Science and Mathematics Education Centre

Diagnosis of Student Understanding of Content Specific Science Areas Using On-Line Two-Tier Diagnostic Tests

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Declaration

To the best of my knowledge and belief this thesis contains no material previously published by any other person except where due acknowledgment has been made.

This thesis contains no material which has been accepted for the award of any other degree or diploma in any university.

Signature:

Date: October 2008

Abstract

The purpose of this research was to develop an on-line two-tier diagnostic instrument that could be used to identify alternative scientific conceptions held by students and to ascertain the conceptual level at which students are functioning. The instrument was designed to identify alternative conceptions held in relation to concepts that underpin the objectives listed in each of the four content strands of the New Zealand Science Curriculum. The stem questions of the first tier were designed around the curriculum objectives for Levels 4, 5 and 6. Distracters for the second tier were developed from alternative conceptions identified from surveys, teacher predictions and telephone interviews. A 52 item instrument was built into a Microsoft Word format with drop down menu functionality, and then transferred into an on-line format on a web site. The instrument link was sent by email to a student sample in the age range of Year 9 to 11. The student responses were analysed by answer selection and alternative conceptions were identified and classified. The instrument proved to be an economical rapid response tool for identification of student alternative conceptions to inform the design and development of student science learning programmes. The instrument and the component two-tier items have the potential to be used as part of an item bank for formative assessment tests to enhance student learning in science. The on-line functionality of the instrument has the potential to provide the 21st century learner with formative self assessment opportunities to enhance personalized self-directed learning programmes.

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Overview of the chapter

The first part of Chapter 1 provides a description of the purpose of the research, a summary of the research background and a glossary of definitions of terms used in the thesis. This is followed by a description of the rationale for the research leading on to the context of distance education and information communication technology in the development of an on-line two-tier diagnostic instrument for specific content areas in science. The second part of the chapter is a summary of the research methodology and the last part of the chapter is an overview of the research.

Purpose of study

The purpose of this study was to develop a diagnostic instrument that can be used to ascertain a student's conceptual level using the referent, the New Zealand Science Curriculum Statement. The instrument was used to diagnose the science curriculum level at which the student is working by identifying alternative conceptions held in relation to concepts identified in the objectives listed in each of the four content strands in the New Zealand Science Curriculum. Student alternative conceptions were identified from surveys to ascertain alternative conceptions in student samples. The instrument was constructed and delivered in an on-line format to enable rapid response by students, rapid feedback from the teacher, and provide information as part of the discernment process for designing a suitable learner-centred science programme for the student. (Also in dot point in Appendix A.)

Background to study

In his book *Educational psychology: A cognitive view,* Ausubel (1968, p. vi) made the following statement: "The most important single factor influencing learning is what the learner already knows. Ascertain this and teach him accordingly." Ausubel's fundamental idea is that learning takes place by the assimilation of new concepts and propositions into existing concept propositional frameworks held by the learner. Ausubel made the very important distinction between rote learning and meaningful learning. Meaningful learning requires three conditions: 1) The material must be conceptually clear and presented with language and examples relatable to the learner’s prior knowledge; 2) The learner must possess relevant prior knowledge; and 3) The learner must choose to learn meaningfully.

Treagust, Duit and Fraser (1996) stated:

> The many empirical studies provide ample evidence that students hold pre-instructional conceptions in many fields and that these are substantially different from the scientific and mathematical concepts taught in school. Most of these conceptions are strongly held and are hence very resistant to change. (Treagust et al., 1996, p. 2)

