ESSA: Developing and scoping a test to explore scientific literacy and achievement in NSW

by Deborah Panizzon, Dagmar Arthur and John Pegg

In 2007, all Year 8 students in Department of Education and Training schools in NSW will complete the Essential Secondary Science Assessment (ESSA) test (NSW DET, 2005). It will complement other assessments currently undertaken in this State in the areas of literacy (English Language and Literacy Assessment—ELLA) and numeracy (Secondary Numeracy Assessment Program—SNAP). In this paper, we outline the focus and structure of the ESSA test, designed as a diagnostic tool to identify *what* students know and *can do* and where teaching needs to be directed to enhance scientific understanding. To guide the development of assessment items that would achieve this purpose, the Structure of the Observed Learning Outcome (SOLO) model was utilised as the theoretical framework (Biggs & Collis, 1882; 1991). With a trial and large-scale pilot already completed, this paper outlines the purpose and scope of ESSA and how it will help inform teacher practice.

Introduction

In NSW, as in other States in Australia, there has been a shift over the last few years towards an inclusive view of assessment with a change from an 'assessment *of* learning' to 'assessment *for* learning' (Board of Studies, 2003, p. 4) perspective. This focus has come directly from the UK (Black & Wiliam, 1998; Black & Harrison, 2002) where it is defined as 'any assessment for which the first priority in its design and practice is to serve the purpose of promoting learning' (Wiliam, 2006). In the USA, it is referred to as *embedded assessment* (Stiggins, 2002; Wilson & Sloane, 2000) because student progress is integrated into the teaching process. Regardless of the terminology used, assessment is conceptualised as being linked intrinsically to what happens on a daily basis in the classroom so as to provide feedback to both student and teacher and for reporting purposes. Ultimately, this approach results in 'constructive alignment' as curriculum content, teaching practice, and assessment supports one another to enhance student learning (Biggs, 1996).

The critical shift in this view of assessment is that it becomes an *ongoing* activity that provides students with clear indications about what *they know* and *can do* while identifying the concepts requiring further development (Bell & Cowie, 2001; Hackling, 2004; Treagust, Jacobowitz, Gallagher & Parker, 2001). For the teacher, it highlights the kinds of learning experiences required if students are to move forward in their scientific understanding. In this sense, assessment is used to *diagnose* a teaching/learning situation and provide information that can be used by both learner and teacher.

In contrast, most high-stakes testing attempts to rank students in order of ability with minimal feedback given to students about the *quality* of their achievement. This information can be used as an indicator 'of the quality and intellectual wealth of a country' (Swain, 2000, p. 139) evidenced by the widespread comparisons undertaken with the Third International Mathematics and Science Study (TIMSS) and the Program for International Student Assessment (PISA) results. Similarly, most States and Territories in Australia conduct large-scale, externally prepared and marked tests for Year 12 students with results used to select candidates for particular courses in higher education.

Given that NSW already has access to this type of testing, educational advisers from the Educational Measurement and School Accountability Directorate from the NSW Department of Education and Training (DET) developed a test to 'support and enhance learning' in the junior years (Shepard, 2000, p.4). The Essential Secondary Science Assessment (ESSA) was designed to provide students with an opportunity to demonstrate their understandings of the science syllabus. To achieve this outcome, the Structure of the Observed Learning Outcome (SOLO) model (Biggs & Collis, 1982; 1991) was adopted as the theoretical framework. The model also underpins the Scientific Literacy Progress Map (MCEETYA, 2003) by providing descriptions about the level of scientific understanding demonstrated in a response. This model is currently being used by the authors for a large research project relating to the assessment practices used by teachers in Science, Mathematics and English in rural and regional schools.

In this paper, we outline the focus, structure and implementation process for ESSA, an overview of the SOLO model, and discuss the ways in which ESSA will inform teacher practice. Although of direct interest to teachers of science in NSW, ESSA will be available for use by education systems across Australia. However, we consider that any discussion that helps to inform and enhance the teaching and learning process is relevant to all science teachers.

What is the focus of ESSA?

The NSW Science Syllabus for Years 7-10 comprises two stages, that is, Stage 4 includes Years 7 and 8, while Stage 5 addresses Years 9 and 10. The Essential Secondary Science Assessment was developed to assess Year 8 students' understandings of the syllabus. In particular, it is intended to:

- Provide formative information about students' achievement;
- Provide resources and training for teachers; and
- Raise the profile of science education in NSW schools.

