SCIENCE CURRICULUM PROJECT

PROGRESS OF STUDENTS THROUGH THE SCIENCE CURRICULUM: A FOCUS ON MATTER (CHEMISTRY)

STAGE 4, PRE-GRADE 10 REPORT

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EXECUTIVE SUMMARY

This research is designed to examine the implementation of the spiral curriculum structure introduced in the Philippines as part of the K to 12 curriculum reform. The curriculum emphasises the understanding and application of scientific knowledge, the learning of scientific inquiry skills, and the development and demonstration of scientific attitudes and beliefs. The spiral curriculum was initiated with Grade 7 implementation in School Year (SY) 2012/13. By the end of SY 2015/16, this cohort of students will be the first to have completed the full 7–10 new curriculum.

Due to the recency of the reform, the influence of its characteristics and design on outcomes is not yet known. Important questions remain unanswered. How is the curriculum implemented by teachers? Does the teacher's specialisation influence student outcomes? How do other factors such as teacher training, experience, student access to materials, and school size influence student outcomes? How do the students' skills progress as they complete the curriculum? Is spiralling handled differently across year levels?

This research is designed to investigate the progress of students' conceptual knowledge and skills for each unit of Chemistry ("Matter") over the four years of the junior secondary curriculum. Identification of progress is achieved by assessing students in Grades 7–10. Data representing factors presumed to influence student learning outcomes include teacher information, lesson plans, and classroom observations of selected classes.

This report covers the data obtained in order to address the research question:

Do students enter Grade 10 with the level of conceptual knowledge and skills they need in order to engage with the Grade 10 science (chemistry) curriculum?

The report includes analysis of data obtained from a pre-Grade 10 test on chemistry-related skills. The pre-Grade 10 test was developed to assess whether students are appropriately prepared to access the new curriculum. Students were tested in March 2016, before beginning the chemistry unit "Matter," which is taught to Grade 10 students during the third quarter of the school year. The student results indicate that the sample assessed was distributed normally across the test. Although this demonstrates that the test itself is well-targeted for the population, the results also indicate that a sizeable proportion of students entering Grade 10 is not well prepared to engage with the conceptual knowledge and skills required by the Grade 10 chemistry curriculum. A larger proportion of students attending science-oriented high schools is well prepared for Grade 10 entry. Details of the knowledge and skills best and least well demonstrated by the students are provided in the report.

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PROJECT INTRODUCTION

Note: This is the same information provided in the reports for Stages 1, 2 & 3 (pre-Grades 7, 8 & 9)

In 2011, the Philippine Department of Education (DepEd) initiated a basic education reform. This reform is known as the K to 12 program. This program covers Kindergarten and 12 years of basic education: six years of Primary School, four years of Junior High School, and two years of Senior High School. The rationale for this reform is to provide sufficient time for mastery of concepts and skills, to develop lifelong learners, and to prepare graduates for tertiary education, middle-level skills development, employment, and entrepreneurship.

In the K to 12 program, a new curriculum for science has been implemented in schools across the country. Through implementation of this curriculum, the aim is to develop scientific literacy among students such that they are able to make judgments and decisions on the applications of scientific knowledge that may have significant impact in everyday life (DepEd, 2013). The new curriculum is designed according to the three domains of learning science: (1) understanding and applying scientific knowledge; (2) performing scientific processes and skills; and (3) developing and demonstrating scientific attitudes and values.

The new curriculum includes statements outlining the progression of science inquiry skills and expectations of the rate at which students will develop these skills, addressing some of the recommendations resulting from a comparison of the Philippines curriculum with those of three other countries (Care & Griffin, 2011). Concepts and skills are presented with increasing levels of complexity from one grade level to another in spiral progression to develop a deeper understanding of core concepts.

DepEd implemented the new curriculum for Grades 1 and 7 (the 2nd year of Elementary School and 1st year of Junior High School, respectively) in public schools during SY 2012-2013 and it is being progressively introduced in other grade levels. In SY 2014-2015, it was implemented in Grades 3, 7, 8, and 9 respectively. In SY 2015-2016, the new curriculum for Grades 4 and 10 is being implemented in all public elementary and secondary schools.

This research project was designed to investigate how students' knowledge of science content and their inquiry skills develop through the spiral curriculum. Determining what students know and can do at various stages is a process that can be used to inform subsequent teaching and assist with future reviews of the science curriculum domains and learner modules. The over-arching goals for the study are outlined below. This report addresses the first goal, with a focus on students entering Grade 10.

1. *investigate the progress of students' knowledge and skills as they complete the spiral science curriculum, with emphasis on whether students have developed the prerequisite knowledge for the next year of study*
2. determine the level of conceptual knowledge and skills students have developed before they enter junior high school
3. determine the level of conceptual knowledge and skills achieved after four years of the spiralling curriculum
4. assess the effect of factors such as previous teacher specialisation, teacher training, experience, student access to materials, school size and school specialisation, on student achievement and curriculum implementation

5. investigate extent to which teachers are implementing science inquiry teaching practices in the Grade 10 Chemistry classroom, where science inquiry is specifically outlined as a content component
6. determine the relationship between teachers' implementation of science inquiry practices and students achievement of science inquiry skills.

