M. Potgieter and B. Davidowitz,
S. Afr. J. Chem., 2010, **63**, 75–82,
<http://journals.sabinet.co.za/sajchem/>.

Grade 12 Achievement Rating Scales in the New National Senior Certificate as Indication of Preparedness for Tertiary Chemistry

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Received 15 February 2010, accepted 14 June 2010.

ABSTRACT

There has been much discussion on the impact of the new curricula for Grades 10–12 on the preparedness for tertiary studies of the 2009 cohort in subjects such as mathematics, chemistry and physics. Using the Chemical Competence Test that was developed and refined earlier, we have evaluated the proficiencies of incoming students to determine the shifts in preparedness for tertiary chemistry that occurred after students wrote the National Senior Certificate (NSC) in South Africa for the first time in 2008. Data were collected in 2009 for first-time entering students at the Universities of Pretoria (UP) (N = 828) and Cape Town (UCT) (N = 315) and compared with that of students who were educated according to the former National Education curriculum (NATED 550) (2005: N_{UP+UCT} = 776). The raw score results showed a decline in proficiency in all topics, and significantly reduced skills development, with mastery of acids and bases showing the most serious decline. Rasch analysis of the data indicated that a 12 percentage point shift in preparedness occurred in 2009 compared with 2005. The contribution to this shift of a mismatch between the new NSC rating scale and the one used previously was also investigated. The implications of the findings for selection and placement and teaching of first year chemistry courses are discussed.

KEYWORDS

Chemical education, preparedness, tertiary chemistry, Chemistry Competence Test, National Senior Certificate, achievement rating.

1. Introduction

The South African education system has undergone major changes which began with the Department of Education adopting outcomes-based education as the foundation for the curriculum in South Africa.[1] New curricula were introduced for all subjects taught in the Further Education and Training (FET) phase (Grades 10–12),[2] including Mathematics and Physical Science. Since a relatively small percentage of learners graduating from secondary schools enter tertiary education, the focus of secondary education was adjusted to satisfy a much wider range of constituencies than was the case in the previous dispensation. Another significant change was the decision to discontinue the standard and higher grade delivery of subjects; instead all candidates would write the same National Senior Certificate (NSC) examinations for the subjects that they are enrolled for at the end of the FET phase.

The National Curriculum Statement (NCS)[2] introduced a new Knowledge Area in Chemistry, namely Chemical Systems, which aims to take chemistry beyond the test tube and the classroom and into the real world. It includes global cycles in Grade 10, resources of the lithosphere (mining and mineral processing) and the atmosphere in Grade 11 and chemical industries in Grade 12 (petrochemical, fertilizer, chlor-alkali and battery industries). Another major change for teachers and learners is the introduction of the 3rd learning outcome, LO3. The introduction of chemical systems was supposed to provide the content and context for assessing LO3. According to the NCS curriculum statement:

> 'CHEMICAL SYSTEMS 18,75 %
> The content and context provides opportunities to focus assessment on Learning Outcome 3, viz. evaluating
> - competing knowledge claims
> - the impact of science on human development
> - the impact of science on the environment.' (p. 47).

In addition, the organic chemistry content has been expanded compared with the former National Education curriculum, NATED 550, to include amines, amides, ketones and arenes. There is also a stronger focus in the NCS curriculum on the links between the chemical and physical properties of compounds as well as types of reactions: substitution, addition and elimination reactions where students are expected to name, identify and know the reaction conditions for each type.

The implementation of outcomes-based education as well as new curricula for Mathematics and Physical Science in the FET phase of secondary schools in South Africa was likely to change the proficiencies of future first-year university students. Tertiary institutions would need to be informed to accommodate these changes in order to ensure a smooth transition from secondary to tertiary education. With the possible exception of academic development programmes for under-prepared students, however, most university lecturers in chemistry would assume that first-year students have a basic knowledge and understanding of subjects such as Mathematics, Chemistry and Physics on which they can build more advanced concepts and skills. Such assumptions are seldom formally tested or confirmed. From a tertiary perspective, therefore, it is imperative that shifts in proficiencies of students upon entry to tertiary education are

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carefully monitored, especially during a transition period.

At the end of 2008 the first cohort of students who were taught according to the new curricula within the outcomes-based education paradigm from Grade 1 to Grade 12 wrote the new NSC examinations. The results of these examinations have received careful scrutiny by bodies such as Umalusi in an attempt to determine whether there had been a shift in standards as measured against previous years.[3–5] Once this particular cohort of students entered tertiary studies, it became apparent from the results of the first class tests that they were not adequately prepared for tertiary studies. The concern of educators was reflected in several articles which appeared in the local press with headlines such as 'Students are set up to fail'[6] and 'Net 17% van eerstejaars slaag chemie'.[7] Rather than relying on indirect or anecdotal evidence the purpose of this study is to report on the use of our specially-designed test instrument to accurately document any shifts in preparedness for tertiary chemistry that occurred since the introduction of the new curricula for key subjects such as Mathematics and Physical Science.

