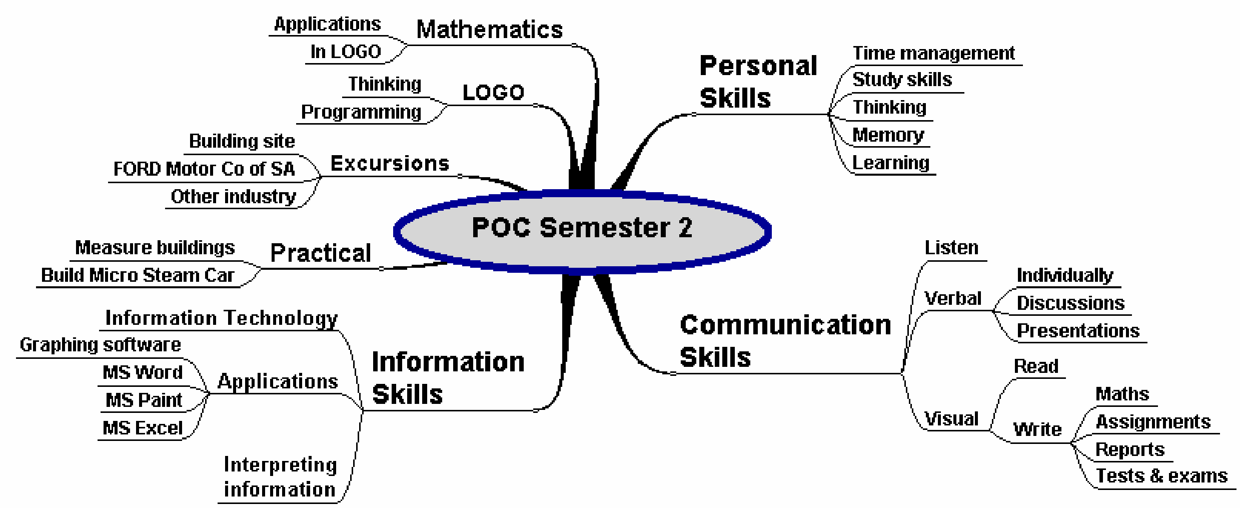

Figure 2 Overview of the content of the second semester Professional Orientation course (POC) module

Curriculum design principles in the Professional Orientation Course

Each student brings to the learning environment a unique set of needs, values, interests, learning and thinking styles and skills that must be taken into consideration when developing a curriculum to enhance success.[2, 3] Complementary to the scientific engineering knowledge basis, engineering educators recognise the importance of team work, communication and problem-solving skills. This is in agreement with the required outcomes for an accredited bachelors degree as identified by the Engineering Council of South Africa (ECSA) (1998). The ECSA outcomes are similar to the attributes that ABET requires of engineering graduates in the United States.

The design of the curriculum to support at-risk students has to make provision for mastering skills and competencies that are part of a development that will be of a permanent nature. These attributes are vital to succeed academically and need also to be transferred to the world of work of the professional engineer. In the Professional Orientation course the following principles are seen as fundamental to the design of such a curriculum.

Interrelatedness and interaction between the educational, social, economic and environmental factors which influence students' orientation towards study as well as achievement is acknowledged. In the Professional Orientation course a holistic and integrated perspective towards development and support is fostered.

A **flexible structure** is maintained within the framework of the intended learning outcomes. This ensures that the pace of learning and the learning content are adaptable to address changing and diverse needs of the students.

Learning content is integrated with skills development. Learning content and learning processes are assimilated into the conceptual and psychological framework of the learner. New knowledge is constructed from existing knowledge and learning takes place when a learner constructs meaning by making associations within his/her own field of learning experiences.[4]

At-risk students, who have shortcomings in their educational background, often find it difficult to construct meaning and rely on rote-learning without understanding.

Learning community. The creation of a learning community entails both social and academic matters and comprises three stages, namely, socialisation, group building and human relations training.[5] This process of active participation involves a high level of staff and student involvement. Astin[6] points out that student-student interaction has a strong positive effect on leadership and academic development, problem-solving skills and critical thinking skills. Chickering and Ehrman[7] stress that learning is enhanced when it is collaborative and social.