Underpinning the NSW Science Syllabus and ESSA is the notion of teaching science within a *context*. These are devised by teachers in schools to embrace the interests of students and help them recognise and appreciate the relevance of science in their everyday lives. The syllabus also emphasises the need for students to develop the skills necessary for planning and conducting first-hand investigations, implementing problem-solving strategies, along with an ability to think critically. A clear, central focus of the NSW syllabus is the notion of *scientific literacy* as defined by the OECD (2003, p.133).

> The capacity to use scientific knowledge, to identify questions, to investigate, and to draw evidence-based conclusions in order to understand and help make decisions about the natural world and the changes made through human activity.

To address these foci, ESSA items are linked to four main strands identified in the science syllabus.

- *Strand 1: Knowledge and Understanding* includes the outcomes 4.1-4.5 described as the Prescribed Focus areas. These embrace the history, processes, applications and interactions between science, technology, society and the environment along with real-world issues arising from these interactions. Additionally, outcomes 4.6-4.12 describe knowledge and understanding of the physical world, matter, the living world, and the Earth and space.
- *Strand 2: Planning and Conducting Investigations* covers outcomes 4.13-4.15 relating to the planning of investigations, the gathering and recording of valid and reliable first-hand data.
- *Strand 3: Communicating* embraces outcomes 4.16-4.18 involving the gathering of data and transforming it for a particular purpose and audience.
- *Strand 4: Critical Thinking* includes outcomes 4.17, 4.19, 4.20 and 4.21 requiring students to make and justify predictions, generalisations, inferences; identify cause and effect relationships; use models to explain phenomenon; and, evaluate problem-solving strategies (NSW DET, 2005).

In developing items representing a pattern of progress in the development of scientific understanding, the SOLO model was used as the theoretical framework. An earlier version of the model was used for the Scientific Literacy Progress Map (MCEETYA, 2003) with a more recent model being utilised in ESSA.

What is the SOLO Model?

The SOLO model has been used to assess students' understandings of diffusion and osmosis (Panizzon, 2003; Panizzon & Pegg, 2002), evaporation and photosynthesis (Levins & Pegg, 1993), magnetism (Guth & Pegg, 1994), sight (Collis, Jones, Sprod, Watson, & Fraser, 1998), matter and energy transfer (Fraser, 2005) and air pressure (Tytler, 1993). The underlying focus of the model is on the quality of learning or understanding demonstrated in a response, which is content and context specific.

The important variables determining the quality of a response includes the working memory available (i.e., the mental capacity of the student to process incoming material), the amount of information that can be retained by the learner, and features specific to the learning task (Biggs & Collis, 1991).

Table 1. ***Modes of functioning***

Sensori motor mode	Evident when a person reacts to the physical environment. For the very young child it is the mode in which motor skills are acquired. In adult life, this mode is utilised as skills associated with various sports develop and evolve.
Ikonic mode	Occurs when a person internalises actions in the form of images. It is in this mode that the young child develops words and images that represent objects and events. For the adult, this mode of functioning assists in the appreciation of art and music and leads to a form of knowledge referred to as intuitive.
Concrete symbolic mode	Apparent when a person thinks using a symbol system, such as written language and number systems. Thinking in this mode is reliant on a 'real-world' referent. It is this mode that is commonly addressed in learning in the upper primary and secondary school.
Formal mode	Evident when a person is able to consider highly abstract concepts. Students operating in this mode are no longer restricted to a real-world referent and are able to work with 'principles' and 'theories.'
Post formal mode	Occurs when a person is able to question or challenge the fundamental structure of theories or disciplines (Biggs & Collis, 1982). This is the least understood mode of functioning.

Incorporated in the SOLO model are two important features. The first concerns the abstractness of the response and refers to the type of intellectual functioning required to address a scientific question. It is termed the *mode of thinking* (Table 1).