Preparedness for tertiary chemistry in our view does not consist only of content knowledge, but also of conceptual understanding of fundamental concepts assumed as pre-knowledge for tertiary chemistry. In addition, an appropriate level of mathematical and other skills, e.g. understanding of scientific terminology and representational competence, is required for mastery of chemistry at tertiary level.

2. The Chemistry Competence Test (CCT)

In order to assess and monitor preparedness in chemistry at the secondary–tertiary interface a suitable test instrument is required. A literature search revealed the lack of test instruments with the appropriate focus, depth and coverage for application in the South African context. Results from South African matriculation examinations are not suitable for the diagnostic purposes that we propose for two reasons. Firstly, a single mark is reported for both the physics and chemistry components of the syllabus; secondly, performance data on individual sections or questions in the Physical Science paper are not available.

In the absence of tailor-made instruments we embarked on the development of a test instrument which meets the most stringent requirements of validity and reliability required in educational assessment. The design criteria for our instrument, called the Chemistry Competence Test, CCT, have been described in an earlier paper[8] and are briefly summarized below. Since the curricula for first-year chemistry at major South African tertiary institutions do not differ to a large extent, the CCT instrument was designed to cover fundamental concepts generally accepted as pre-knowledge in all subject topics included in a typical first-year chemistry syllabus in South Africa. It was also structured to capture conceptual understanding rather than recall or application of practiced procedures.[9,10] To this end, *conceptual items* were chosen which test a student's understanding of chemical ideas associated with each question, rather than *algorithmic questions* that can be answered by applying a set procedure to generate a response.[9] Since proficiency in chemistry also requires the development of a range of skills, several items were included for skills assessment. These skills include the ability to interpret scientific terminology, representational competence i.e. the ability to interpret symbolic, macroscopic and submicroscopic representations[11,12] and basic mathematical skills.[13,14] The best items for assessment of mathematical skills are those that can be answered without the use of a calculator, rather than items requiring complex computations (see ref. 14 for a similar strategy).

The CCT instrument was piloted and refined over a number of years (2003–2005)[8,15], and has been used in an unmodified form since that time.[16] The instrument includes test items on 11 different topics: five basic concepts topics, four specialist topics and two sets of items for the assessment of mathematical skills and other skills that are required for chemistry. The majority of the 65 test items that are included in the instrument were obtained from sources in the literature. Sixty items are in multiple-choice format and the remainder require self-constructed responses which are subsequently coded by the researchers. Baseline data were collected at the Universities of Pretoria, UP, and Cape Town, UCT, in 2005 and 2007 and used as a reference point for the current study. Five institutions were involved in data collection in 2009 (UP, UCT, University of Stellenbosch, Rhodes University and Walter Sisulu University) which contributed a total of 2580 student records to the data bank for 2009. In this paper we report on the findings for UP and UCT only. The availability of data collected over a five-year period for these two institutions enabled us to compare the performance of two different education systems in terms of preparing students for tertiary chemistry studies.

3. Aim of the Study

The aim of this study was to evaluate any significant shifts in the level of preparedness for first-year chemistry between 2005 and 2009 so that teaching at tertiary level can respond in a meaningful way to the changes that are detected. We wanted to answer the following questions:

- How does the level of preparedness for tertiary chemistry studies of the 2008 matric cohort compare with that of cohorts who completed matric before the introduction of the new National Curriculum Statement?
- How do the new NSC achievement ratings scales (1–7) compare with performance symbols awarded previously in terms of calibrating preparedness for tertiary chemistry?

4. Methodology

4.1 Sample

In order to obtain a clear picture of the contribution of the FET phase of education towards preparedness of students for tertiary chemistry, students who sat for international school-leaving examinations, those repeating first year chemistry courses and those matriculating before 2008 were excluded from this study. The CCT instrument was used to collect data at the beginning of the year during the first week of instruction for two cohorts of first-year mainstream students at UP and UCT, respectively. These cohorts are BSc students at UP who have enrolled for the first semester General Chemistry module, CMY 117, and students in the BSc and Chemical Engineering programmes at UCT who have enrolled for CEM1000W, the first year General Chemistry course offered at that institution.

4.2 Rasch Analysis

The Rasch measurement model[17] was chosen for statistical analysis of data because it enhances the quality of the project at various levels. It elevates test design to a level of sophistication that is not possible when using raw scores only. The rigour of analysis is increased and the assumption of linearity is met – an assumption often ignored in the analysis of educational data.[18] This method generates *linear* item measures to reflect the relative difficulty of test items and *linear* person measures relating to the ability a person exhibits on a particular construct, in this case proficiency in chemistry. These measures are a more accurate

Table 1 Comparison of performance results over time for UP CMY 117 cohorts.