Instructional strategy in the Professional Orientation Course

The main aim of the Professional Orientation course is the development of each student's academic potential in order for him or her to pursue engineering studies successfully. The instructional approach[4] in the course is illustrated in Figure 3. Broadly speaking this approach is based on the Herrmann four quadrant whole brain model,[8] the Felder Silverman model of learning styles,[3] and the Lumsdaines' modes of student learning.[9] The instructional approach in the POC underpins the principle of the basis models, namely, there are different ways of learning; students arrive at tertiary institutions with established ways of thinking and doing and students should acquire the ability to be able to function in all learning (thinking) style modes.

POC students complete the Felder Solomon Index of Learning Styles (ILS)[10] as part of course activities. This is followed up with a discussion of the outcomes of the ILS, and of the existence of and diversity in thinking, learning and teaching preferences. The aim is to make the students aware of their own preferences and the need to develop functionality in their less preferred thinking and learning modes.

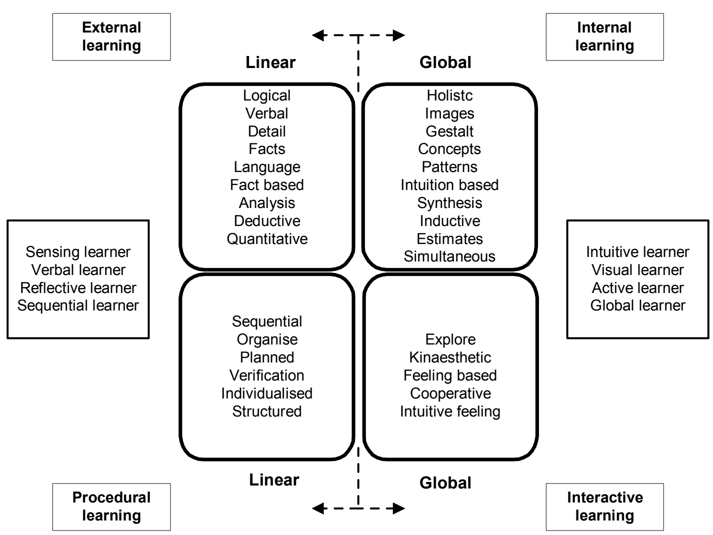

Figure 3 **Instructional approach in the Professional Orientation course (POC)**

Learning activities in the Professional Orientation course adhere to the principles of outcomes based education and are also guided by ECSA's exit level outcomes[11] for engineering graduates as they are applicable to the course content of the course.

In addition to the four quadrant whole brain principle, different learning styles and different learning modes, the following are viewed as core pedagogical principles in the Professional Orientation course.

Active learning, which involves activities that engage students in doing something instead of only observing what, can or should be done. Students are made aware of their own learning actions and that they must consciously plan, implement, monitor and evaluate these actions. **Face to face interaction** is the main mode of interaction between facilitators (lecturer and tutors) and the students. However, it should be stressed that this does not resemble a traditional lecture style interaction. The Professional Orientation course is presented in a computer laboratory where facilitator-student and student-student communication are mostly one-on-one or in informal small groups. Students are encouraged to **work cooperatively** in study groups. An approach of **continual** (formative) **assessment** and extensive **feedback** on performance is followed. Students are encouraged to deliver a high standard of work and perform at their best.

Mathematics in the Professional Orientation Course

The content of the module in the first semester focuses on fundamental mathematical concepts. The aim is to give students a thorough understanding of 2-D functions and their graphs as these concepts form the basis for calculus. This support in mathematics is given in addition to and separately from the standard first semester calculus module that is presented by the Department of Mathematics. The main components of the mathematics in the Professional Orientation course can be summarised as follows:

- Active exploration of the graphs of 2-D functions.
- Use of computer graphing technology. A very simple and basic program[12] is used that only draws the graphs. All mathematical interpretation and deductions have to be done by the student.
- Working alone.
- Informal group work.
- One-on-one interaction between students and facilitator.
- Formulating mathematical concepts orally.
- Expressing mathematical concepts in writing.
- Assessment and grading of answer sheets.[13]
- Extensive feedback.

In the second semester mathematical skills are purposely facilitated in practical activities. One such activity is to have students measure the height of two selected buildings on campus. This practical serves as an example how the skills outlined in Figure 2 are deliberately integrated in one activity. The aims of the practical are to estimate and determine the height of a building using appropriate tools, to promote group work and to compile a (scientific) report. The practical is done in groups of three, but each student has to submit an own report. The report has to be compiled according to a prescribed format given and must include diagrams. The mathematics involved is trigonometry (angle of elevation, angle of depression and side length of a triangle). The tools used are an abney level and a measuring tape. Time scheduled for the practical is three hours. Compiling the report takes about another hour depending on a student's level of competency in writing and IT skills. Table 1 gives a summary of the skills integrated in this activity.