PROJECT METHOD

PROJECT PARTICIPANTS

DepEd regular high schools and science-oriented high schools from the National Capital Region (NCR) are targeted in this study, as well as high schools in Regions VI and VII. The science-oriented high schools are of particular interest, in view of the presumption that teachers at these schools might have more expertise in the teaching of science and might therefore implement the curriculum somewhat differently to teachers within the mainstream. NCR is selected because of its relatively large population and consequent role as education provider for a relatively large number of students with elementary and secondary education. Regions VI and VII (Western and Central Visayas) are selected because of their inclusion within the BEST initiative.

Development phase

As part of the development of the assessment tools for the project, approximately 200 students enrolled in 2-4 schools in the Metro Manila region take each grade-level test (for Grades 7, 8, 9 and 10) to provide item level data to contribute to the test development. Each grade-level test development activity comprises:

a. Curriculum audit: analysis and identification of major themes/skills for analysis
b. Drafting of items
c. Item review and selection of items for pilot test form
d. Administration of items to pilot participants
e. Analysis of pilot quantitative data
f. Finalisation of grade level test.

Research phase cycles

For the research each year, 16 schools are recruited: four in each of Region VI (Western Visayas), Region VII (Central Visayas), NCR, and NCR Science-oriented High Schools. Three sections within each school are selected for participation. The main activity in each school comprises student assessment. In some schools, classroom observations are to be undertaken across sections. This provides the opportunity to identify the degree of alignment between planned and implemented curriculum and in addition examine the possibility that delivery of the curriculum varies across sections.

PROJECT RESEARCH DESIGN

For the main study, students are tested directly *before* completion of each unit of Chemistry. The rationale for this approach is a focus on depth of student learning, as opposed to knowledge acquisition or surface learning. The approach provides an indication of the skill-level of students prior to each relevant quarter, including the level of skill retained from the previous relevant quarter. The skill-level is indicative of the knowledge, skills, and understanding retained long-term from previous units of the subject and other sources.

The dependent variable throughout the phases of the study is student outcomes, as measured through tests of chemistry knowledge and skills developed in alignment with the curriculum. Independent variables to explore include (variably across phases) chemistry content delivered, teacher, teacher training, science specialisation, access to materials, class size, and school type. Confounding variables include homogeneous/heterogeneous student grouping, socio-economic status (SES), language background, and metro/regional/rural location.

Student assessment schedule

The phases of the study are scheduled in order to assess each grade level as it begins the Chemistry quarter, within the shortest amount of time possible in order to expedite feedback of results to DepEd.

Pre7	Jun 2015 before Unit 1, Grade 7 Chemistry (SY2015/2016)
Post7	Grade 7 sub-study end of QTR 1 (SY 2015/16)
Pre8	Nov 2015 before Unit 3, Grade 8 Chemistry (2015/2016)
Pre9	Aug 2016 before Unit 2, Grade 9 Chemistry (2016/2017 school year)
Pre10	Jan 2016 before Unit 4, Grade 10 Chemistry (2015/2016 school year)
Post10	Mar 2016 after Unit 4, Grade 10 Chemistry (2015/2016 school year)

PROJECT INSTRUMENTS

For Students

Tests are developed to assess student learning. Five linked tests are developed in order to locate students on the same scale across the grade levels of interest in the study. The tests of approximately 50 items are linked by sets of common items. The use of common items enables the comparison of student acquisition of skills and knowledge across different grade levels. The process of test development includes initial curriculum mapping and development of a test blueprint, item development, item review and selection for a pilot study, analysis of pilot data, and selection of items for the final test form.

The set of chemistry tests for the curriculum study is designed to cover the concept domain (Matter), strands (Properties, Structure and Changes, Inquiry Skills) and sub-strands (see Figure 1). Each strand is not covered in the same proportion across the five tests. This is a consequence of the curriculum design, which the tests reflect. The set of tests for the full study includes:

1. Pre-Grade 7 (Base-Line or Entry Level)
2. Pre-Grade 8
3. Pre-Grade 9
4. Pre-Grade 10
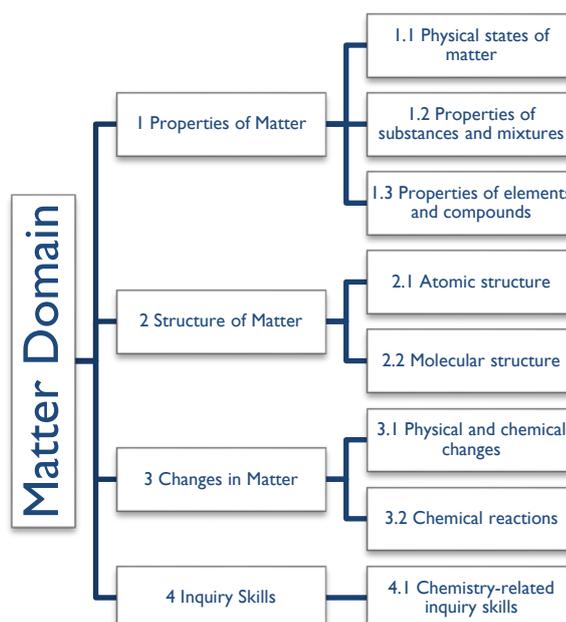5. Post-Grade 10 (Final)

Figure 1. Matter test domain structure

PROJECT PROCEDURES

The main procedures are:

- liaising with DepEd Central and in NCR, Regions VI and VII for the purposes of recruitment
- recruitment within the NCR for the purposes of piloting tests
- fieldwork associated with research data collection from students and schools
- analysis and reporting.