Comparison CMY 117 results: 2005–2009		UP Mainstream (CMY 117)						Change *	CMY 117 Subset **	
		2005 N = 518		2007 N = 580		2009 N = 828			2009 N = 576	
Topic (Subset)	n (items)	Performance /average %	Std Error	Performance /average %	Std Error	Performance /average %	Std Error	Performance /%	Performance /average %	Std Error
Basic concepts										
Atoms & Ions	8	65.8	8.7	69.9	8.0	54.8	9.3	–19.2	58.5	9.6
Mole Concept	6	52.4	10.1	47.2	10.3	40.2	8.0	–19.3	42.8	8.6
Phases of Matter	8	56.8	6.2	59.4	7.1	52.4	6.0	–9.8	55.9	6.1
Solutions	6	51.7	9.1	52.6	8.6	46.0	8.4	–11.8	47.8	9.4
Reactions	8	35.8	7.6	39.8	6.7	28.3	5.5	–25.1	30.5	5.8
Special topics										
Acids & Bases	6	65.6	6.2	69.4	8.1	33.0	4.8	–51.1	34.5	5.3
Chemical Equilibrium	6	53.5	8.0	55.8	7.3	50.4	7.8	–7.8	54.3	7.6
Electrochemistry	5	39.6	6.4	42.6	7.9	36.1	7.8	–12.2	39.1	8.0
Organic Chemistry	6	58.0	8.1	57.0	8.6	53.9	10.8	–6.3	58.8	11.1
Process skills										
Skills (Maths)	10	51.8	8.2	51.4	7.3	42.2	7.1	–18.2	45.2	7.5
Skills (Other)	6	46.1	8.5	51.9	10.4	37.0	9.3	–24.5	39.2	9.3

* Percentage change between 2009 and the average of 2005/2007 performance on each topic.
** Subset of students with minimum performance in NSC 2008 for Mathematics (70 %) and Physical Science (60 %).

indication of item difficulty and person performance, respectively, than traditional raw score results. The Rasch model also allows for equating of test data between different versions of the same test as it evolves over a period of time.[17] Comparison of results collected over many years, even if the instrument is subsequently modified, is therefore possible. Also, item difficulties can be anchored to predetermined baseline measures against which shifts in performance can be measured accurately in later years. The Rasch model is, therefore, ideally suited to the objectives of this study.

5. Results and Discussion

In this section we present the performance on the CCT based on raw score data as well as data transformed according to the Rasch measurement model for both UP and UCT. A selection of findings from the Umalusi Maintaining Standards Report[3] published in 2009 is included to assist interpretation of the trends that emerged from these results. The last part of this section deals with the comparison of the different performance rating scales used by NSC and NATED 550 in terms of their calibration of preparedness for tertiary chemistry.

5.1. Analysis of Raw Score Data from the Chemical Competence Test

Performance results based on raw score data collected in 2005, 2007 and 2009 are reported for the UP and UCT cohorts in Tables 1 and 2, respectively. The performance data are the averages of correct answers given to test items in each topic. The standard errors associated with average performance values are typically large since the test was designed to cover a wide range of difficulties in each topic. Performance results for UP mainstream students on all topics included in the CCT instrument were remarkably stable between 2005 and 2007 (Table 1).

The data show that average performance on any of the topics did not deviate more than the standard errors associated with the measurement during period 2005–2007. The poor performance on the topics Reactions and Electrochemistry that was recorded in 2005 was repeated in 2007. By comparison, the 2009 data show a decline in proficiency (conceptual knowledge and understanding) in all topics, and significantly reduced skills development. This decline is quite dramatic for Acids and Bases, but also more than the standard errors for the two Skills topics and basic concepts topics such as Atoms & Ions, Mole Concept and Reactions. The findings for the subset of students shown in the columns, CMY 117 subset, will be discussed later.

Performance results for the UCT cohort as reported in Table 2 show the same general trends as those for the UP students except for larger differences observed between 2005 and 2007 results. Owing to logistical problems, the percentage of chemical engineering students for the 2007 sample was lower than for 2005 and 2009. Changes in performance reported in Table 2 are therefore expressed relative to 2005 data alone rather than relative to the average of the 2005 and 2007 data as in the case of UP. In general, performance on all topics declined sharply in 2009, but it is most marked for Acids and Bases. A small gain in the 2009 performance on Organic Chemistry at UCT is observed which corresponds to the fact that this topic was the one that showed the smallest decline in performance at UP in 2009.

There is a clear correlation between the results reported in Tables 1 and 2 and differences between the syllabus for Physical Science as formulated in the new National Curriculum Statement, NCS,[2] and the syllabus for Physical Science in the former National Education (NATED 550) curriculum. The sharp decline in proficiency in acid-base chemistry can be attributed to the fact that this topic has been moved to earlier years in the FET phase and was not examinable in the final NSC examination in 2008. It is quite possible that teachers skipped this topic to make space in an overcrowded syllabus or touched on it only briefly in Grade 10 or 11. The small performance gain at UCT and small decline at UP in Organic Chemistry reflects the fact that the coverage of this topic in the new NCS has been increased significantly.