Educational research over the last 20 years has indicated that students bring their own ideas into the science classroom and make sense of a particular scientific concept in their own way (Osborne & Freyberg, 1985). Their conceptions are often different from the accepted scientific conception but do, nevertheless, make sense to the students in the context their own world, are often strongly held and are hence very resistant to change (Treagust, Duit & Fraser, 1996). Research shows that students often do not see what they are required to learn in the school science laboratory as being relevant to their own life experiences (Hodson, 1990; Tasker and Freyberg, 1985). They may appear to understand and accept the scientific explanation for a particular phenomenon but do not transfer this understanding to the everyday world situation (Osborne & Freyberg, 1985). Students then often revert to their own alternative conception that makes more sense to them and with which they feel more comfortable (Watson & Kopniek, 1990). It is only when the scientifically acceptable explanation makes more sense to the student than his or her own explanation, that the student will accept the scientific concept and incorporate it into his or her own understanding (Davis, 2001; Duit & Treagust, 2003; Hewson, 1996; Posner, Strike, Hewson & Gertzog, 1982). It is therefore necessary at the start of a new topic to find out about the student's own understanding and then to implement appropriate strategies so that the student’s own concepts are challenged. The student needs to see that his/her own conceptions are less plausible than the accepted scientific conception. This type of pedagogical approach can bring about conceptual change which is essential for understanding science in the student’s own world. (Hewson, 1996).

The above ideas have had a major influence on science curriculum development in New Zealand. Osborne and Freyberg in their book *Learning in science - The implications of children's science (1985)* made the following statement:

> Recent findings from a range of studies, including our own work in the *Learning in Science Project (LISP)* in New Zealand show that children bring to science lessons views of the world and meanings for words that have a significant impact on their learning. As a consequence children's ideas are influenced in unanticipated ways by science teaching. (p. 58)

The New Zealand Ministry of Education professional development guide for teachers of science, *Learning strategies and teaching approaches* (1991), contains the following statement:

> Research on how students learn shows that they must have opportunities to think for themselves - to imagine alternative ways to get to the same goal, and to seek and solve problems. All students bring their own ideas and creative potential to their learning and it is important for teachers to build on this. (p. 1)

The publication goes on to state that “Meaningful learning explores students' own ideas and gives them the opportunity to develop these ideas by encouraging them to see that science gives more useful explanations than their own”(p. 3). The learning theory outlined above is essentially the constructivist viewpoint that forms the basis for teaching approaches and strategies for many modern science curricula. There are many versions of constructivism but generally, to constructivists, a learner actively constructs knowledge as s/he seeks to make sense of his/her own experience. Understanding is, therefore, not something that can be given, nor can it be passively received. Constructions are formed as learners seek to understand their experiential world making connections with pre-existing knowledge, forming and testing hypotheses to explain observations (Yager, 1991). The learner is in search of viable explanations for his/her experiences or observations. Treagust et al. (1996) made the following statement:

> The constructivist view allows us to explain that students' pre-instructional conceptions are difficult to change by instruction because they guide or even determine students sense making process when information is provided by the teacher or textbook. (Treagust et al.1996, pp. 7-8)

Similarly, Duit, Treagust & Mansfield(1996) state that:

> Investigations of students' conceptions reveals important insights into student' ways of thinking and understanding in science and mathematics, but also can help researchers and teachers revise and develop their own science and mathematics knowledge…….Thus revealing students' alternative conceptions can also lead teachers to re-evaluate their own understanding of scientific concepts. (Duit, Treagust & Mansfield, 1996 p. 17)

The New Zealand science curriculum statement *Science in the New Zealand Curriculum* suggests for two of the ways for enhancing achievement:

> Students have an opportunity to clarify their own ideas, to share and compare, question, evaluate and modify their ideas, leading to scientific understanding. (Ministry of Education**,** 1993, p. 10)

> Teachers and students work within a supportive atmosphere of mutual respect where all the experience, ideas and beliefs, which students bring into the learning situation are acknowledged as a basis for learning. (Ministry of Education, 1995 p. 10)

The New Zealand Curriculum Draft for consultation 2006 emphasises in a more general cross curricular context the need for students to build on what they already know in a community of learners.

> Students learn best when they are able to integrate new learning with what they already understand. When teachers deliberately build on what their students know and have experienced, they maximize the use of learning time, anticipate students' learning needs, and avoid unnecessary duplication of content. Teachers can help students to make connections across learning areas as well as to home practices and the wider world. (Ministry of Education, 2006b, p. 24)

Definition of terms used in this thesis

Alternative conceptions – beliefs held by students which are at odds with orthodox science (evidence supported by the majority of scientists) (Taber, 2000, p. 63).