PROJECT DATA ANALYSIS

Student data are collected via pencil and paper tests, with student responses provided on scannable forms. Completed forms are then scanned, and raw data cleaned prior to analysis. All tests are developed and scored on the basis of Item Response Theory. Test results are to be used primarily as an indication of student learning in research reports to be provided to DepEd. In addition, individual class results in aggregated form are provided to participating schools in order to supply teachers with relevant information about student learning levels, and hence the most appropriate levels for teaching and learning interventions. At no point in the study are any individual student scores or grades reported. For school use, student results across descriptive skill-levels are provided.

PROJECT INSTRUMENT DEVELOPMENT

The curriculum audit was conducted in a workshop in March 2015. Participants were six UP NISMED science education specialists, two UP Integrated School science faculty, one science education faculty of the UP College of Education, one ACTRC staff member, and ACTRC's Program Leader for Curriculum. The curriculum audit involved curriculum analysis and identification of concepts and skills for the Grade 7-10 science curriculum. To make the curriculum audit more efficient, two or three experts were grouped to work on each of the grade levels (Grades 7 to 10). The blueprint to structure the development of test items for each grade level was created using the audit information. This included the identification of concepts and skills students need to have in order to access a specific grade level chemistry curriculum.

The blueprint took into account the following questions:

- What strands run through the different grades?
- What is the most communicative terminology to use for these strands?
- What strands appear only at one grade or some grades?
- What is the relative importance of the categories/strands at each grade level?

To articulate the skills integral to each grade level of the curriculum, specific behaviours that a student could demonstrate were identified. Descriptions of behaviours that could be demonstrated in a pen and paper test were written for each statement. Where the same behaviours appear at multiple grade levels, these were noted at each relevant level. The behaviours were also classified as 'essential' or 'advantageous.'

After the two-day workshop on curriculum audit, another two-day workshop on item writing and review took place, focusing on guidelines for writing test items, multiple choice terminology, and multiple choice guidelines. Sample test items were provided. The experts drafted and panelled multiple-choice test

items. Following Day 1 of this workshop, the blueprint was revised. This involved six steps: (1) the domain (conceptual knowledge and skills), strands, and sub-strands were reviewed; (2) the distinction between essential and advantageous behaviours was elucidated, insofar as essential behaviours are those that a student needs to have achieved in order to engage with the demand of the (next) year level, while advantageous behaviours are not essential but enhance their progress; (3) capabilities (what we want students to be capable of) were reviewed (added, deleted, modified or moved); (4) indicative behaviours (those behaviours that allow test developers to infer whether students have the capability) were assigned to capabilities; (5) indicative behaviours were reviewed; and (6) indicative behaviours were linked to grade levels. Finally, numbered statements and behaviours were incorporated into the test blueprint.

Multiple-choice test format was selected as the most efficient method of assessing at large scale. The advantages of the format include student familiarity, ease of administration, and cost-effectiveness of scoring.

The item writing responsibilities were shared between team members located in Metro Manila and in Melbourne. All items were written to the test blueprint. Once each item was written and the skill identified, it underwent a panelling process to enhance item quality. Each item was panelled twice, by team members in each geographical location. This process drew on the expertise of all team members and ensured items adhered to guidelines for best practice in objective item writing and contained language and concepts that were Philippines appropriate.

STAGE 4 METHOD

This stage of the project focuses on the measurement of the understanding and skills of Grade 10 students as they begin the Matter topic in the 4th Quarter of the school year. The purpose of this measurement is to determine the readiness of the Grade 10 students for the Grade 10 Matter curriculum.

Table 1. Curriculum focus by quarter across grades

	G6	G7	G8	G9	G10
1st Quarter	Matter	Matter	Force, Motion & Energy	Living Things and Their Environment	Earth & Space
2nd Quarter	Living Things and Their Environment	Living Things and Their Environment	Earth & Space	Matter	Force, Motion & Energy
3rd Quarter	Force, Motion & Energy	Force, Motion & Energy	Matter	Earth & Space	Living Things and Their Environment
4th Quarter	Earth & Space	Earth & Space	Living Things and Their Environment	Force, Motion & Energy	Matter

The blueprint for the Pre-Grade 10 test is shown in Table 2. The blueprint includes the prerequisite concepts and skills considered necessary for students to engage in the Grade 10 Matter curriculum. This blueprint is the combination of the prerequisite concepts and skills determined by the expert panel in March 2015 and additional prerequisites added after the analysis of the Pre-Grade 9 test.