The overall decline in performance in the CCT from 2005 to 2009 as reflected by the results shown in Tables 1 and 2 may be attributed to multiple factors of which two will be considered in this article: the mismatch of Grade 12 achievement rating scales between the NSC and the previous system which gave more weak students access to mainstream chemistry than would have been the case before 2009 and the inclusion of new content material which resulted in an overcrowded syllabus for Grade 12. Information on the contribution of both of these factors was obtained from recent Umalusi reports.[3–5] The results

Table 2 Comparison of performance results over time for UCT CEM1000W cohorts.

Comparison CEM1000W results: 2005–2009		UCT Mainstream (CEM1000W)						Change *
		2005 N = 258		2007 N = 180		2009 N = 315		
Topic (Subset)	*n* (items)	Performance /average %	Std Error	Performance /average %	Std Error	Performance /average %	Std Error	Performance/%
Basic concepts								
Atoms & Ions	8	68.1	7.4	58.9	8.3	60.1	7.3	–11.7
Mole Concept	6	58.8	11.2	49.5	10.2	44.6	9.9	–24.1
Phases of Matter	8	65.2	5.9	59.2	6.4	50.7	5.5	–22.2
Solutions	6	56.6	10.0	53.5	9.0	45.3	7.4	–20.0
Reactions	8	41.4	6.1	39.2	7.6	28.3	4.2	–31.6
Special topics								
Acids & Bases	6	58.7	6.8	63.5	5.7	27.6	2.2	–53.0
Chemical Equilibrium	6	51.4	8.9	50.0	8.5	43.0	10.0	–16.3
Electrochemistry	5	44.0	8.7	45.0	7.7	40.6	9.0	–7.7
Organic Chemistry	6	53.3	8.7	55.1	8.4	56.1	11.4	5.3
Process skills								
Skills (Maths)	10	60.0	7.3	49.0	8.0	45.4	6.7	–24.3
Skills (Other)	6	53.3	8.8	46.0	9.6	40.2	9.4	–24.6

* Percentage change between 2009 and 2005 performance on each topic.

of Rasch analysis of our data provided further information on the contribution of the first factor, i.e. the mismatch between achievement scales.

5.2. Rasch Analysis of Raw Score Data

The first research question for this study deals with the level of preparedness for tertiary chemistry studies of the 2008 matric cohort compared with that of cohorts who completed matric before the introduction of the new National Curriculum Statement. In order to answer this question in a rigorous manner raw score data were transformed to linear measures according to the Rasch measurement model to allow direct comparison of data collected in 2005 and 2009. The combined 2005 sample of mainstream students at UP and UCT ($N = 776$) was used to determine item difficulties, called item measures. These item measures were used as reference to anchor the data collected for the two cohorts in 2009 ($N = 1143$) to allow accurate measurement of the magnitude of the shift in preparedness observed in 2009 relative to that of 2005 (Fig. 1). The zero marker for person measures on the *x*-axis of Fig. 1 is a rough indication of the performance level that was required in 2005 at UP and UCT for passing first-year chemistry. The mean person measure for the 2005 data set is +0.26 logits, which indicates that the majority of students were adequately prepared to pass first-year chemistry. In 2009, however, the mean person measure has shifted to –0.25 logits, which indicates that a much larger proportion of students may be at risk of failing under similar conditions of teaching and learning as in 2005. According to the Rasch model the meaning of this difference of *ca.* 0.5 logits between mean person measures for 2005 and 2009 is interpreted as follows: In 2005 the average CCT respondent would have a 50 % probability of answering items with difficulty 0.26 logits correctly, whereas the average CCT respondent in 2009 would have a 38 % probability of answering the same items correctly. This means that on average