Alternative frameworks – Students' own beliefs and expectations differing in significant ways from those to be taught (Driver, 1983, p. 3).

Asynchronous – A process where various aspects of content are developed and delivered in isolation from each other, or intermittently (Ministry of Education, 2002c p. 63).

Belief – knowledge that is viable in that it enables individuals to meet their goals in specific circumstances (Tobin, 1996, p. 175).

Children's science – Children's views of the world and meanings for words which are unexpectedly different from those of adults in general and scientists in particular, and which influence children's subsequent learning in science (Osborne & Freyberg, 1985, p. 1).

Concept - A perceived regularity in events or objects, or records of events or objects, designated by a label such as a word (Novak, 1996, p. 32).

Constructivism – A theory of learning or meaning making, that individuals create their own new understandings on the basis of an interaction between what they already know and believe and ideas and knowledge with which they come into contact (Richardson, 2003, p.1).

Context – The topic chosen by the teacher with the specific intention of linking the more abstract science ideas - the concepts - to the everyday world of the lived experience (Hipkins, Joyce & Bull, 2000, p. 1).

Diagnostic assessment – Assessment designed to ascertain the learning needs of the student (A diagnostic question is one which can provide evidence of a learner's understanding of a specific point or idea) (Millar & Hames, 2001b, p. 1).

Feedback – Information about a gap between the actual level and the reference level of a system parameter which is used to alter the gap in some way (Ramaprasad, 1983, p. 4).

Formative assessment – A process, one in which information about learning is evoked and then used to modify the teaching and learning activities in which teachers and students are engaged (Black, Harrison, Lee, Marshall & Wiliam, 2003, p. 122).

Learning object (LO) – An independent and self-standing unit of learning content that is predisposed to reuse in multiple instructional contexts (Polansi, 2003, p. 6).

Life-world – The everyday lived experience that learners bring to a learning setting (Kalantzis, 2004, p. 3).

Metacognition – Knowledge about, and awareness and control over, personal practice (Baird & White, 1996, p. 190).

Misconceptions - Student held conceptions or ideas that are not in harmony with science views (scientifically acceptable evidence) or are even in stark contrast to them (Duit & Treagust, 2003, p. 671).

Pedagogy – The science, art and craft of teaching and learning (Wenmoth, 2003).

Preconceptions – Pre-existing organising principles in the learner's cognitive structure (Ausubel, 1968, p. 335).

Proposition - A statement about an object or event in the universe, either naturally occurring or constructed. A proposition contains two or more concepts connected with other words to form a meaningful statement (Novak, 2004, p. 1).

Science – A way of investigating, understanding and explaining the natural, physical world. It involves generating and testing ideas, making observations, and carrying out investigations and modeling, in order to develop scientific knowledge, understanding and explanations. Scientific progress comes from logical, systematic work, and from creative insight, built on a foundation of respect for evidence. It incorporates knowledge from many cultures and periods of history (Ministry of Education, Science Essence Statement, 2006d, p. 1).

Summative assessment – Processes that summarise and report students' achievements at a given point in time (Education Review Office, 2007, p. 3).

Synchronous – A process where various aspects of content are developed and delivered in relationship with each other, or concurrently (Ministry of Education, 2002c, p. 64).

Understanding - The extent to which one's internal mental models successfully predict and explain events in the external (everyday) world (Fisher & Lipson, 1986, p. 785).

World view – The general belief system motivating and guiding the inquiry (Novak, 1990, p. 34).

Rationale of study

Effective learning can best be achieved by implementing assessment strategies for ascertaining what students know at the start of a new topic and incorporating these into science teaching schemes. There are a large range of strategies available, but the most useful must survey as many students as possible and not disrupt classes to any great degree. Probably the best way to find out what students think about a particular topic is by talking to them individually. Interviews, however, are time consuming, require purposeful sampling from classes and also require skill and experience on the part of the interviewer. Interviews are not feasible for a teacher as part of an on-going teaching programme (Duit, Treagust & Mansfield, 1996). This situation is particularly the case in the distance education setting.

