Measuring Student Readiness as a Means of Evaluating Science Curriculum Reform

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ABSTRACT
As part of the K to 12 curriculum reform in the Philippines, a new spiral science curriculum has been implemented in 2012, where students learn chemistry, biology, earth science and physics for one quarter of each school year from Grades 7 to 10. This paper describes an innovative approach to assessing the development of students’ chemistry concepts and skills as part of an evaluation of the spiral chemistry curriculum. For each grade level, the curriculum was audited to identify the prerequisite concepts and skills assumed by the chemistry curriculum. "Pre-tests" were designed to assess student mastery of these requirements and their precursor concepts as students entered into the chemistry quarter at each grade level. Test data were analysed to describe increasing levels of student competence and these levels were compared to the prerequisites for each grade level in order to identify the proportion of students deemed ready to learn the grade level curriculum. This approach provided a means of evaluating the structure of the spiral curriculum and the degree to which it offered the opportunity to students to engage with the intended curriculum.

Introduction
The K to 12 Reform in the Philippines
In 2011, the Philippine Department of Education (DepEd) initiated a large-scale education reform. This reform is known as the Enhanced Basic Education Program or, more commonly, the K to 12 program. This program covers Kindergarten and 12 years of basic education: six years of elementary education, four years of junior high school, and two years of senior high school. The aims of this reform are to provide sufficient time for mastery of concepts and skills, develop lifelong learners, and prepare graduates for tertiary education, middle-level skills development leading to technical-vocational-livelihood related jobs, employment, and entrepreneurship. The predecessor of the K to 12 curriculum, the Basic Education Curriculum (BEC), was a 10-year basic education program with 6 years of elementary education and 4 years of high school, after which students could proceed to University or take Technical-Vocational courses.

In accordance with the Education for All (EFA) reforms, the K to 12 program is aimed at expanding the Philippine education system so that it is aligned with the systems of other countries. The program is designed to prepare Filipino students for success in the globalized and competitive world of the 21st century (Rep. Act No. 10533, 2013a, Sec.2) and to maximize their potential and better meet the social needs of the country (SEAMEO-Innotech, 2012:p. 3). Teachers and facilitators of learning are expected to use the K to 12 curriculum to equip school
graduates with the following 21st century skills: (a) information, media and technology skills, (b) learning and innovation skills, (c) effective communication skills, and (d) life and career skills. DepEd has been implementing the new curriculum in phases, starting in School Year (SY) 2012-2013 for Grades 1 and 7 (the 1st year of Elementary School and 1st year of Junior High School, respectively) and it is being progressively introduced in other grade levels in each school year. The first Grade 6 and Grade 12 students will complete elementary and senior high school respectively in 2018.

Table 1. Implementation of the K to 12 Program in Phases

<table>
<thead>
<tr>
<th>School year</th>
<th>Grade levels implemented</th>
</tr>
</thead>
<tbody>
<tr>
<td>2012-2013</td>
<td>Grades 1 and 7</td>
</tr>
<tr>
<td>2013-2014</td>
<td>Grades 2 and 8</td>
</tr>
<tr>
<td>2014-2015</td>
<td>Grades 3 and 9</td>
</tr>
<tr>
<td>2015-2016</td>
<td>Grades 4 and 10</td>
</tr>
<tr>
<td>2016-2017</td>
<td>Grades 5 and 11</td>
</tr>
<tr>
<td>2017-2018</td>
<td>Grades 6 and 12</td>
</tr>
</tbody>
</table>

Main Features of the Science Curriculum in the K to 12 Program

In the K to 12 program, a new curriculum for science has been implemented in schools across the country. Through a learner-centered and inquiry-based 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). What resulted is a “spiral” science curriculum (refer to Table 1) where concepts and skills in Life Sciences, Physics, Chemistry, and Earth Sciences are revisited at each grade level with increasing depth and complexity, paving the way to a deeper understanding of core concepts.

Table 2. K to 12 Science Curriculum Focus by Quarter across Grade Levels

<table>
<thead>
<tr>
<th>Quarter 1</th>
<th>Grade 7</th>
<th>Grade 8</th>
<th>Grade 9</th>
<th>Grade 10</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Matter</td>
<td>Force, Motion &amp; Energy</td>
<td>Living Things &amp; their Environment</td>
<td>Earth &amp; Space</td>
</tr>
<tr>
<td>Quarter 2</td>
<td>Living Things &amp; their Environment</td>
<td>Earth &amp; Space</td>
<td>Matter</td>
<td>Force, Motion &amp; Energy</td>
</tr>
</tbody>
</table>
The spiral science curriculum differs from the previous Basic Education Science Curriculum, in which only one specific area or discipline in science was taught for each grade level for the entire school year, as shown in Table 3.