Activity	Skill
Teamwork	Personal skills
Using a measure tape and abney level	Technical skills
Estimation Calculation Trigonometry	Mathematical skills
Word processing, retrieving and inserting images, compiling graphics	IT skills
Report writing	Communication skills

Table 1 Integrated skills in a practical measuring campus buildings

Entry attributes of engineering study

Admission to study at the University of Pretoria is based on the calculation of a so-called M-score that is calculated from a student's final school examination results. For engineering study a minimum M-score of 18 points out of a possible 30 points is required. For prospective engineering students with an M-score ranging from 12 to 17 an additional admission test is given. Admission to the 5YSP is then considered on the results of the test.

The data[14] in Table 2 shows the average M-scores in 2000-2003 for three groups of freshmen engineering students, namely 4YSP students, 5YSP students who were enrolled for the Professional Orientation course (POC) and other 5YSP who did not take the POC. The data indicates that the average M-scores for both groups of students on the 5YSP are consistently lower than that of the students on the standard 4YSP. In 2000 the M-score of the POC students was the lowest of all the groups and significantly lower than that of the standard 4YSP students. A low M-score is an indication of deficiencies in schooling and the resulting challenges associated with learning facilitation in a developmental support course as in the Professional Orientation course. For example, only 19 of the 2000 Professional Orientation course students had limited previous experience with computers and none of them had used a computer for mathematics before. This limited experience comprised, on average, one to two hours of computer use that was scheduled as a computer literacy period in the formal school timetable in their final year of secondary schooling.

	Average M-scores			
Students	**2000**	**2001**	**2002**	**2003**
Standard 4YSP students	25	25	24	23
POC students	18	17	18	19
Other 5YSP students (without the POC)	19	19	19	19

Table 2 M-scores of first year engineering students

Results and discussion

At the University of Pretoria experience has identified two possible problem areas in the background of freshmen engineering students, namely, capability in fundamental mathematical concepts and competence in technical communication skills. In the Professional Orientation course the development of these skills forms an important part of the course strategy and content. As the same mathematics modules are compulsory for all engineering disciplines of both the 4YSP and the 5YSP in the first two years of study, the focus in this paper is on student performance in the mathematics modules of the first two years of study. Analysing performance in these mathematics modules can serve as an indicator to determine the effect of the additional developmental support that the POC students get.

The following selected data reflects on the performance of first entrant engineering students who enrolled at the University of Pretoria in 2000. First entrant engineering students exclude students who repeat their first year of study as well as students who previously had done any tertiary course at the University of Pretoria or elsewhere. For the purpose of this paper the 2000 group is selected because relevant longitudinal data is available and completion of studies for the 4YSP students could be expected in 2003 and for the 5YSP students in 2004. Furthermore, since 2000 the current instructional strategy (Figure 3) and mathematics content are characteristic of the Professional Orientation course. Data is given as available at time of writing and compares the performance in mathematics of the POC students with that of the standard 4YSP students and the other 5YSP students.

The data in Table 3 gives the total number of enrolments of first entrant engineering students in 2000.

4YSP	POC	Other 5YSP
356	33	84

Table 3 Enrolment of first entrant engineering students in 2000

The data in Table 4 gives the percentages of students who passed the mathematics modules in the first two years of study. The pass rates in Table 4 are given as percentages of the number of students who wrote the final examination in a module irrespective of whether the pass was a first time pass or a pass after a second (third) attempt. All the POC students passed the first course in calculus (WTW114) with the first attempt. This may be attributed to the POC students' experience in the mathematics component of the POC course. It should be noted that the mathematics in the Professional Orientation course does not involve coaching in the content of the standard calculus course but is focused on developing students' understanding of the fundamental concepts underpinning calculus. The pass rate of the 2000 POC students in all the mathematics modules of the first two years of study compares favorably with that of the 4YSP students and is better than that of the other 5YSP students. The initial developmental support given in the Professional Orientation course can reasonably assumed to be a significant contributor to the POC students' level of performance.