Table 2. Blueprint for pre-Grade 10 Matter test

Strand	Proportion of items	Prerequisite concepts and skills	Curriculum Links
			(learning competencies unless otherwise stated) *Source for curriculum links: K to 12 Curriculum: Science*
1.1 Physical states of matter	5%	• properties of elements - using periodic table • relates increased speed of atom to increased temperature • relates gas expansion to increase in molecular speed	(Gr8) Learners learn that particles are always in motion. They can now explain that the changes from solid to liquid, solid to gas, liquid to solid, and liquid to gas, involve changes in the motion of and relative distances between the particles, as well as the attraction between them.
1.2 Properties of substances and mixtures	0%		
1.3 Properties of elements and compounds	5%	• identifies (with access to periodic table) that elements with 'ine' suffix have similar properties • associates melting with increased kinetic energy of molecules	(Gr8) Learners learn that particles are always in motion. They can now explain that the changes from solid to liquid, solid to gas, liquid to solid, and liquid to gas, involve changes in the motion of and relative distances between the particles, as well as the attraction between them. (G7) Learners recognize that materials combine in various ways and through different processes, contributing to the wide variety of materials. Given this diversity, they recognize the importance of a classification system. They become familiar with elements and compounds, metals and non-metals, and acids and bases.
2.1 Atomic structure	16.7%	• identifies that like charges repel and unlike attract • recognizes elements that make up sugar • links charges to subsequent movement of particles • identifies electrons as smaller than protons, neutrons & atoms • recognizes that valence electrons form bonds • determines no. of electrons in atom given atomic no.	(Gr9) Learners describe how atoms can form units called molecules. They also learn about ions. Further, they explain how atoms form bonds (ionic and covalent) with other atoms by the transfer or sharing of electrons. They also learn that the forces holding metals together are caused by the attraction between flowing electrons and the positively charged metal ions. Learners explain how covalent bonding in carbon forms a wide variety of carbon compounds. Recognizing that matter consists of an extremely

		- recognizes that atoms are the smallest component of an element - applies size of charge to magnitude and direction of force	large number of very small particles, counting these particles is not practical. So, learners are introduced to the unit—mole. (G8) Using models, learners learn that matter is made up of particles, the smallest of which is the atom. These particles are too small to be seen through a microscope. The properties of materials that they have observed in earlier grades can now be explained by the type of particles involved and the attraction between these particles.
2.2 Molecular structure	41.7%	- compares masses given in molecules, moles and grams - associates positive ion formation with losing electron - identifies elements as metal/non-metal with access to periodic table - recognizes meaning of one mole of a molecule - compares masses of molecules given periodic table - classifies methane (CH_4) as a hydrocarbon given other classes of molecules - describes motion of atoms in a solid - recognizes components of CO_2 from descriptions containing words like 'atom' and 'molecule' - calculates molar mass of a compound (with subscripts) given periodic table - compares forces of attraction within solid and liquid - recognizes that ideal gas stops moving at 0K - compares properties of the Celsius and Kelvin scales - calculates the number of moles given mass and molar mass - recognizes outer electrons involved in bonding - determines no. of valence electrons in element given periodic table	(Gr9) Learners describe how atoms can form units called molecules. They also learn about ions. Further, they explain how atoms form bonds (ionic and covalent) with other atoms by the transfer or sharing of electrons. They also learn that the forces holding metals together are caused by the attraction between flowing electrons and the positively charged metal ions. Learners explain how covalent bonding in carbon forms a wide variety of carbon compounds. Recognizing that matter consists of an extremely large number of very small particles, counting these particles is not practical. So, learners are introduced to the unit—mole. Learners explain how new compounds are formed in terms of the rearrangement of particles. They also recognize that a wide variety of useful compounds may arise from such rearrangements.

		- recognizes that carbon is essential component of organic compounds - calculates mass of a number of moles of substance given molar mass - compares kinetic energy of particles within solid and gas - identifies hydrocarbons as molecules containing only hydrogen and carbon - applies meanings of words 'atom', 'element' and 'compound' - recognizes organic compound based on molecular formula - identifies formula of ionic compound with two subscripts	
3.1 Physical and chemical changes	5%	- links change from solid to liquid to particle speed and spacing - recognizes that matter is conserved during phase changes and reactions - recognizes changes at atomic level when a metal is hammered flat	(G9) Learners learn that the forces holding metals together are caused by the attraction between flowing electrons and the positively charged metal ions. (Gr8) Learners learn that particles are always in motion. They can now explain that the changes from solid to liquid, solid to gas, liquid to solid, and liquid to gas, involve changes in the motion of and relative distances between the particles, as well as the attraction between them. They also recognize that the same particles are involved when these changes occur. In effect, no new substances are formed.
3.2 Chemical reactions	26.7%	- identifies balanced chemical equation with coefficients and subscripts - classifies unknown chemical as compound based on description of changes when heated - associates covalent bonding with sharing electrons - recognizes type of bonding from elements involved (ionic) - identifies electron loss/gain in ion formation - recognizes carbon atoms form covalent bonds	(Gr9) Learners describe how atoms can form units called molecules. They also learn about ions. Further, they explain how atoms form bonds (ionic and covalent) with other atoms by the transfer or sharing of electrons. Learners explain how covalent bonding in carbon forms a wide variety of carbon compounds. Recognizing that matter consists of an extremely large number of very small particles, counting these particles is not practical. So, learners are introduced to the unit—mole. Learners explain how new compounds are formed in terms of the rearrangement of particles. They also recognize that a wide variety of useful compounds may arise from such rearrangements.

		- identifies correct prefix to balance chemical equation without brackets - recognizes nobel gases have low reactivity - matches chem equation to description in words using mole - interprets prefixes and suffixes in chem equation - relates chemical properties to no. of valence electrons - identifies elements with 'ine' suffix have similar properties (have access to periodic table too) - recognizes that covalent bonds are formed between non-metals - provides prefix to balance chem equation involving molecules with two subscripts	(G8) Use the periodic table to predict the chemical behaviour of an element. (S8MT-IIIi-j-12)*
4.1 Chemistry-related inquiry skills (note: many of these skills are assessed in the context of 1.1, 1.2 and 3.1	0%		

* Learning competency code in the K to 12 Basic Education Curriculum for Science

PRE-GRADE 10 PILOT SAMPLE

For the piloting of the pre-Grade 10 test, N = 266 Grade 10 students from two regular high schools in the Metro Manila region took the test in February 2016. The students in this convenience sample had completed Grade 9 Matter during the previous school year, but had not yet undertaken Grade 10 Matter. The purpose of the pilot was to evaluate the performance of each item and to obtain item characteristics in order to develop a psychometrically sound test. In other words, this process was undertaken for test development purposes.