The second feature depends on an individual's ability to deal with relevant cues and is referred to as *levels of response*. They form a cycle of learning providing a hierarchical description of the nature of the *structure* of a response. The three *levels* include:

- *Unistructural* (U): where the individual focuses on the domain/problem, but uses only one piece of relevant data so the response may be inconsistent.
- *Multistructural* (M): where two or more pieces of data are identified as independent units. No integration is demonstrated between the data with inconsistencies often evident in the response.
- *Relational* (R): where all data are available to the learner, with each piece woven into an overall mosaic of relationships culminating in a logical endpoint. The whole has become a coherent structure lacking inconsistencies within the given context.

Importantly, these same three levels occur within each of the five modes of thinking. A diagrammatic summary of how a learning cycle and modes of thinking relate is provided in Figure 1. This is the SOLO model underpinning the Scientific Literacy Progress Map (MCEETYA, 2003).

While the U, M, and R levels identify a cycle of learning in a mode, investigations over the last decade have indicated that a single cycle is restrictive and does not explain fully the development of a scientific concept (Collis et al., 1998; Levins & Pegg, 1993; Panizzon, 2003; Pegg, 2003). (1998 and 1993 indicate more than a few years) Subsequently, two cycles of learning U_1–M_1–R_1 and U_2–M_2–R_2 have been incorporated into the model for the concrete symbolic and formal modes (see Figure 2).

In Figure 2 the 'previous mode' is the ikonic mode and the six levels represented are those in the concrete symbolic mode. The diagram illustrates the cognitive development expected moving from U_1 to M_1 to R_1 forming the first learning cycle, followed by U_2 to M_2 to R_2 representing the second learning cycle. In science, the U_1–M_1–R_1 cycle is descriptive with a focus on developing a 'big picture' or macroscopic idea of the concept being developed. In contrast, in the U_2–M_2–R_2 cycle, students are able to explain the cause and effect or scientific process underpinning a concept.

The differentiation between the two learning cycles is best explained using an example. In Year 7 students' explanations of day and night responses representative of the U_1–M_1–R_1 cycle in the concrete symbolic mode focus on describing the movement of the Earth, Sun and the Moon. There is often a great deal of confusion about where each of these is positioned relative to one another. However, in the U_2–M_2–R_2 cycle of the same mode, students recognise that the spinning of the Earth on an axis affects which parts of the Earth will receive sunlight at a point in time. Furthermore, they use this understanding to explain why we experience variations in daylight and time across and within different countries. Clearly, there is quite a different focus in the responses between the two cycles, and this emerges consistently in our work with students.

How is ESSA structured and marked?

The SOLO model provides the framework for the type and level of item incorporated into ESSA. The ESSA test includes two sections comprising a series of 75 multiple-choice questions