Table 3. Science Curriculum before the K to 12 Program

<table>
<thead>
<tr>
<th>High School Level</th>
<th>Science Discipline</th>
</tr>
</thead>
<tbody>
<tr>
<td>First Year</td>
<td>Earth &amp; Environmental Science</td>
</tr>
<tr>
<td>Second Year</td>
<td>Biology</td>
</tr>
<tr>
<td>Third Year</td>
<td>Chemistry</td>
</tr>
<tr>
<td>Fourth Year</td>
<td>Physics</td>
</tr>
</tbody>
</table>

**Research goals**

ACTRC is undertaking a broad program of research to investigate the implementation of the K to 12 Science Curriculum reform. This paper covers the data obtained in order to address the following research questions:

- Do students enter junior high school with the level of conceptual knowledge and skills they need to engage with the Grade 7 science (chemistry) curriculum?
- Do students enter the third quarter of Grade 8 with the level of conceptual knowledge and skills they need to engage with the Grade 8 science (chemistry) curriculum?

The data used in this paper were derived from a pre-Grade 7 test and a pre-Grade 8 test on chemistry concepts and related skills. Both of these tests were developed to assess if students are appropriately prepared to access the new curriculum. For pre-Grade 7, students were tested at the start of the school year in June 2015, before beginning the Grade 7 chemistry unit “Matter” (or any other secondary school subject). For pre-Grade 8, students were tested in November 2015, before beginning the Grade 8 chemistry unit “Matter” (which is taught during the third quarter of the school year).

**Research design**

The pre-Grade 7 test provided a unique opportunity to obtain baseline data on student understanding and skills in science. Grade 7 students complete Matter in the first quarter of the year as their first unit of science study at junior high school (Table 2). Also, only in the Grade 7 chemistry curriculum is science inquiry explicitly listed as a conceptual topic to be covered. For both Grade 7 and Grade 8, in order to investigate whether the entry conceptual knowledge and skills of students were sufficient for them to engage in the curriculum, readiness tests were
designed to assess students’ prerequisite concepts on Matter at the beginning of each quarter in which Matter was taught. Using this approach the readiness of each student for the content of the coming quarter could be determined. This design assessed the competence level of students at the point at which the concepts were needed to facilitate future learning. The competence level combined students’ learning when taught a concept or skill in earlier grade levels with their long-term retention of those concepts and skills. If the research design had taken a more traditional route, it would have assessed students at the end of the previous grade level and would have measured only the first of these two components. In doing so, the question of retention would not have been answered.

The research design was cross-sectional in nature, rather than being a longitudinal study in which the same students were followed over the grade levels. The reason for selecting a cross-sectional design was the need to provide timely feedback to the curriculum designers.

The design of tests of prerequisite concepts necessitated a different approach to that typically taken when designing achievement tests. Typically, the content of achievement tests is determined by auditing the curriculum. However, in this case, a simple audit of the curriculum for preceding grade levels was insufficient because not all concepts taught in a particular grade were required for learning the next grade level. For example, the properties of metals are taught in Grade 7, are not a prerequisite for Grade 8, but are for Grade 9, where students learn how to explain these properties using the atomic-level structure of metals. Because of this, the first stage of the test design process was carried out by experienced educators who identified the prerequisite concepts and skills required by each grade level curriculum. These concepts and skills were then cross referenced against the curricula for earlier grade levels to identify the point at which each skill or concept was first taught. This meant that a concept taught in Grade 7 would not feature in the Grade 8 pretest if it was not required for learning within that grade.

Another important factor in the design of the tests was the introduction of ‘precursors’ into the tests. Precursors were defined as ideas that come before a prerequisite concept. The decision to include precursors into the readiness tests was based on the need for the research findings to inform future curriculum decision making. The research findings should be able not only to identify how many students were ready for the grade level curriculum but also to determine what those students who did not have the prerequisite concepts were actually ready to learn. For example, students in Grade 7 require an understanding of the macroscopic properties of solids, liquids and gases. They need to be able to take these properties and apply them to new situations – the study of solutions. However, if students were found not to have this prerequisite concept, did they even know the terms ‘solids’, ‘liquids’ and ‘gases’? Could they name common examples of each? That is, did they have the precursors to the prerequisite concept? This information would be crucial to future curriculum design should the research find a mismatch between the long-term retention of concepts and the expectations of the curriculum.