Data from the pilot sample were analysed using the one-parameter simple logistic model (Rasch, 1960). The items were found to fit the model, showing that they measure the same construct and that the spread of the items was appropriate for the student sample. Test items were examined for item fit, discrimination, and difficulty.

From the results of the analysis, 60 items were identified for use in the final test. These items were selected on the basis of sound psychometric qualities and coverage as specified by the test blueprint. Table 3 shows the distribution of the items against the test blueprint and provides a sample of key concepts and skills tested.

Table 3. Pre-Grade 10 test contents

Strand	Number of items	Key concepts/skills
1.1 Physical states of matter	3	Properties of elements based on the Periodic Table of Elements; kinetic energy in relation to temperature increase and expansion
1.2 Properties of substances and mixtures	0	NA
1.3 Properties of elements and compounds	3	Properties of groups in the Periodic Table of Elements; kinetic energy of molecules in relation to melting
2.1 Atomic structure	10	Relative sizes of atoms and subatomic particles; charge interactions; use of the Periodic Table of Elements to determine number of subatomic particles
2.2 Molecular structure	25	Mole concept; molecular formulas; organic compounds
3.1 Physical and chemical changes	3	Conservation of mass in physical and chemical changes
3.2 Chemical reactions	16	Balancing equations; formation of ionic and covalent bonding; reactivity of elements based on the Periodic Table of Elements
4.1 Chemistry-related inquiry skills	0	NA
Total	60	

The test performed well. The spread of items matched the range of student abilities, providing a reliable tool for the measurement of student abilities. The person-separation reliability of the test was 0.811 (note, this index is comparable to alpha reliability and is well within the acceptable range.)

STAGE 4 RESEARCH

CHARACTERISTICS OF THE PRE-10 SAMPLE

Four schools in each of Regions VI and VII, and eight schools in NCR were recruited, providing a sample size of 16 schools (the NCR sample was distributed across regular high schools and science-oriented high schools). Twelve full classes from each of the regions were targeted. Schools were requested to provide classes distributed across sections, in order to ensure a heterogeneous sample. For the regular schools in each of the three regions, 1-3 teachers were selected to have their students assessed, providing a total of approximately 10 teachers for each region. The four science-oriented high schools provided one teacher per school. In total, N = 1649 Grade 10 students were assessed across 45 different classes, 34 different teachers, and 16 schools in three regions (Table 4).

Table 4. Test set-up for pre-Grade 10 research phase

Region	School Type	Schools	No. of Teachers	No. of Classes
Region VI	Regular	A	3	3
		B	3	3
		C	2	3
		D	2	3
Region VII	Regular	A	2	3
		B	3	3
		C	1	3
		D	2	3
NCR	Regular	A	3	3
		B	3	3
		C	3	3
		D	3	3
	Science-oriented	E	1	2
		F	1	2
		G	1	3
		H	1	2

The sample of students from these classes consisted of more females than males in both regular and science-oriented high schools, and this imbalance was more pronounced within Regions VI and VII. This is consistent with the proportions of students tested in the pre-Grade 8 and pre-Grade 9 samples, as reported in the Stage 2 and 3 reports. The specific numbers are provided in Table 5. Enrolment data shows a slightly higher proportion of female students within our sample schools when compared to region averages. However, this is insufficient to account for the discrepancy. It is hypothesized that attendance patterns may be

different for female and male students. Within the science-oriented schools, only the special science classes participated in the study.

Table 5. Distribution of students by region, school type and gender

Region	School Type	Female Students	Male Students	Gender not specified	Total
Region VI	Regular	250 (61.1%)	159 (38.9%)	0 (0%)	409 (100.0%)
Region VII	Regular	271 (59.3%)	185 (40.5%)	1 (0.2%)	457 (100.0%)
NCR	Regular	260 (52.1%)	239 (47.9%)	0 (0%)	499 (100.0%)
	Science-oriented	188 (66.2%)	95 (33.4%)	1 (0.4%)	284 (100.0%)
Total		969 (58.8%)	678 (41.1%)	2 (0.1%)	1649 (100.0%)

The test data collected from the student sample was calibrated using the one-parameter simple logistic model (Rasch, 1960) and student ability estimates were produced.

Analysis showed that there was a statistically significant difference between the performance of male and female students within the science-oriented high schools ($t_{(154.66)}$ = 4.472, p < 0.001), with male students (mean = 64.42, SD = 12.32) outperforming female students (mean = 57.94 SD = 9.74). In the regular high schools, however, there was no statistically significant difference ($t_{(1116.08)}$ = -0.631, p = 0.528) between the performance of male students (mean = 47.73, SD = 9.20) and female students (mean = 48.02, SD = 7.65).