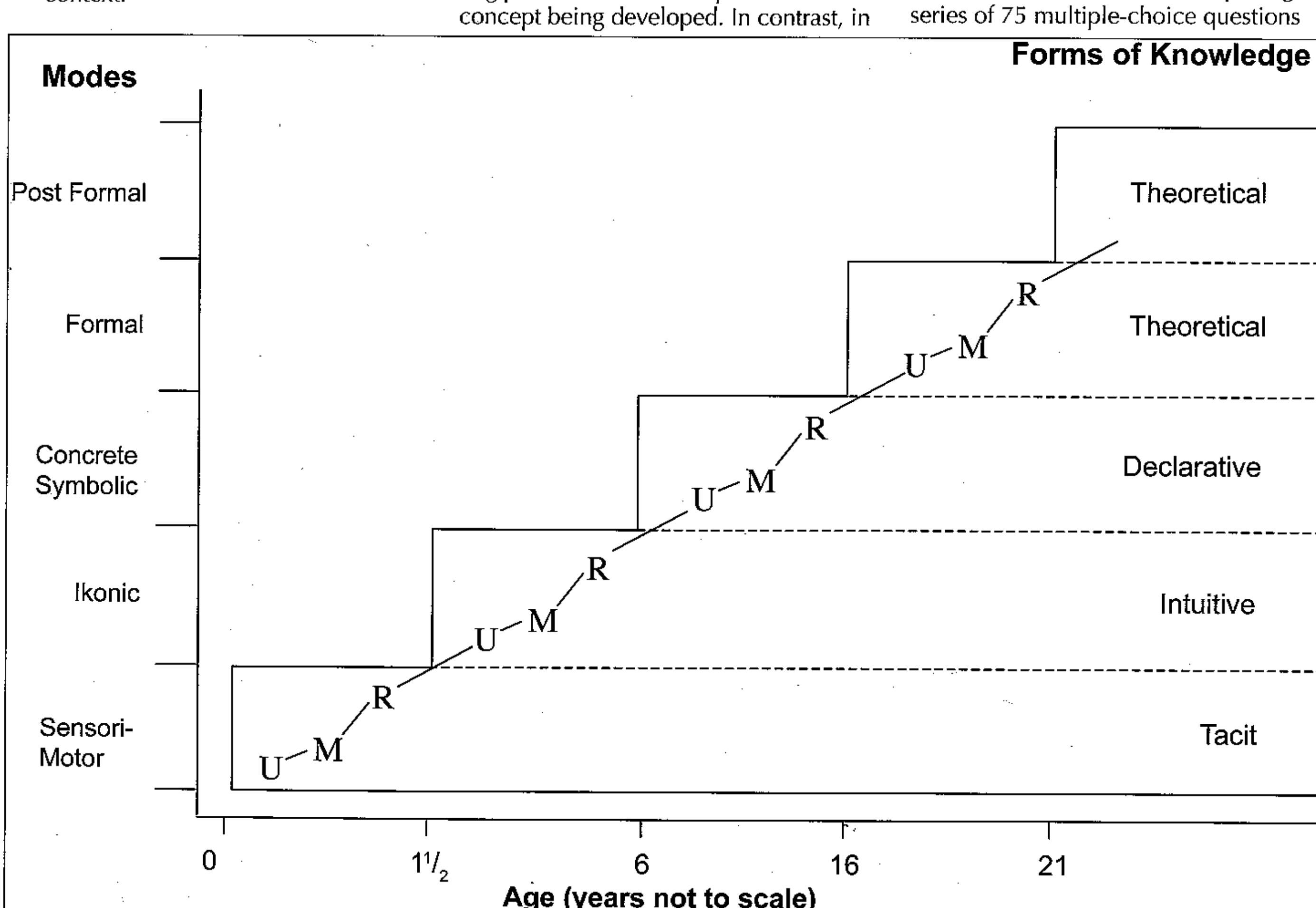


Figure 1. *Modes and learning cycles of the SOLO model (Adapted from Biggs & Collis, 1991)*

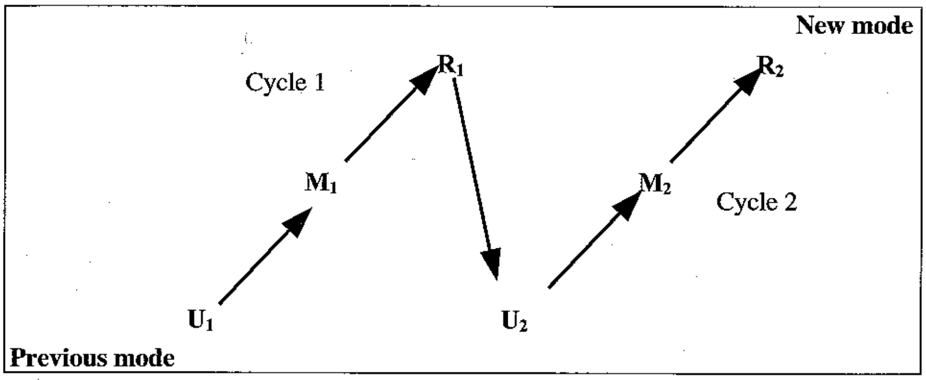


Figure 2. *Two learning cycles in the concrete symbolic mode*

and three extended response items. All items are designed to be topical, relevant and interesting to students at a Year 8 level. An example of the type of stimulus material used is provided in Figure 3.

The multiple-choice items (e.g., Figure 4) provided in ESSA represent the four strands of the NSW Science syllabus (see Table 2) and the unistructural, multistructural, and relational levels in the concrete symbolic mode of the SOLO model. Students' responses to these items are marked electronically.

In contrast, the extended response questions (e.g., Figure 5) allow students the opportunity to *explain* their understandings of scientific phenomena in greater detail. A marking matrix is developed for each question using the six SOLO levels in the concrete symbolic mode (Figure 2). Student responses are scanned into the computer so that marking can be done electronically. The ease of this electronic process emerged recently during the marking of a pilot study of ESSA undertaken by advisers from the Educational Measurement and School Accountability Directorate in December 2005 with Year 8 students from 112 schools in NSW. To assess the responses, thirty experienced Head Teachers were invited to mark 13 000 responses over a 4-day period. This was the first time that large-scale external marking of students' scripts had been undertaken electronically in NSW.