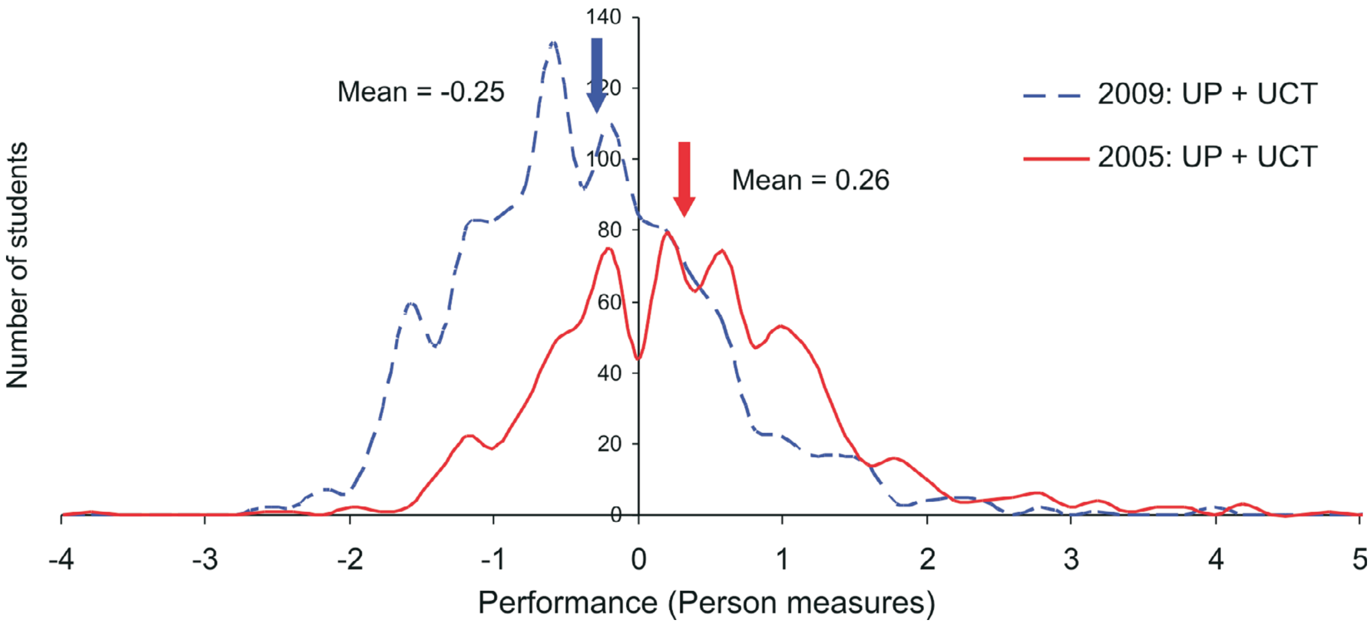

Figure 1 Performance distributions for the combined UP and UCT mainstream chemistry students on the CCT in 2005 and 2009

a decrease of 12 percentage points in the preparedness of students for tertiary chemistry occurred in 2009 compared with the findings in 2005. Students are therefore significantly less prepared in terms of knowledge and conceptual understanding of basic chemistry concepts and in terms of the mathematical, representational and scientific language skills required for first-year chemistry. These findings have important implications for teaching, as well as for selection and placement, at all tertiary institutions in South Africa.

5.3. Umalusi Maintaining Standards Report

In 2001 the South African government established the statutory body, Umalusi, for quality assurance of general and further education and training. Umalusi commissioned a research project to set and maintain standards of the new NSC examinations in relation to the standard of the previous Senior Certificate examinations. Specialist task teams were appointed by Umalusi to perform in-depth evaluations for the period 2005–2008, of intended curricula and final examination papers as well as the NSC exemplar papers supplied for six subjects, including Mathematics and Physical Science. This allowed comparison of the NSC examinations with those of the previous dispensation.[3] The Umalusi investigations were completed in June 2009 and their findings were communicated by means of reports and workshops.[4,5] Extracts of the findings of the task teams for Mathematics and Physical Science are given below:

Physical Science

- Content depth: The cognitive demand of the new curriculum (NCS) falls between the old higher grade (HG) and standard grade (SG) curricula.
- Content breadth: The NSC for the FET phase exceeds the previous HG curricula by an estimated 30 % in terms of required teaching time. In addition to covering about 80 % of the topics in the old curriculum the NCS contains many new topics, such as chemical systems, semiconductors and biopolymers.
- Examination guidelines issued by the Department of Education in 2008 and 2009 specified only about 44 % of the FET syllabi as examinable for the 2008 NSC examination. However, the estimated teaching time required for examinable material in 2008 still exceeds that of examinable material in the former HG syllabi by an estimated 11 %. This has serious implications for pacing; topics are likely to be covered in a rush, or in a superficial manner.
- The demand of the NSC final exam paper does not compare favourably with a combination of the former HG and SG exam papers. Instead, it corresponds closely to that of the previous Physical Science HG papers.
- A learner who attained an A (over 80 %) on the former Physical Science HG exams would have attained a rating of 7 (over 80 %) for Physical Science on the NSC 2008.

Mathematics

- In terms of cognitive demand the new NSC curriculum for Mathematics falls between those of the former Mathematics standard grade and higher grade.
- The NSC examination was on par with former Mathematics SG, therefore significantly lower than Mathematics HG. The 2008 NSC Mathematics papers would not discriminate between the high achievers since the paper included only 22 % of conceptually demanding questions rather than the 40 % recommended in the Subject Assessment Guidelines (Umalusi report, 2009, p. 8)
- A learner who attained an *A, B and perhaps high C* on the former Mathematics HG examinations would now achieve a rating of 7 for Mathematics on the NSC 2008.
- Concern is raised about the lack of challenge at the top end of the rating scale and therefore the lack of discrimination between more able candidates.

To summarize, the intention of pitching the cognitive demand of both the NSC curricula and examinations for Mathematics and Physical Science between that of the former HG and SG levels for these subjects was only realized in terms of the content depth of curricula. The syllabus for Physical Science suffers from content overload and the 2008 examinations for both Mathematics and Physical Science did not match the recommendations of the Subject Assessment Guidelines with Mathematics being too 'easy' and Physical Science too 'difficult'.