The benefit of Rasch modelling is that the students and items can be placed on the same scale. This enables the comparison of students with the concepts and skills assessed by the test. The common logit scale for the pre-Grade 10 test is shown in Figure 2. The representation is known as a variable map and the distribution of students is shown on the left side with students represented by 'X'. The items are shown on the right side and each item is shown as a number according to the test order. The logit scale in this map extends from -2.5 to 2 logits. The most difficult item on the test is shown to be Item 15, and the easiest is shown to be Item 1 (Figure 2).

The relative positions of items and students are dictated by the data fit to the Rasch model. When an item is positioned at the same horizontal level as the student, the student has a 50/50 chance of answering that item correctly. When the item numbers are linked with the concept or skill assessed by the item, the horizontal alignment identifies which concepts or skills the aligned students (as represented by 'X's) are ready to learn. For usability, levels containing similar

skills are identified, and a level description is written to encapsulate the main ideas that students in each level are ready to learn.

The pre-Grade 10 test conceptually and empirically separates into four levels (A through D). These levels are described in Figure 2.

Levels A to D contain the prerequisite concepts and skills for Grade 10 Matter. Some of these concepts and skills were introduced to students in Grade 9 and some were introduced in earlier grades. The level descriptions order these from easiest to most difficult, based on the results of the testing. The students assigned to each level via the analysis are considered "ready to learn" the concepts and skills associated with that level. The levels show that some students have mastered more of the prerequisites than others. For example, students at Level B are ready to learn to relate the microscopic properties of matter, such as atomic mass, charge, speed of particles and spaces between particles, to macroscopic phenomena such as gas expansion and phase changes, while students at Level A are still about to recognize properties of matter at the atomic level. Considering Levels B and C, we have, at Level C, students who are beginning to use the Periodic Table of Elements to aid them in computing the mass of elements and compounds with subscripts, while, at Level B, students are still about to learn to use the same tool for computing masses of monoatomic elements and compounds. It should be noted that the chemical symbols of these monoatomic elements and compounds do not have subscripts. The level descriptions, however, do not readily indicate readiness for Grade 10 Chemistry until they are checked against each of the topics to be covered.

There are three content areas covered in Grade 10 Chemistry: gas laws, biomolecules and chemical reactions. Each of these content areas has specific minimum prerequisite knowledge that the students must have in order to engage the topic. The topics on gas laws require students to have knowledge of motion and distances between gas particles and the ability to relate these to macroscopic properties and the typical behaviour of gases. In the topics on biomolecules, it is assumed that students already have knowledge of chemical formulas and familiarity with the elements carbon, hydrogen, oxygen and nitrogen. Lastly, in the topics on chemical equations, the students must be already knowledgeable on chemical formulas and the mole concept. All these prerequisites are met, at the minimum, by students at Level C. Table 6 presents the learning standards (by content area) for Grade 10 Matter from the K to 12 Basic Education Curriculum and the corresponding levels for students to be considered ready to learn this content.

Level D – Students at this level are beginning to understand how valence electrons govern the chemical properties (reactivity) of elements.

Level C – Students at this level are starting to develop a deep understanding of the connection between the macroscopic properties (e.g. changes when metal is hammered, when a solid is melting), the microscopic structures of elements and compounds (molecules, atoms and subatomic particles), and the symbolic and mathematical representations of substances (chemical formulas and equations). They begin to learn to engage with the topics of chemistry at a more abstract and symbolic level, with minimal reference to the observable behaviours of matter. They are beginning to learn that compounds are formed when electrons are transferred or shared between atoms (ionic or covalent bonding). They are also beginning to interpret chemical reactions (using prefixes and subscripts in balancing) and recognize them only as rearrangement of particles (conservation of matter). Students at this level also begin to use information from the Periodic Table to determine mass of elements and compounds (with subscripts).

Level B – Students at this level are beginning to understand the connection between the particles that make up matter and the chemical formulas that represent them. They are also beginning to learn that particles (atoms and molecules) have other measurable properties (e.g. mass, speed and distance) that can be used to compare them, and to relate these properties to observable changes in matter, such as gas expansion and phase changes. They are learning to use the Periodic Table to classify elements as metals or non-metals and to compute masses of elements and simple compounds (i.e., those without subscripts). They are beginning to understand the use of the "mole" to describe the number of particles and the mass in grams of elements and compounds.

Level A – Students at this level are starting to recognize the properties of matter at the atomic level. They are beginning to learn that protons and electrons have charges that dictate whether they attract or repel when placed near each other and that electrons are the particles involved in bonding. Students at this level also begin to relate temperature to the speed at which molecules move.