Diagnostic tests or surveys of the multi-choice type have certain drawbacks because they are often compiled by teachers with a correct answer in mind, together with a number of 'distractors' designed by teachers to give particular types of error (Osborne & Freyberg 1985, p. 166). In most types of multi-choice items, the origin of the distracters is not specified and the items do not necessarily investigate conceptual understanding. Distractors based on students' answers to open-ended questions provide better indicators of students' conceptual understanding of specific content areas in science. Osborne and Freyberg (1985) found that, although the range of ideas that students hold is large, on a particular concept their ideas can be grouped into four or five categories. Treagust (1995a) describes an approach using two tiers of multiple choice items with distractors to diagnose students' conceptual understanding of specified content areas in science. The first tier involves a **content response** and the second tier a **reasoning response.** The items are developed based on research literature and responses by students to free response items and interviews. The source of the items is specified clearly and the conceptual area is documented by propositional knowledge (Duit et al., 1996). Thus, carefully compiled multi-choice surveys can be useful for ascertaining students' ideas and alternative conceptions. The instruments are easy to mark and quick to analyse, and can be useful for evaluating evidence for conceptual change if the survey is administered again at the end of the topic. Instruments of this type take a lot of time to design but once established can provide the teachers with useful data for remediating learning.

The two-tier format for a multi-choice type diagnostic instrument offers an opportunity to ascertain the deeper level of understanding that students may have in relation to a particular scientific concept. In the first tier, the student can make a decision between a choice of two possibilities e.g. 'True' or 'False'. The second tier provides four possible reasons to explain the reason for the first tier choice. If the two-tier instrument is carefully designed it can ascertain common alternative conceptions that students at a particular academic frequently have.

With increasing use of computers and the Internet in education, much interest has been shown in the development of this technology to deliver teaching and learning to students. Technology has greatly increased the scope for flexibility in the learning environment whereby students can undergo learning anywhere, anytime, and at any pace. In other words, there is scope for customisation and personalisation of student learning. The trend can be summarized succinctly as moving towards a learner-centred, digitally-minded pedagogical paradigm. With a smorgasbord of choice for students of electronic modules, reusable learning objects (Longmire, 2000) can be customised to the needs of each student. In order to match the teaching with students' need, the electronic diagnostic test becomes a powerful and useful tool for both student and teacher.

It is in the electronic teaching environment that two-tier diagnostic tests have been adapted and trialed for use as diagnostic instruments to provide a basis for individualisation of student science learning programmes as well as for ascertaining conceptual change and hence value added. These diagnostic indicators can provide information for both learner and facilitator which enables units of learning to be selected depending on the conceptual level of the learner and alternative conceptions that can affect constructions of understanding. On the basis of this information, a customized, learner-centred programme of learning can be designed that may enable the student to reach his/her potential over an appropriate period of time.

Distance education and information communication technology

Distance education can provide a learning environment that is flexible, learner-centred and personalised. With suitably designed modules, it is possible to provide the granularity that will enable the learner to have a smorgasbord of choice in terms of the makeup of his/her programme in terms of academic level, interest, learning style, pace and preferred medium. Digital technology greatly increases the possibilities with the provision of reusable learning objects (Longmire, 2000) that can be used to build programmes that will enhance and ultimately replace the traditional print-based medium.

The New Zealand Correspondence School is moving into this learner-centred, digitally-minded paradigm for provision of access to learning. The problem for distance education is that it is more difficult than in the face-to-face environment to ascertain the full range of scientific alternative conceptions that exist in a cohort of students. Synchronous teaching strategies offer possibilities with virtual classrooms and videoconferencing for the type of interaction that can be used in the face-to-face environment and these strategies have been shown to work well with small groups of students. Hard copy pencil and paper diagnostic surveys are a more economical way of ascertaining the range of student scientific alternative conceptions that a student or cohort of students hold prior to planning a suitable programme of learning. This type of instrument has proved effective for this task in face-to-face settings as a more economical strategy for ascertaining student alternative conceptions in order to inform the subsequent pedagogical process.