Along with prerequisites and precursor concepts, a small number of concepts were included in each test that were considered to be advantageous for students studying at each grade level. These concepts were not designated prerequisites but were sophisticated skills that would help students to get the most out of the topics within the curriculum of the grade level. For example, knowing that ice and water were the same substance with only the arrangement of molecules
changed was considered to be helpful for Grade 7 students, even though this concept is not required.

Test design and development
Each of the tests was made up of 50-60 items. Multiple-choice test format was selected as the most efficient method of assessing the large number of students. This format is also very familiar to Philippine students.

The process of test development comprised initial curriculum mapping, development of test blueprint, item development, item review, item selection for pilot, analysis of pilot data, and selection of items for the final test form. The blueprint to structure the development of test items was created using the curriculum audit information. This included a balance of the prerequisite, precursor and advantageous concepts and skills that students need to have in order to engage in a specific grade level chemistry curriculum. The prerequisites for Grade 7 were based on the Grades 3-6 curricula.

Sample
A convenience sample of 12 regular high schools was used for this study, across three of the 18 administrative regions within the Philippines. The broader program of research also included data collected from 4 science-oriented high schools, but the results from these schools are not included in this paper. These three regions are the National Capital Region (NCR), Region VI (Western Visayas) and Region VII (Central Visayas). Three classes from the relevant grade level within each school were selected for participation. It is usual for regular high schools within the Philippines to stream classes. For this study, one high, one medium and one low performing class was used from each school. This sampling strategy was used to facilitate data collection from a range of student abilities. The sample totals are included in Table 4.

Table 4. Student Numbers by Test, Region and School Type

<table>
<thead>
<tr>
<th>Test</th>
<th>Total</th>
<th>NCR</th>
<th>VI</th>
<th>VII</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pre-Grade 7</td>
<td>1997</td>
<td>546</td>
<td>566</td>
<td>485</td>
</tr>
<tr>
<td>Pre-Grade 8</td>
<td>1798</td>
<td>539</td>
<td>481</td>
<td>463</td>
</tr>
</tbody>
</table>

Test Analysis Method
Student data were collected via pencil and paper tests, with student responses provided on scannable forms. Completed forms were then scanned, and raw data cleaned prior to analysis. The student test data collected was calibrated using the one parameter simple logistic model (Rasch, 1960). The analysis of the data yielded two sets of estimates: the student ability estimates and the item difficulty estimates. The student ability estimates are transformations of student raw scores onto the logits scale, and based on the model, are estimates of the true ability of the students. The item difficulty estimates are measures of how difficult the items were for the students. These estimates, also expressed on the logits scale, were derived from the proportion of students who answered each of the items correctly.

Rasch modelling enabled comparison of the students’ ability and the difficulty of the skills assessed by the test. The model is based on the principle that a student whose ability is equal to the item difficulty has a 50/50 chance of answering the item correctly. If an item’s difficulty is
lower than a student’s ability then the student has a greater than 50/50 chance of answering it correctly. If an item’s difficulty is higher than a student’s ability then the student has a less than 50/50 chance of answering it correctly. Because each item assesses a specific skill, the interpretation of the results may also be extended to include the conclusion that a student whose ability is equal to an item difficulty is ready to learn the skill the item is assessing (Griffin, 2007).

There were no a priori assumptions made regarding the order of difficulty of the items used in the study. It was through the item difficulty estimates that the level and order of difficulty of the items were established. The estimates were also used to identify clustering of items, indicating sets of skills that have a similar level of difficulty. Levels were assigned to the clusters, and the skills assessed in each level were summarized in descriptions to capture the main ideas represented at each level. The levels were defined by cut-off points, and the test items and the students whose ability fell within a level’s cut-off points were assigned to that level. Accordingly, students within a level were considered to be ready to learn the skills on that level. This method identified six levels of proficiency among the pre-Grade 7 students and four levels of proficiency among the pre-Grade 8 students.

Using information from the curriculum audit, the identified proficiency levels were categorized into two types: those that included precursors or prerequisites, and those that included only advantageous/supportive concepts. Students assigned to levels that included precursors or prerequisites were deemed not ready to engage with the curriculum, since the curriculum assumes understanding of the precursors and prerequisites. Students assigned to levels that included only advantageous/supportive concepts were deemed ready to engage with the curriculum, since they had demonstrated understanding of the precursors and prerequisites. Following identification of the levels at which students were considered ready to learn different concepts and skills, the students were grouped according to readiness or non-readiness for the intended curriculum. This approach was adopted for each of the grade levels.