Figure 2. Skill level descriptions and variable map of student and item distribution
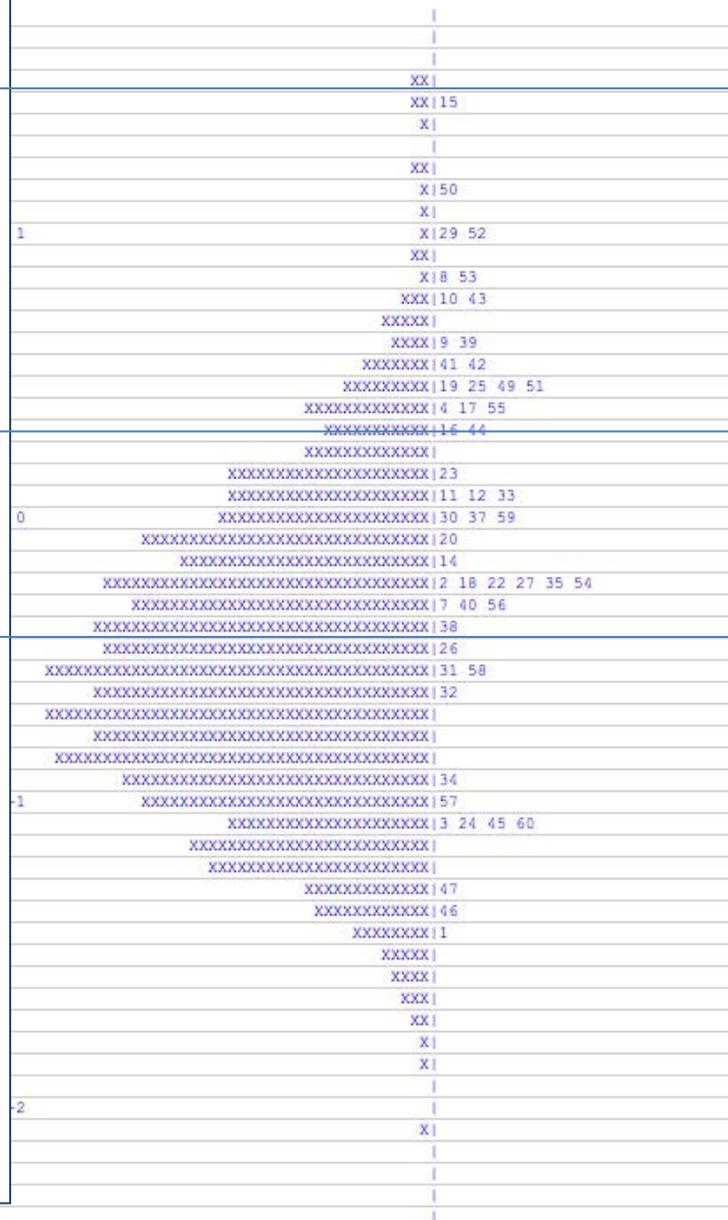
Note. X represents 2.1 students

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                                          XX  |
                                          XX  | 15
                                           X  |
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                                           X  |
                                           X  | 29 52
                          1                XX |
                                           X  | 18 53
                                         XXX  | 10 43
                                       XXXXX  |
                                      XXXX  | 9 39
                                    XXXXXXX  | 41 42
                                  XXXXXXXX  | 19 25 49 51
                              XXXXXXXXXXXX  | 4 17 55
                             XXXXXXXXXXXX  | 16 44
                              XXXXXXXXXXXX  |
                        XXXXXXXXXXXXXXXXXXXX  | 23
                          XXXXXXXXXXXXXXXXXX  | 11 12 33
                        XXXXXXXXXXXXXXXXXXXX  | 30 37 59
              0     XXXXXXXXXXXXXXXXXXXXXXXX  | 20
                       XXXXXXXXXXXXXXXXXXXX  | 14
             XXXXXXXXXXXXXXXXXXXXXXXXXXXXXX  | 2 18 22 27 35 54
                XXXXXXXXXXXXXXXXXXXXXXXXXX  | 7 40 56
                XXXXXXXXXXXXXXXXXXXXXXXXXX  | 38
                   XXXXXXXXXXXXXXXXXXXXXXX  | 26
           XXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX  | 31 58
                 XXXXXXXXXXXXXXXXXXXXXXXXXX  | 32
             XXXXXXXXXXXXXXXXXXXXXXXXXXXXX  |
                XXXXXXXXXXXXXXXXXXXXXXXXX  |
              XXXXXXXXXXXXXXXXXXXXXXXXXXX  |
                 XXXXXXXXXXXXXXXXXXXXXXXX  | 34
     -1              XXXXXXXXXXXXXXXXXXX  | 57
                XXXXXXXXXXXXXXXXXXXXXXX  | 3 24 45 60
                XXXXXXXXXXXXXXXXXXXXX  |
                  XXXXXXXXXXXXXXXXXXX  |
                     XXXXXXXXXXXXXX  | 47
                     XXXXXXXXXXXXX  | 46
                        XXXXXXXXX  | 1
                            XXXXX  |
                             XXXX  |
                              XXX  |
                               XX  |
                                X  |
                                X  |
                                  |
     -2                           |
                                X  |
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Table 6. Content areas, concepts and levels of readiness-to-learn

Content Area	Spiralling of Concepts Grade 3 – Grade 10 (Grade 10 Matter)	Level
Gas Laws	Learners investigate how gases behave in different conditions based on their knowledge of the motion of and distances between gas particles. Learners then confirm whether their explanations are consistent with the Kinetic Molecular Theory. They also learn the relationships between volume, temperature, and pressure using established gas laws.	C
Biomolecules	In Grade 10, they learn more about carbon compounds that include biomolecules such as carbohydrates, lipids, proteins, and nucleic acids. Further, they will recognize that the structure of these compounds comprises repeating units that are made up of a limited number of elements such as carbon, hydrogen, oxygen, and nitrogen.	C
Chemical Reactions	In Grade 9, learners described how particles rearrange to form new substances. In Grade 10, they learn that the rearrangement of particles happen when substances undergo chemical reaction. They further explain that when this rearrangement happens, the total number of atoms and total mass of newly formed substances remains the same. This is the Law of Conservation of Mass. Applying this law, learners learn to balance chemical equations and solve simple mole-mole, mole-mass, and mass-mass problems.	C

Note: The entries in the columns "Content Area" and "Spiralling of Concepts Grade 3-Grade 10" are obtained from the curriculum guide for Science. These concepts will be tackled in Grade 10 Matter.