			4YSP		POC		Other 5YSP	
Year	**Semester**	**Module**	**% pass**	**N**	**% pass**	**N**	**% pass**	**N**
1	1	WTW114	95.79%	356	100.00%	33	84.52%	84
1	2	WTW126	88.89%	351	93.94%	33	68.75%	80
1	2	WTW128	88.41%	345	93.75%	32	78.57%	69
2	1	WTW218	90.85%	284	92.86%	28	61.90%	42
2	1	WTW286	92.14%	280	96.43%	28	65.78%	38
2	2	WTW228	93.20%	294	96.43%	28	82.98%	47
2	2	WTW263	96.23%	292	96.43%	28	89.58%	47

Table 4 First time enrolments who passed the mathematics modules of the first two years of study

The data in Table 5 gives the retention of students in the mathematics modules. Table 6 identifies the coding of the mathematics modules at the University of Pretoria and summarises the contents thereof.

	Enrolled in 2000		
	4YSP	**POC**	**Other 5YSP**
	N=356	**N=33**	**N=84**
Pass WTW286	72.47%	81.82%	29.76%
Pass WTW228	76.97%	81.82%	46.43%
Pass WTW263	78.93%	81.82%	51.91%

Table 5 Retention of students in mathematics modules

WTW114	Calculus	Functions, limits and continuity. Differential calculus of single variable functions, rate of change, graph sketching, optimisation and applications. Mean value theorem. Rule of L'Hospital. Definite and indefinite integrals, the fundamental theorem of calculus, the mean value theorem for integrals, integration techniques. Vector algebra.
WTW126	Linear Algebra	Matrices and their algebra, systems of linear equations, subspaces of 3^n, bases, determinants. Mathematical induction. Complex numbers and factorisation of polynomials.
WTW128	Calculus	Important inverse functions. Integration techniques, improper integrals, numerical integration, elementary differential equations. Volume and surface area, arc lengths, conic sections. Elementary power series and Taylor's theorem. Plane curves, polar coordinates and vector-valued functions.
WTW218	Calculus	Vector functions and multivariable functions. Multiple integrals. Line and surface integrals. Theorems of Green, Gauss and Stokes. Applications.
WTW286	Differential equations	Theory and solution methods for linear differential equations and systems of linear differential equations. Solution methods for first order non-linear differential equations. The Laplace transformation.
WTW228	Calculus	Sequences and series. Power series. Fourier series. Applications to differential equations.
WTW263	Numerical methods	Solution of non-linear equations, direct and interactive methods of solving systems of equations (linear and non-linear), solution of differential equations, numerical interpolation and curve fitting.

Table 6 First and second year mathematics modules for engineering students

The data in Table 5 is an indication of the overall attrition rate of the mentioned students within the first two years of study. Continuation to the final year of engineering study is not possible if a student does not pass the mathematics modules of the first two years. Four of the 33 POC students changed course after the first year and enrolled for a BSc degree. Of the remaining 29 POC students, 27 were successful in completing these mathematics modules. The data in Table 5 gives a bleak picture of the retention rate of the other 5YSP students. Formal academic support through peer tutoring is available (compulsory) to all students on the 5YSP in the first year mathematics modules. However, from the low retention of the other 5YSP students, it seems as if the effect of this support is not carried over to the subsequent year. In comparison, the POC students seem to have benefited from the additional support given in the Professional Orientation course that has a broader developmental focus rather than merely a reinforcement of class work.

Figure 4 compares the average marks of the 4YSP students, POC students and other 5YSP students of the 2000 first entrant enrolment for the mathematics modules of the first two years of study. Figure 5 shows the average performance in the mathematics modules for the first year of study during 2000-2002.