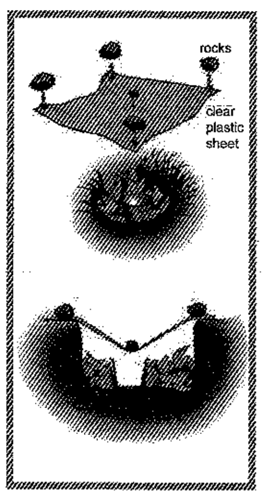
Clearly, a practical skills component that assesses students' abilities to conduct investigations is missing from the test. While the multiple choice and extended response items allow students to interpret graphs and experimental results, it is hoped that an online practical skills section will be incorporated into ESSA in the future. Planning for this is in place and tenders will be called very soon for the development of the relevant software.

Survival in the desert

In arid conditions, the experts recommend that you take extra water with you when you travel.

In emergency situations, a *solar still* may produce some water.

Here is a diagram of a solar still.



What you need
- Spade
- Cup
- Fresh leaves
- Clear plastic sheet
- Rocks

What to do
1. Dig a hole in the ground in a sunny spot.
2. Place an empty cup into the middle of the hold and then surround the cup with fresh fleshy leaves from nearby bushes and trees.
3. Lay a plastic sheet across the hole, holding it in place with some heavy rocks.
4. Place a small rock in the centre of your plastic sheet, so that the sheet forms a 'v' shape directly over the cup.
5. Look in the cup every couple of hours.

Since about 1960, the solar still has been presented in many survival guides as an effective method of obtaining water in arid regions. However, there is some debate about whether a solar still is really useful.

Figure 3. ***Stimulus material for ESSA multiple choice items***

How can ESSA inform teacher practice?

Once ESSA is marked for the cohort results are analysed by staff from the Educational Measurement and School Accountability Directorate in NSW DET. Each school receives data summarising the achievement of individual students, various groups of students within the school, and a summary of the school's performance as a unit. Additionally, information on individual student performance is available for parents in hard copy as a report.

The ESSA data will be provided online to schools through the *NSW DET's School Measurement, Assessment and Reporting Toolkit* (SMART) packages. The SMART ESSA package contains electronic printable files including:

- An *ESSA Student report for parents;*
- An *ESSA Individual student report* that identifies test items answered correctly or incorrectly by each student and information about overall achievement;
- Tables and reports about individual, school and state-wide achievement; and
- Detailed analysis of some test items, accompanied by teaching strategies to improve student knowledge, understanding and/or skills related to the concepts tested (Figure 6).

In addition to the links with the syllabus, the item summary (see Figure 6) provides valuable insights about what options students selected and the possible reasons for these choices. For example, it is interesting that 24.2% of the students for this item selected Option 1 suggesting that it takes the moon one day to go once around the sun. In trying to understand why a student made this selection, the *Distractor Analysis* (see Figure 6) indicates that this may relate to students' observations about the visibility of the moon in a 24-hour cycle.

To help the teacher explore this area further, the major idea or concept is specified along with reference to other items assessing similar ideas in the test. Such information allows teachers to investigate the extent of the misunderstanding and diagnose whether particular strategies, sequences or modes of teaching being used in their classrooms are resulting in students developing inaccurate or confused scientific conceptions. Data collected over the long-term will identify scientific concepts that are more or less demanding for Year 8 students so that teachers can consider alternative ways of helping their students construct scientific understandings.

Read ***Survival in the desert*** on page 2 of the magazine, then answer questions 1 to 4.