**Test Results**

Table 5 shows the distribution of Grade 7 students across the six levels of proficiency identified by the pre-Grade 7 test analysis. The top two levels – E and F – indicate readiness to learn the curriculum. The ‘Frequency’ column indicates the number of students at each level. As the table shows, 39% of Grade 7 students were identified as ready to learn the curriculum and 61% were identified as not ready.

<table>
<thead>
<tr>
<th>Level</th>
<th>Frequency</th>
<th>Percentage</th>
<th>Ready/not ready percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td>F</td>
<td>180</td>
<td>11.30%</td>
<td>Ready 39%</td>
</tr>
<tr>
<td>E</td>
<td>439</td>
<td>27.50%</td>
<td></td>
</tr>
<tr>
<td>D</td>
<td>331</td>
<td>20.70%</td>
<td>Not ready</td>
</tr>
</tbody>
</table>
Table 6 shows the distribution of Grade 8 students across the four levels of proficiency identified by the pre-Grade 8 test analysis. As with Grade 7, the top two levels – in this case C and D – indicate readiness to learn the curriculum. Note that although the analysis identified only two lower levels of proficiency at which Grade 8 students were not ready to learn the curriculum, 73% of students were found to be performing at those two levels. The proportion of Grade 8 students found to be ready for the curriculum was 27%.

Table 6
Distribution of Grade 8 Students Across Levels

<table>
<thead>
<tr>
<th>Level</th>
<th>Frequency</th>
<th>Percentage</th>
<th>Ready/not ready percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td>D</td>
<td>54</td>
<td>3.60%</td>
<td>Ready 27%</td>
</tr>
<tr>
<td>C</td>
<td>344</td>
<td>23.20%</td>
<td></td>
</tr>
<tr>
<td>B</td>
<td>625</td>
<td>42.10%</td>
<td>Not ready 73%</td>
</tr>
<tr>
<td>A</td>
<td>460</td>
<td>31.00%</td>
<td></td>
</tr>
<tr>
<td></td>
<td>1483</td>
<td>100%</td>
<td>100%</td>
</tr>
</tbody>
</table>

It should be noted that while the results show a large percentage of students are not yet ready for the grade level curriculum they are about to experience, this research does not explore the reasons why students have not learned or retained concepts taught in previous grade levels. Although factors such as curriculum implementation, teacher specialization and training, and school resources may contribute, the resulting situation facing teachers is the same: a large percentage of the students are not ready for the current grade level curriculum. Changes to the curriculum structure could be made to take into account the realities of student learning that have contributed to this situation.

Evaluation of the science curriculum structure
This section explores how the research findings have been used to evaluate the curriculum structure. The revision process will be illustrated using the concepts associated with solids, liquids and gases in the Grade 7 and 8 curriculum as an example. The relevant aspects of each level description for the pre-Grade 7 and pre-Grade 8 results are shown in Table 7.

Table 7. Aspects of level statements related to solids, liquids and gases

<table>
<thead>
<tr>
<th>Pre-Grade 7</th>
<th>Pre-Grade 8</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>D: ...gases are compressible</td>
</tr>
</tbody>
</table>
F: ...understand the use of words describing the properties of matter, including mass, shape and volume

E: ...substances that exist in different states (ice and water) differ in terms of molecular arrangement

B: ...particulate nature of matter, e.g. that ice and water are the same substance with different arrangements of particles

D: ...use their understanding of how matter behaves to make predictions in real-life settings; that a gas cannot be held in one’s hand,...and that a solid is not always flat

A: ...macroscopic properties of solids, liquids and gases

Note: The level descriptions for the two tests were not part of the same scale. The alignment in the table is conceptual only.

Grade 7

The current Grade 7 curriculum contains a topic ‘Solutions’ for which an understanding of solids, liquids and gases is a prerequisite. The Grade 7 Science Learner Materials provide an indication of the prerequisite concepts required to engage in the Solutions topic. The Learner Materials are produced by the Philippines Department of Education (DepEd) and are available free of charge for use in all DepEd schools. They are used as textbooks in the majority of schools. The following paragraph is taken from the introductory section of the Solutions topic:

Solutions are homogeneous mixtures. When you put sugar into water, the solid becomes part of the liquid and cannot be seen. You can say that the sugar dissolves in water or the sugar is soluble in water. Solutions may be solids dissolved in liquids or gases dissolved in liquids. There are also solutions where a gas is dissolved in another gas, a liquid in another liquid or a solid in another solid. Gaseous, liquid, and solid solutions are all around you. Many commercial products are sold as solutions.