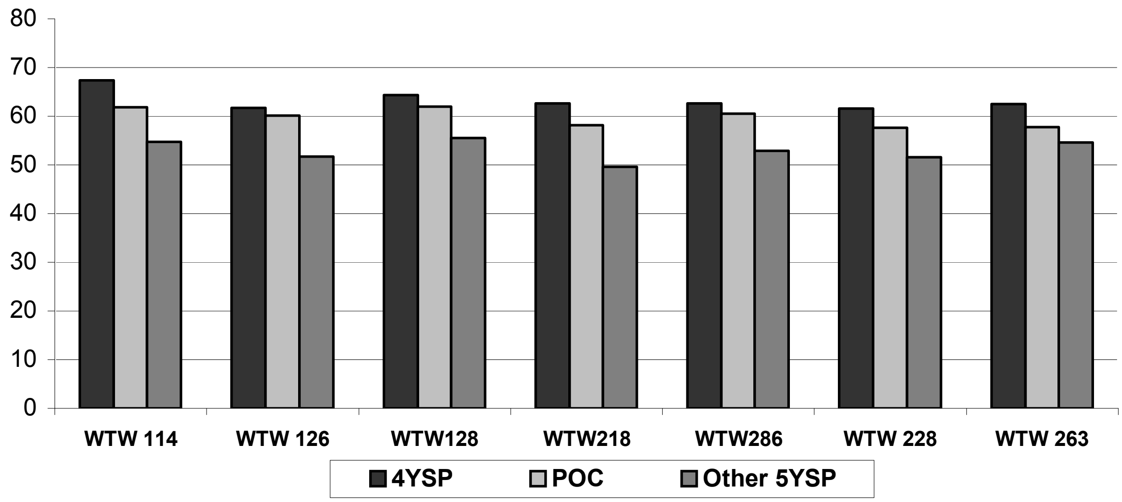

Figure 4 Average marks in mathematics modules of the first two years of study

The data in Figure 4 gives the average marks in mathematics modules for the first two years of study for first entrant freshman engineering students in 2000. In spite of the fact that the 2000 POC students had the lowest M-score (Table 2), their performance in all the mathematics modules compares favorably with that of the 4YSP students and they outperformed the other 5YSP students who were not registered for the Professional Orientation course. Regarding performance in the mathematics modules of the first year of study, this tendency is not restricted to the 2000 enrolment. The data in Figure 5 indicates that the good performance of the POC students in the first year mathematics modules is also displayed during 2001 and 2002. It may be concluded that the POC students, through the teaching and learning approach followed in the Professional Orientation course, acquire the skills to study mathematics and carry these skills over to their subsequent mathematics modules.

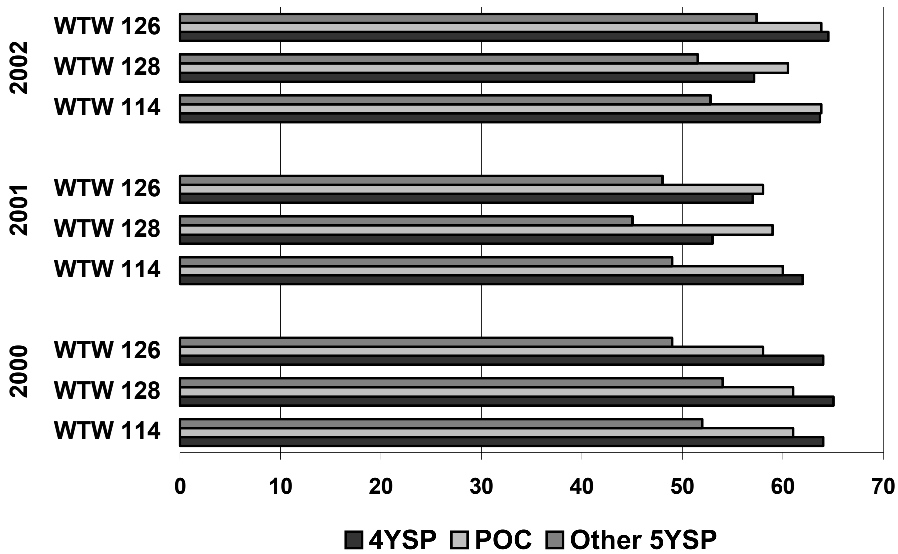

Figure 5 Average marks in mathematics modules of the first year of study

Figure 6 summarises the enrolments, retention and graduates of students on the 5YSP during 1994-2004 and Table 7 summarises the academic achievement of the 2000 POC students in 2004.