In order to identify the percentage of students well prepared to engage with the conceptual knowledge and skills required by the Grade 10 Matter curriculum, the distribution of students across the various levels was identified for each school type (Table 7). These data are also shown graphically in Figure 3.

Table 7. Distribution of students across competence levels
(A = lowest, D = highest)

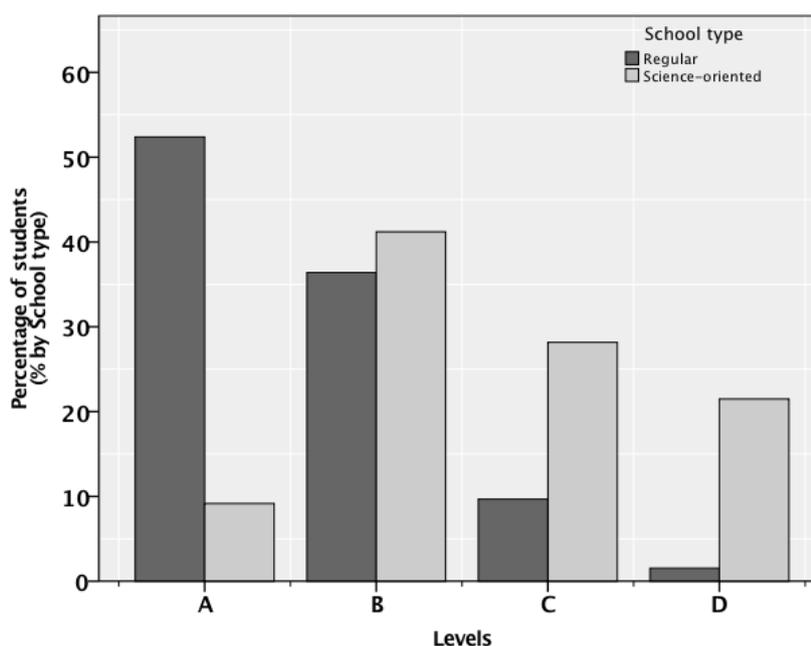| Level	Regular			Science-oriented		
	Frequency	Percentage	Cumulative percentage	Frequency	Percentage	Cumulative percentage
D	21	1.5%	100.0%	61	21.5%	100.0%
C	132	9.7%	98.5%	80	28.2%	78.6%
B	497	36.4%	88.8%	117	41.2%	50.4%
A	715	52.4%	52.4%	26	9.2%	9.2%

Figure 3. Distribution of pre-Grade 10 students across levels in regular and science-oriented high schools

As shown in Table 8, these data indicate that 50% of students in science-oriented high schools and 11% of students in regular high schools are ready to engage with the conceptual knowledge and skills required by the Grade 10 Matter curriculum (those at levels C and D). In effect, this group of students is ready to learn what is stated regarding properties and structure of matter in the section on Spiralling of Concepts Grade 3 – Grade 10 of the K to 12 Science Curriculum, as presented in Table 6. This suggests that approximately one half of students at science-oriented high schools would have difficulty managing the Grade 10 Matter curriculum. In regular high schools, the situation is much more serious, with almost 90% of students starting the Matter quarter with insufficient prerequisite learning.

Table 8. Comparison of student readiness by school type.

	Regular High Schools		Science-oriented High Schools	
	Ready	Not ready	Ready	Not ready
Pre-Grade 7	619 (39%)	978 (61%)	361 (90%)	39 (10%)
Pre-Grade 8	398 (27%)*	1085 (73%)	242 (78%)*	72 (22%)
Pre-Grade 9	207 (13%)*	1395 (87%)	223 (74%)	78 (26%)
Pre-Grade 10	153 (11%)	1212 (89%)	141 (50%)*	143 (50%)

* denotes significant ($p < 0.00001$) decline in readiness from previous grade

CONCLUSION

The linking of the test blueprint to the topics covered in the previous grade levels suggests that it is safe to assume that the Grade 10 curriculum provides enough opportunities to learn the prerequisite knowledge and skills to engage with the Grade 10 topics on Matter. The separation of these topics into three content areas that are not strictly related raises the possibility that varying levels of ability may be required for students to engage with each area. Notwithstanding, the consistency of the readiness levels across the three content areas (see Table 6) suggests that the topics for Grade 10 Chemistry are of a uniform level of complexity for the students. This consistency points to a well-organised grouping of topics for Grade 10, which the empirically derived levels of students' ability support.

The data indicate that a large majority (89%) of Grade 10 students from regular high schools and 50% of students from science-oriented high school are not ready to engage with the knowledge and skills required by the Grade 10 Matter curriculum. This indicates the students' lack of mastery of the prerequisite knowledge and skills. These students have not yet reached the required level of understanding regarding atomic structure of matter and chemical reactions at the Grade 9 and Grade 10 levels, and are still operating at the level addressed by the Grade 8 curriculum. Since the K to 12 core curriculum at the Senior High School level includes Physical Science (required in all tracks of the curriculum) and General Chemistry 1 and 2 of the STEM strand of the academic track, these students can be expected to have difficulty in these required subjects at the Senior High School level.

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Science Curriculum Project: progress of students through the science curriculum: a focus on matter (chemistry)

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