1. What is the energy source for the solar still?
   - gravity
   - friction
   - the Sun
   - the plants
2. What is the function of the rock at the centre of the plastic sheet?
   - to absorb heat
   - to direct water into the cup
   - to catch water on the surface
   - to stop the cover from blowing away
3. What is the source of the water in the solar still?
   - plastic sheet
   - collecting cup
   - leaves in the hole
   - rocks on the sheet
4. What occurs during condensation?
   - gas turns to liquid
   - liquid turns to gas
   - solid turns to liquid
   - liquid turns to solid

Figure 4. ***Examples of multiple choice items***

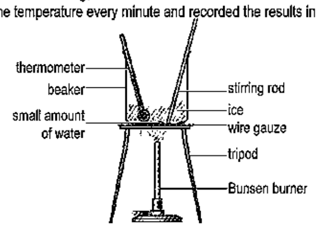
Table 2. ***Proportion of multiple choice ESSA items across strands in the NSW Science Syllabus***

Strand	% of Total
1. Knowing and understanding	55
2. Planning and conducting investigations	15
3. Communicating	15
4. Critical thinking	15

Extended answer tasks

Heating ice

A science class was doing an experiment to observe temperature changes when heating ice. Each group started the experiment with four cubes of ice and a small amount of water in a beaker. They heated the beaker, with constant stirring, over a low Bunsen burner flame as shown in the diagram below. They measured the temperature every minute and recorded the results in a table.



One group of students obtained the following results.

Time (in minutes)	0	1	2	3	4	5	6	7	8	9
Temperature (in °C)	1	1	1	4	15	29	45	61	75	89

a) Using the information from the result table, describe what was happening in the first 9 minutes of the experiment.

b) Using your knowledge of the particle theory, explain why this happens.

Figure 5. ***Example of extended response question***

Where to from here?

ESSA was implemented with 15 nominated schools as a limited trial in September 2005 and followed by an extensive pilot in December 2005 in NSW. In May 2006 another major trial occurred in Western Australia to test items with students outside of the NSW context. These items will be used in a final large-scale pilot in late 2006 with over 400 NSW schools who volunteered for inclusion in this stage of the process. ESSA will become compulsory for all NSW DET schools in 2007 with non-government schools being able to participate in the program. It will probably be conducted in Term 4 (November/December) of each year.

What professional development opportunities are available?

Workshops are being conducted around NSW by staff from the Educational Measurement and School Accountability Directorate. Once ESSA becomes compulsory in 2007, it is expected that further professional development will be made available to science teachers. As with the High School Certificate and School Certificate, teachers will be able to apply to become markers for ESSA. However, use of the electronic system will allow all teachers to have access to the professional development opportunities. This overcomes some of the inequities experienced by rural and regional teachers who struggle to extricate themselves from school and family commitments to attend extensive marking periods in Sydney.

Currently, we are developing a booklet based on ESSA for science teachers. The purpose of the publication will be to provide background information about the SOLO model, examples of ESSA items and student responses, how they were coded, and teaching suggestions to help improve student understandings of scientific concepts. Consequently, the booklet will be a useful resource for all science teachers.

Further contacts

For further information about ESSA, please contact Dagmar Arthur at dagmar.arthur@det.nsw.edu.au or at (02) 9707 6283. Queries relating to the SOLO model and current research being undertaken in the area of assessment should be directed to dpanizzo@une.edu.au or at (02) 6773 5061.

Notes

All material in this manuscript is original where due acknowledgement has been made, and no copyrights have been breached.