In distance education, where student numbers per teacher can be comparatively large in addition to the greater difficulty of synchronous interaction, an on-line adaptation of these diagnostic instruments would provide for much more rapid feedback and for electronic processing of the student responses. Economic factors play a significant part in the desirability of such diagnostic indicators (Barrett, 1998). With economic rationalisation, The New Zealand Correspondence School, like all educational institutions, has to balance the educational needs of students with cost of providing the programmes of learning they need. Greater learner-centredness is more costly due to the time spent developing appropriate programmes for cohorts of students. On-line multichoice diagnostic indicators with rapid analysis of student responses offer a possible economical yet effective and reliable way of ascertaining student understanding of science and alternative conceptions as well as the level of student thinking to inform the development of appropriate programmes.

Information communication technology (ICT) has huge potential for the distance learner in providing a means to achieve social interaction as a vehicle for the learning process. This potential can be achieved synchronously by involvement in virtual classrooms or by videoconferencing. Asynchronous interaction via bulletin boards also provides opportunities for greater interactivity and can have certain advantages over the conventional classroom in terms of the degree of student participation and the thought processes that go into student contributions (Kassop, 2003). ICT also can provide the learner with increased access to units of learning that allow for a hugely increased choice and for customisation of learning programmes according to the needs of the individual learner (Sampson, Karagiannidis & Kinshuk, 2002). Ascertaining these needs is an essential process in order to map learning pathways that lead to the outcomes desired by the learner, but also provide learning opportunities that form stepping stones (Niedderer, 1997) along the learning path or the scaffolding (McKenzie, 1999) to facilitate the construction of new understandings. The learning process need not be sequential, although parts will need to be, but can be branched according to the needs and choices made by the learner in consultation with the learning programme facilitator.

The New Zealand Correspondence School has been a distance education provider for more than 80 years. In that time, it has become the major distance education provider in New Zealand for secondary, primary and early childhood students. Up until the year 2000, distance education has been primarily via paper-based resources supplemented by telephone communication. In the past the mode of educational delivery has been transmissional whereby the pedagogy has been embedded in the paper-based resources. These resources had a structural design whereby the resources were essentially sequences of paper-based reusable learning objects (RLOs) consisting of a teaching unit followed by activities for students to apply their learning, followed by an assessment activity to measure achievement. With the advent of ICT, resource development is moving away from static paper-based resources to dynamic systems for students to access their learning. These dynamic systems include virtual classrooms, videoconferencing, teleconferencing as well as increased use of telephone interaction. This type of change in distance education has been described as from transmissional to transactional pedagogy (Garrison, 2000; Wilson & Spink, 2005). The integration of ICT into teaching and learning increases the ways in which learning can take place for the distance learner via a combination of modes of discourse. The use of static and dynamic resources through synchronous and asynchronous interaction by which students can access their learning is summarized in Figure 1.1 (Ministry of Education, 2002a, p. 10).