5.4. Comparison of Achievement Rating Scales for Mathematics and Physical Science (2005–2009)

Because of the apparent correspondence between the achievement rating categories used in the new NSC and NATED 550 it may be assumed that a direct comparison would be possible, e.g. a rating of 7 on the new scale would be equivalent to a Higher Grade A since it also represents an achievement of 80 % and above. Many universities therefore did not adjust their admission requirements for students registering for the first time in 2009 but simply converted them to the new rating scale. For example, at UP the minimum requirements for admission to BSc Chemistry in 2008 was a C (60–69 %) for Mathematics HG and a D (50–59 %) for Physical Science HG and in 2009 it was changed to a rating of 5 (60–69 %) for Mathematics and 4 (50–59 %) for Physical Science. The CCT provides a way to test the comparability of the different rating scales with respect to preparedness for tertiary chemistry, thereby answering the second research question for this study. An analysis of CCT performance relative to Grade 12 performance in Mathematics and Physical Science was performed for UP cohorts of mainstream BSc students enrolled for CMY 117 and the results are reported below. The sample selection of only UP chemistry students was based on convenience, the relative size of this subset of records and on the fact that these students represent the majority of students included in this study.

5.4.1. *Performance on the CCT according to Grade 12 Mathematics Performance*

The 2005 and 2009 samples of CMY 117 students were divided into subgroups according to their performance in Grade 12 Mathematics HG in 2004 (or earlier) and Grade 12 Mathematics in 2008, respectively. The average performance on our CCT as reflected by person measures was then determined for students in each of these subgroups. The results of this analysis are shown in Fig. 2. A separate bar is drawn for each subgroup and mapped onto the person measures obtained for the CMY 117 cohort in 2005. Each bar depicts the mean value and one standard deviation for performance in terms of person measures.

Figure 2 clearly demonstrates that there is a mismatch between Grade 12 rating scales for Mathematics performance in 2004 and 2008 as measured by the CCT instrument. The mean performance value for a rating of 7 in 2008 is lower than the means for Mathematics HG A and B symbols and marginally higher than that of a HG C symbol in 2004. It should be noted that the mean of a rating of 6 attained for Mathematics in 2008 is lower than that of a HG D symbol in 2004 in terms of performance on the CCT. This means that at the University of Pretoria the current first-year students with a rating of 6 for Grade 12 Mathematics

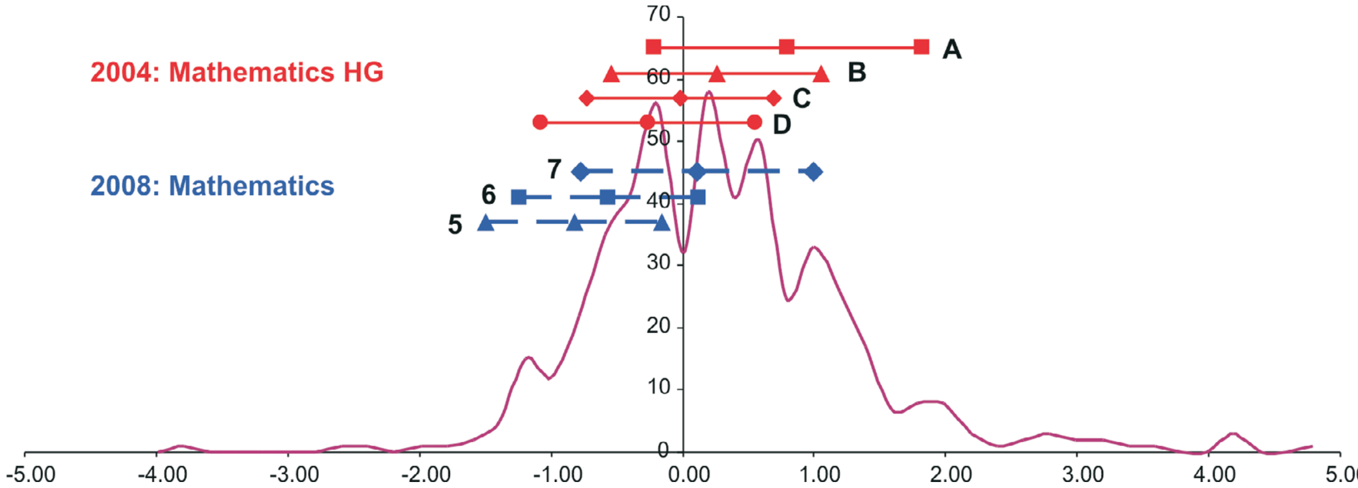

Figure 2 Person measures of the UP mainstream chemistry students on the CCT in 2005 and 2009 according to prior performance in Mathematics

are less well prepared for chemistry than students with a D symbol for Mathematics HG were when they entered university in 2005.

Using the Student Pre-semester Assessment (SPSA) test,[14] it was shown that both mathematics and chemistry background were useful in predicting success in first year chemistry courses in the USA. In South Africa performance in Grade 12 Mathematics is an important criterion for selection into undergraduate science and engineering programmes at all South African universities. The influence of this mismatch between rating scales, which was not anticipated and provided for in admission requirements at the University of Pretoria, can be seen in the difference between the compositions of CMY 117 cohorts in 2005 and 2009 (Table 3).