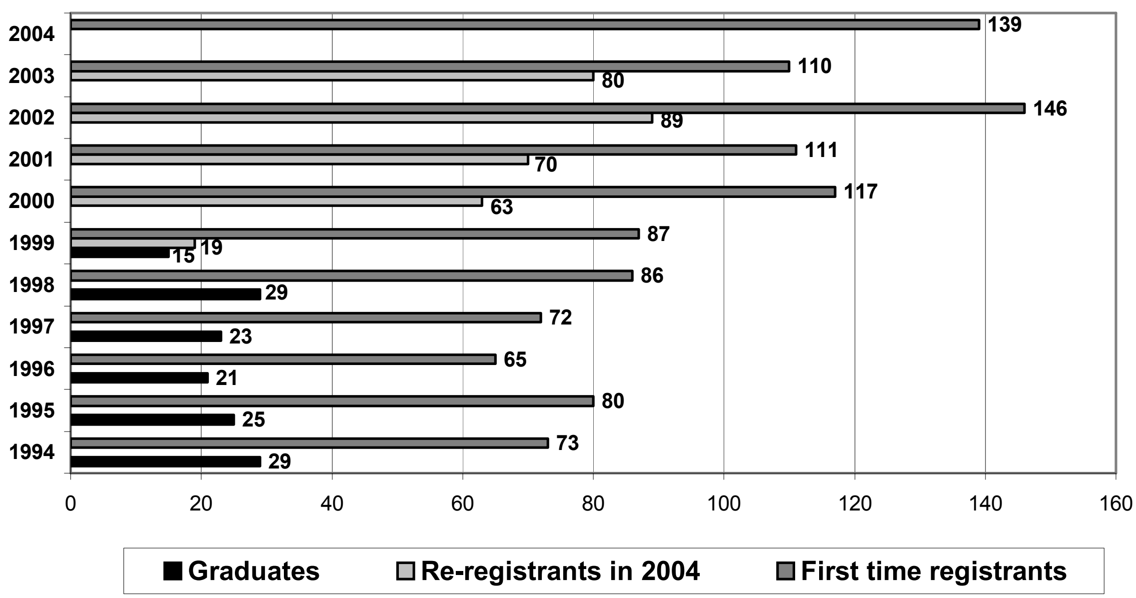

Figure 6 Five Year Study Program performance 1994-2004

POC enrolment in 2000	N=33	
Complete study in minimum 5 years	9	27%
Expected completion of study in more than 5 years	10	30%
Expected total graduates of the 2000 POC group	19	58%
Discontinued engineering study in 2004	4	12%
Discontinued engineering study before 2004	5	15%
Changed course to BSc after first year of engineering study	4	12%
No academic achievement	1	3%

Table 7 Achievement of the POC students enrolled in 2000

The long term effect of developmental intervention as in the Professional Orientation course can only be reflected in terms of achievement of the students which covers the full term of their academic careers. The data in Figure 6 shows, by year of entry into the 5YSP:

- the number of graduates;
- the number of re-registrants in 2004 and
- the number of students that registered for the first time.

Of the 117 students who registered for the 5YSP in 2000, 54% re-registered in 2004. Of the 2000 POC students, 70% re-registered in 2004 whereas 34% of the other 5YSP students re-registered. These figures show that the POC students have a significantly higher retention rate than the other 5YSP students.

At time of writing, final data on the performance of the 4YSP and other 5YSP students who enrolled in 2000 is not available. Only preliminary data of the POC students is available and reflects the achievement of the POC students after the intended five years of study. According to the data in Table 7, 24% of the POC students completed their engineering studies in the minimum scheduled five years and 33% of the students will take longer than five years to complete their studies.

Graduation rates for students on the standard 4YSP at the University of Pretoria varies, on average, between 30% and 33% for graduation within the minimum four years and an overall graduation rate of 60%-65% in engineering.[14] Taking into account that the POC students who registered in 2000 entered with lesser preparedness for engineering study than the 4YSP students, the success rate of their achievement compares favorably with the average performance of students on the 4YSP.

Conclusion

Analysis of data indicates that the developmental support given to students who took the Professional Orientation course enhanced their academic performance in the mathematics modules of the first two years. These students' rate of completing their studies in the minimum set time of five years for the extended program in engineering compares favorably with the average percentage of students on the standard engineering program who graduate after the minimum four years of study.

To determine and enhance the effect of academic support for under-prepared students, continual longitudinal studies should be done. However, initial results indicate that the pedagogical approach in the Professional Orientation course and its manner of implementation offer a significant advantage in supporting under-prepared students for engineering study.

Acknowledgement

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TOBIA STEYN holds degrees in mathematics and education and has been involved in academic support programs at the University of Pretoria since the early 1990's, initially focusing on mathematics support in the Faculty of Science and from 1999 as senior lecturer responsible for a developmental course in the School of Engineering.