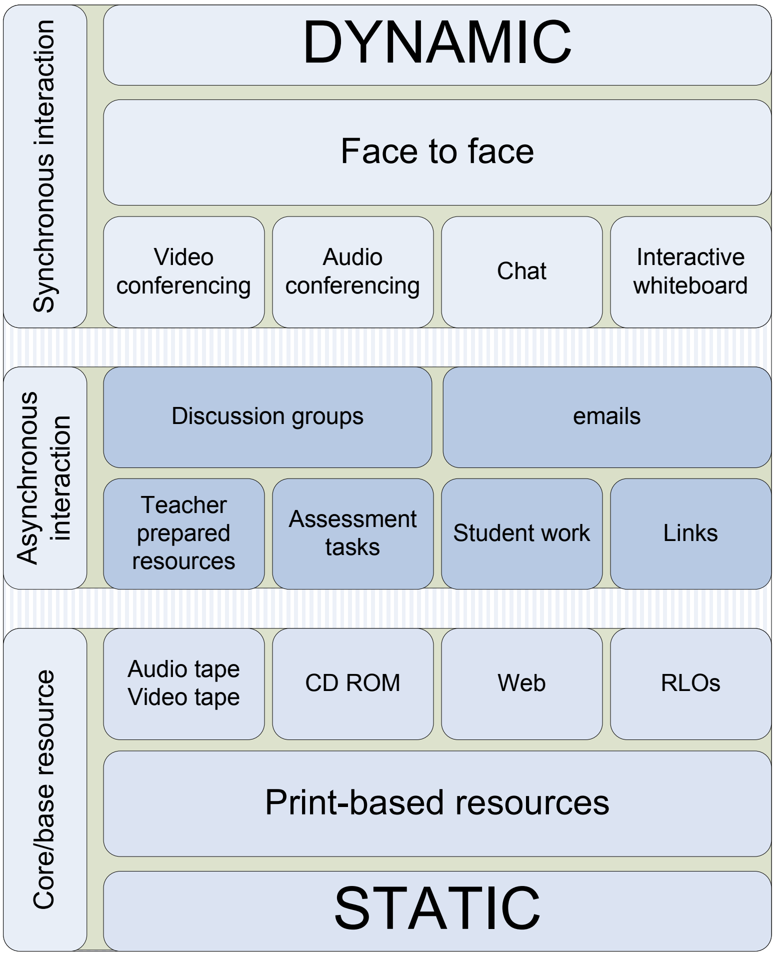


Figure 1.1 Interactions and resources

(Source: From the Ministry of Education publication Digital Horizons, 2002, p.10).

Synchronous interaction is where teaching and learning occur through discursive processes in real time learning environments such as face-to-face, videoconferencing, virtual classrooms and teleconferencing. Asynchronous interaction is where teaching and learning are separated by time such as paper-based correspondence, CD ROM, audio tapes, video tapes, web sites and RLO's. The change in pedagogy is from transmission, whereby knowledge is transferred from teacher to learner via the resource, to transaction, whereby a community of learners interact to achieve shared understandings (Garrison, 2000; Wilson & Spink, 2005). This change in pedagogy coincides with a shift away from delivery of teaching towards access to learning. Thus the use of digital technologies enhances the ability of the learner to access flexible, non-linear programmes appropriate to his/her learning needs with schemes of work succinctly described as learner-centred, digitally- minded.

The programmes of learning (POLs) for students are built by a process consisting of six components as shown in Figure 1.2.

- Discern – ascertaining the needs of the learner.
- Design – working out a programme of learning appropriate to the needs of the learner.
- Develop – selection of appropriate static resources and dynamic processes to provide and implement a coherent, customized programme of learning.
- Access – opportunities learner has for accessing learning.
- Account – formative assessment processes to enable the student to ascertain progress in learning and to inform modification to the POL.
- Assess – summative assessment to measure the learning that has taken place at appropriate stages of the programmme.

Figure 1.2 Stages in building a programme of learning

The first three components begin with 'D' and the last three begin with 'A'. This led to calling the stages of the process the learning D'n'A. The Learning D'n'A can be summarized as shown in Figure 1.3 (The Correspondence School, 2002, p. 3).