Table 3 Composition of CMY 117 cohorts at UP according to Grade 12 performance in Mathematics.

	2005		2009	
Achievement level	Grade 12 Mathematics	% of cohort	Grade 12 Mathematics	% of cohort
80–100 %	HG A	19	7	54
70–79 %	HG B	16	6	31
60–69 %	HG C	26	5	13
50–59 %	HG D	24	4	2

5.4.2. *Performance on the CCT according to Grade 12 Performance in Physical Science*

A similar exercise was carried out to compare the rating scales for Grade 12 Physical Science between 2004 and 2008 with the person measures from the CCT instrument. These results are shown in Fig. 3. The mismatch of rating scales for Physical Science was not as great as for Mathematics in terms of indicating preparedness for tertiary chemistry. There is a close correspondence between the performance means of a HG A symbol in 2004 and a rating of 7 in 2008, but lower categories are less well aligned. A rating of 6 for Grade 12 Physical Science in 2008 compares with both the former HG B and C symbols in 2004, and a rating of 5 for Physical Science in 2008 is similar to a HG D in 2004.

In general, the comparison of the CCT results with the rating scales in NATED 550 HG and the 2008 NSC papers are in good agreement with the conclusions reached by the Umalusi specialist task groups for the A grades namely: A 7 rating for Mathematics in the NSC examination represents the level of Mathematics HG A, B and high C in NATED 550 and a rating of 7 for Physical Science in the NSC exams is comparable to the level of Physical Science HG A in NATED 550. The Umalusi task teams did not give an indication of the match of lower grades for any subjects but this information is available from our study: A 6 rating for Mathematics in the NSC examination is lower than

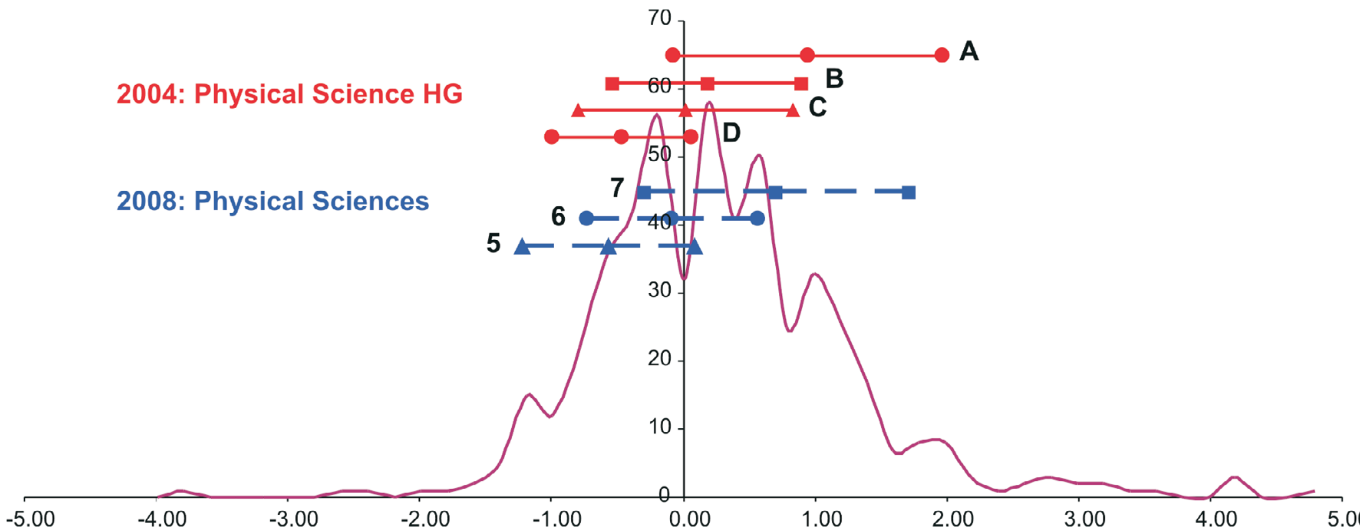

Figure 3 Person measures of the UP mainstream chemistry students on the CCT in 2005 and 2009 according to prior performance in Physical Science

the level of Mathematics HG D in NATED 550, a rating of 6 for Physical Science in the NSC exams corresponds to the level of Physical Science HG B and C in NATED 550, and a rating of 5 corresponds to the former HG D for Physical Science.

5.5. Relative Contribution of Factors to Weaker Performance

Table 3 shows that only 35 % of the 2005 UP cohort attained A or B symbols for Mathematics HG in Grade 12, compared with 85 % of the 2009 cohort. The remaining 15 % of the 2009 cohort would not have qualified for admission in 2005, because they would not have met the minimum requirements for admission, i.e. 50 % for both Mathematics HG and Physical Science HG. To what extent can the poorer performance of the 2009 cohort on the CCT instrument be ascribed to the admission of these under-prepared students? This question is explored below.