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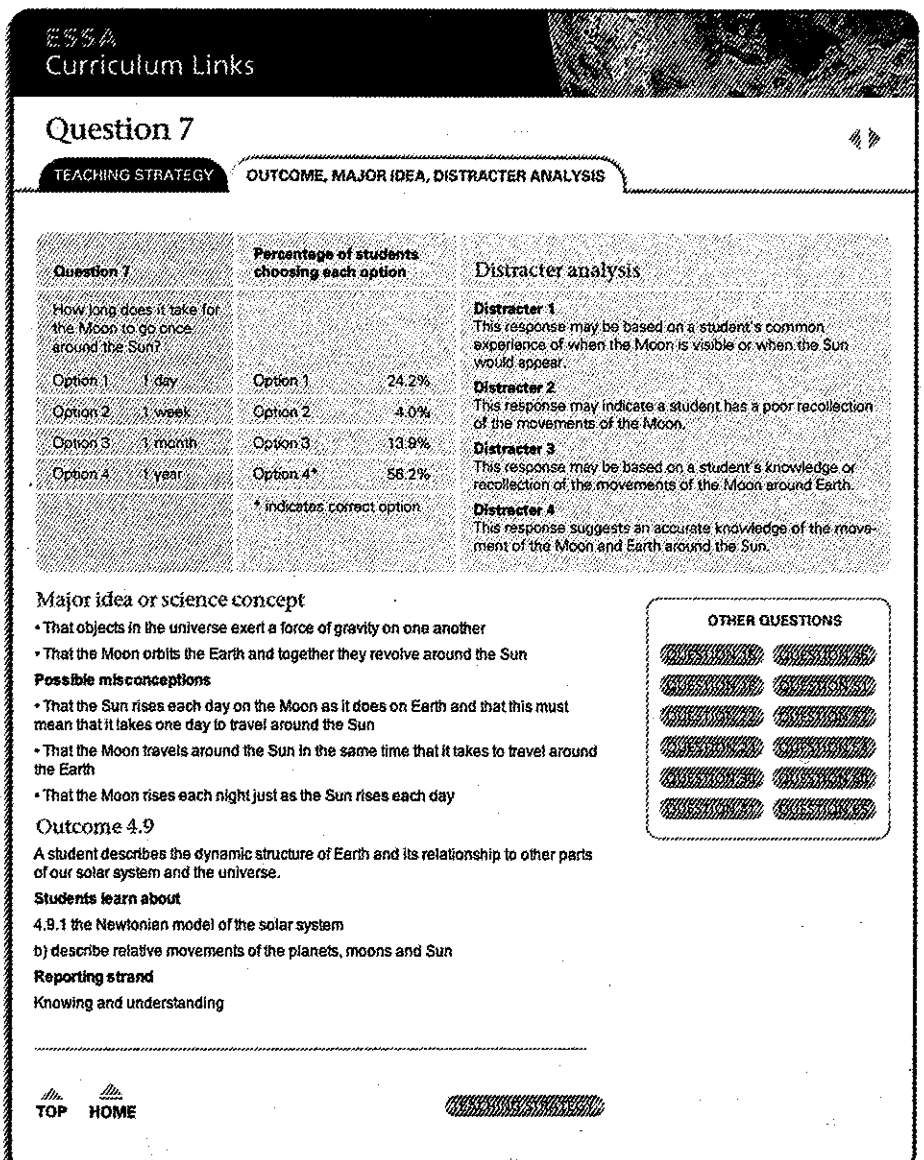

ESSA
Curriculum Links

Question 7

TEACHING STRATEGY | OUTCOME, MAJOR IDEA, DISTRACTER ANALYSIS

Question 7	Percentage of students choosing each option	Distracter analysis
How long does it take for the Moon to go once around the Sun?		**Distracter 1** This response may be based on a student's common experience of when the Moon is visible or when the Sun would appear.
Option 1 1 day	Option 1 24.2%	**Distracter 2** This response may indicate a student has a poor recollection of the movements of the Moon.
Option 2 1 week	Option 2 4.0%	
Option 3 1 month	Option 3 13.9%	**Distracter 3** This response may be based on a student's knowledge or recollection of the movements of the Moon around Earth.
Option 4 1 year	Option 4* 56.2%	
	* indicates correct option	**Distracter 4** This response suggests an accurate knowledge of the movement of the Moon and Earth around the Sun.

Major idea or science concept

- That objects in the universe exert a force of gravity on one another
- That the Moon orbits the Earth and together they revolve around the Sun

Possible misconceptions

- That the Sun rises each day on the Moon as it does on Earth and that this must mean that it takes one day to travel around the Sun
- That the Moon travels around the Sun in the same time that it takes to travel around the Earth
- That the Moon rises each night just as the Sun rises each day

Outcome 4.9

A student describes the dynamic structure of Earth and its relationship to other parts of our solar system and the universe.

Students learn about

4.9.1 the Newtonian model of the solar system

b) describe relative movements of the planets, moons and Sun

Reporting strand

Knowing and understanding

OTHER QUESTIONS

TOP HOME

Figure 6. *Information for teachers and students*

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Dagmar Arthur started her teaching career in 1985. Since 2000 Dagmar has acted in many roles for the NSW Department of Education and Training including as a Science Consultant 7-12, Senior Project Officer, Science for the AGQTP, relieving Senior Curriculum Adviser, Science, and since June 2005 as Team Leader, Essential Secondary Science Assessment.

John Pegg is Professor of Mathematics Education and Director of the SiMERR National Centre located at the University of New England. Currently, he is principal investigator on a number of large research projects to support teachers and enhance student achievement in mathematics and science.