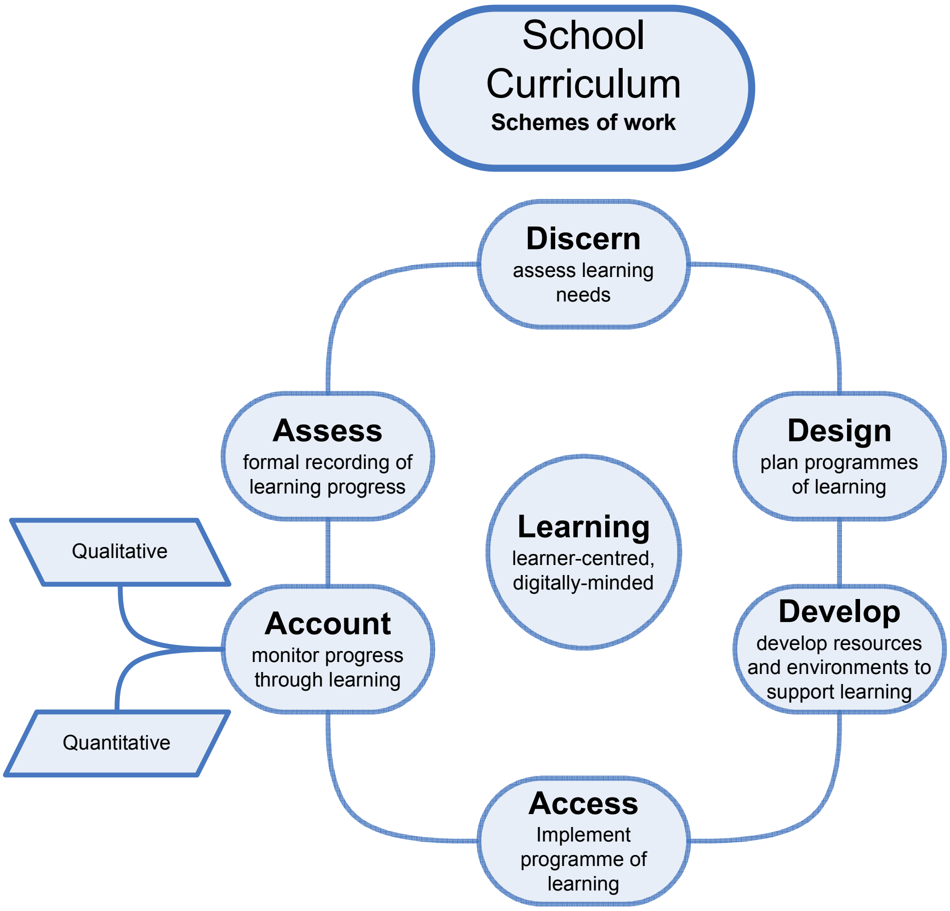


Figure 1.3 The Learning D'n'A

The first component in the learning D'n'A is to discern or identify the needs of the learner. This is important if the programme of learning in which s/he will be a participant is to be designed specifically to meet these needs, rather than simply delivered as an off-the-shelf commodity to be consumed. Information contributing to this process is accessed at two levels. The first level is information about an individual student that can be gathered and stored at the time of enrolment – an initial data capture phase. This generic information can then be available to all those teaching that student, and need not be repeatedly asked for. At the second level of the discernment stage is the information that is specific to the particular subject or programme of learning. Processes need to be devised by teachers and departments for this, and organization systems put in place to allow them to record and manipulate this information easily.

A diagnostic instrument can be used for this part of the discernment component in the learning D’n’A cycle. An on-line two-tier multichoice diagnostic instrument fits in well with this scheme in providing information about the learner quickly that can be processed rapidly to enable a customized programme of learning to be designed and developed for the learner. Once the programme of learning is in place, the development process would involve providing the pedagogical ‘glue’ to link and contextualize the static resources via the dynamic processes allowing for continued formative assessment to enhance learning and fine tune the learning programme to the appropriate content and level.

Summary of the Research Methodology

The New Zealand science curriculum objectives provided an external reference for the concepts in the distance education programme; the curriculum levels represent levels of thinking or conceptual development in the student. Items in the diagnostic test were to be linked to specific curriculum objectives within Levels 4, 5 and 6 of the Science Curriculum Statement. The items in the instrument were also to be referenced to the four contextual strands of the Science Curriculum. The objectives themselves are mostly skill-based and the skill is signified by first word in the objective such as investigate or research. Achieving the skill in each objective is dependent on the learner understanding an underlying scientific concept. These fundamental underlying concepts were identified within each of the four objectives of each strand for each of the Curriculum Levels 4, 5 and 6. A concept map was drawn for each strand and propositional knowledge statements were constructed linking the conceptual development into a sequence within the strand.