A selection was made of only CMY 117 students who completed matric in 2008 with a minimum of 70 % (6 rating) for Mathematics and a minimum of 60 % (5 rating) for Physical Science. The raw score performance of this subset ($N = 576$) is reported in Table 1. These results show that performance on the topics that were explicitly taught and assessed in Grade 12 (Chemical Equilibrium, Electrochemistry and Organic Chemistry) and Phases of Matter is directly comparable to that recorded for the 2005 cohort, but performance on all other topics declined. From an analysis of the response frequencies for this 2009 subset we concluded that command of basic concepts such as acids and bases and the mole concept, as well as skills development (representational competence, logical reasoning, interpretation of scientific terminology, mathematical skills) are considerably weaker than that of the comparable group in 2005, with acids and bases showing the most serious decline. This decline in competence most likely reflects deficiencies endemic to earlier years in the FET phase which could not be corrected in Grade 12. It also raises the concern that the challenge of teaching an overcrowded syllabus may have resulted in omission of important topics, e.g. acids and bases, and may have encouraged memorization at the cost of conceptual understanding and skills development.

6. Implications

The trends reported here are likely to have a major impact on tertiary science and engineering education in South Africa. The implications for both selection and placement and teaching are numerous.

6.1. Selection and Placement

Most tertiary institutions did not anticipate the mismatch between rating scales and did not increase their admission requirements accordingly. As a result a number of students were admitted to mainstream programmes who would not have qualified previously and who are not adequately prepared to succeed. Tertiary educators may be faced with a choice between the lowering of standards of first courses in chemistry, accepting unacceptable failure rates as the norm or adapting their teaching. Zaaiman *et al.*[19] have argued that selection into a programme is a contract to teach at that level. According to this argument, tertiary educators are now obliged to offer substantial additional support to assist under-prepared students. However, that would inevitably happen at a cost, both in terms of staff overload and a negative impact on research output. Due to the weak performance of the 2009 intake of students in the sciences many tertiary institutions have since adjusted their admission requirements upward, but these changes will only take effect in 2011. In the meantime the implementation of transfer mechanisms to reroute students from mainstream to academic development programmes during the first semester may partially address the problem in 2010.

6.2. Teaching

Tertiary educators need to be informed about students' existing level of knowledge, conceptual understanding and skills development so that they can adjust their teaching models, i.e. their offering of teaching and learning opportunities, in an appropriate way to take these into account. This basic truth was captured by David Ausubel[20] in his well known axiom of learning:

> 'The most important single factor influencing learning is what the learner knows. Ascertain this and teach accordingly.' (Ref. 20, p. iv)

There are several areas of concern arising from the results reported in this paper. A detailed analysis of student performance in individual topics and student responses to specific test items is beyond the scope of this paper and will be treated in a follow up article. However, the *main deficiencies* as shown by poor performance in the CCT are described below:

- The fact that acid-base chemistry is no longer examined and may therefore no longer be taught in depth is a source of concern. Apart from its practical relevance to everyday life, it is a fundamental concept not only for chemistry but for the biological sciences as well.
- Stoichiometry is another fundamental concept that is poorly mastered. Together with the Mole Concept it underpins many other topics in basic chemistry, such as Chemical Equilibrium and Chemical Reactions.
- The inability to handle numbers with exponents is a concern since this is the format of scientific notation. It will impact on students' ability to handle Avogadro's number and Planck's constant, to calculate pH and equilibrium concentration or to apply the Nernst equation.
- The inability to carry out unit conversions will negatively affect the solving of quantitative problems in topics such as Gas Laws, Solution Chemistry and Stoichiometry.

7. Conclusions

The current uncertainty in the FET phase of secondary education in terms of curriculum content and level of assessment in key subjects such as Mathematics and Physical Science has a serious impact on tertiary institutions. The fluctuation in the value of rating scales in calibrating preparedness for tertiary studies is expected to continue for a few years. This will complicate selection and placement and will challenge lecturers to be flexible and responsive to the varying needs of their students. Not only should first-year chemistry lecturers familiarize themselves thoroughly with the content of the new curricula for these subjects; they would do well to consider designing short diagnostic tests to assess baseline understanding before embarking on the teaching of new content topics. Lecturers would also have to adjust assessment practices to initiate students into the higher cognitive demand of assessment at tertiary level. However, for the purposes of quality assurance it is of vital importance that flexibility at entry level be associated with rigidity at exit level to ensure that tertiary institutions deliver on their function of the certification of competence.

Acknowledgements

The authors wish to thank Elsie Venter of the Centre for Evaluation and Assessment, University of Pretoria, for statistical processing of data, Kate le Roux, Numeracy Centre, University of Cape Town, and Rene Toerien, Centre for Research in Engineering Education at University of Cape Town for helpful comments on this paper. This material is based upon work supported financially by the National Research Foundation. Any opinion, findings or recommendations expressed in this material are those of the authors and therefore the NRF does not accept any liability in regard thereto.

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