(Department of Education, 2012, p3)

From this paragraph it can be seen that the terms ‘solids’, ‘liquids’ and ‘gases’ are assumed knowledge. In addition to a familiarity with the terminology, an understanding of the macroscopic properties of each is assumed.

To examine the alignment of these expectations with the starting points of students, it is possible to use the level descriptions and student distributions developed from the pre-Grade 7 testing. Figure 1 shows the distributions together with level descriptions that summarise what students are ready to learn about solids, liquids and gases at each of the levels. Students at Level D are ready to learn how to make predictions about the behaviour of solids, liquids and gases in real-life situations. This ability to make predictions, or to generalise the properties of each category of
matter, is exactly what the above paragraph from the Learner Materials indicates is expected of students engaging with the Solutions topic. Since the levels are cumulative, this means that students from Level A to D have not yet learned all of the prerequisite concepts assumed by the curriculum for this topic.

Since the levels are cumulative, this means that students from Level A to D have not yet learned all of the prerequisite concepts assumed by the curriculum for this topic.

**Figure 1.** The distribution of students across the concepts related to solids, liquids and gases at the beginning of the Grade 7 Matter subject.

Since the sample of students used for the research indicates that 61% of students (all those in Levels A to D) are not ready to engage with the Solutions topic, it can be presumed that if a teacher was teaching directly from the Learner Materials, more than half the students would be confused from the outset. This is a reasonable assumption because it is rare for Philippine teachers to use formative assessment data to adjust their teaching to cater for student starting points (Griffin, Cagasan, Care, Vista, & Nava, 2016). In cases like this, the mismatch between curriculum expectations and the research findings suggests that a change to the curriculum structure would be beneficial to student learning.

The research findings can also be used to suggest specific changes that would align the curriculum more closely with student starting points. Useful additions to the Grade 7 curriculum would be the properties of solids, liquids and gases and knowledge of how to generalise these
properties to various real-life situations. This study has shown that 60% of students tested were ready to learn these concepts at the beginning of the Grade 7 Matter curriculum. Although the curriculum for earlier grade levels includes these concepts, the study indicates that they need to be covered in Grade 7 in order for the curriculum to match student needs. It is expected that when there is a match between the curriculum and the readiness of students, greater student learning will result.

Grade 8
The Grade 8 Matter curriculum contains two learning competencies directly related to understanding of solids, liquids and gases. These are:

- Explain the properties of solids, liquids, and gases based on the particle nature of matter.
- Explain physical changes in terms of the arrangement of atoms and molecules.

These learning competencies require students to shift from a macroscopic understanding of solids, liquids and gases to a microscopic or particulate understanding. As Figure 2 illustrates, the level descriptions from the pre-Grade 8 testing show that only students in Level A would not be ready for this content or these particular learning goals.

![Figure 2. The distribution of students across the concepts related to solids, liquids and gases at the beginning of the Grade 8 Matter subject.](image)

This means that 69% of students from the research sample can be considered ready for this particular content, a large difference to Grade 8 Matter as a whole, where only 27% of students can be considered ready. This indicates there is a better match between the curriculum and student readiness for this particular content than other parts of the subject. The fact that 69% of students have the prerequisite concepts for this topic, as opposed to only 40% for the Grade 7
Solutions topic, indicates that, even within this narrow topic, there is a better match between the curriculum and the student prerequisites in Grade 8 than Grade 7.

The findings of this study indicate that the remaining 31% of the Grade 8 students would require more teaching of macroscopic properties before they would be ready to learn about particulate properties. However, the Learner Materials for Grade 8 Science (Department of Education, 2013) anticipate this need and the preliminary activities and explanations contained in the section on the particle model emphasise the macroscopic properties of solids, liquids and gases as well as introducing the basics of the particle model. This ensures that the materials are suitable for the range of typical starting points of students found by the research and indicate that changes to the structure of this topic are not required on the basis of student prerequisite understanding.

Conclusion
Measuring student readiness at the beginning of each grade level within a spiraling curriculum has been shown to be useful in evaluating the structure of the curriculum. By identifying and assessing prerequisite, precursor and advantageous concepts, the readiness of students for the grade level curriculum can be determined. Where discrepancies between the required concepts and student readiness are identified, the inclusion of precursor concepts allows potential changes in curriculum and learning activities to be identified. These have been illustrated in this paper with the example of concepts surrounding solids, liquids and gases, but the process can be generalised to other curriculum components included in the testing.

References
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SEAMEO INNOTECH (2012). K to 12 Toolkit, Manila: SEAMEO INNOTECH.
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