Three surveys were designed, one for each of the three curriculum levels 4, 5 and 6. each question focussed on the concept underpinning each curriculum objective. The questionnaire items used themes that were likely to be relevant and familiar to the life-world experiences of students at that level. Research has shown that student alternative conceptions fall into three to five broad categories (Freyberg & Osborne, 1985). Subsequently, the items in each questionnaire were designed to ascertain the range of student alternative conceptions relating to a each curriculum objective. The items had the format of a question requiring the student to choose between two alternatives (eg true/false) and then write a reason for their choice. The survey items were numbered for clarity and instructions included an example.

The surveys were then given to classes of students in face-to-face schools. The Level 4 survey was given to a Year 8 class, the Level 5 survey to a Year 10 class and the Level 6 survey to a Year 11 class. The purpose of the survey was explained. The survey samples were collected from students working in programmes at each of the three levels and categorised using the SOLO taxonomy (Biggs & Collis, 1982; Biggs, 1995) according to levels of thinking and reasoning. Further surveys were sent to classes of Correspondence School students at Years 9, 11 and 12. This was done at the beginning of the academic year when the students had completed their science programme for the appropriate curriculum level during the previous year but had not yet commenced the programme at the next curriculum level. A sample of respondents to these surveys was given a follow-up telephone interview to check on whether the answers they gave matched their thinking around particular scientific concepts.

A sample of six teachers at the Correspondence School were given the survey and asked to anticipate alternative conceptions by writing down the types of answers that students of a particular age group would give. The teachers selected had long experience in face-to-face schools prior to coming to teach at the New Zealand Correspondence School and were well versed in the scientific alternative conceptions students that each age group held.

The categories of alternative conceptions from the student and teacher surveys were used to construct items for the second tier of each of the questions. There were 52 two-tier items and these were used to construct the diagnostic instrument designed to ascertain student alternative conceptions relating to the underlying concepts of each of the curriculum objectives and sub-objectives at Levels 4, 5 and 6 of the New Zealand Science Curriculum.

Much work was done working on digital formats for the indicators and various systems were tried from the simple HTML version to more complicated Flash-generated versions. Major considerations for workability in the current situation with students at The New Zealand Correspondence were student ICT capability, technical specifications and connectivity. The proportion of students with email addresses at the time of conducting the survey was around 60%. A form handler template was created to put the indicators into HTML format. The tests were then placed on the The New Zealand Correspondence School website. Students were sent a link by email to enable them to access the indicator and select answers to the questions. When completed, the students clicked a 'Send' button to send their responses back to the author via email.

Three cohorts of students were selected, a cohort of Year 9 students on a Level 4 science programme, one of Year 10 students on a Level 5 programme and one of Year 11 students on a Level 6 programme. A total 60 New Zealand Correspondence School students who had email access were sent the indicator. Of these, 47 were completed and returned. The Form Teachers of the students sent a reminder by email and phone to raise the return rate to this level. Care was taken with the distance learners to include the range of students in each sample in terms of gender balance, ethnicity composition, reason for enrolment and level of engagement. The returns were collated on a grid. The student responses were analysed by type and range of alternative conceptions and against the curriculum level to which their programme is designed to teach.

The research showed that the diagnosis of these instruments correlated well with the existing discernment indicators and identified a range of alternative conceptions held by the students.

Overview of the study that follows

After discussing the purpose, background, rationale and contextual significance of this study in Chapter 1, Chapter 2 presents a review of literature related to the research that includes research on learning theories, outcomes of conceptual learning, conceptual change, methods of ascertaining student alternative conceptions, formative assessment, diagnostic assessment and the distance learning context.

Chapter 3 provides a description of the methodology used to help identify students' alternative conceptions. This procedure involved the development of concept maps and propositional statements and the design of stem questions. This led on to identification of student alternative conceptions by three search techniques, building of the diagnostic instrument. The final stages involved putting the instrument into an on-line format and trialing the instrument with student cohorts.

Chapter 4 describes how the alternative conceptions identified from three search techniques were analysed and collated as identified alternative conceptions.

Chapter 5 describes the results of the administration of the on-line diagnostic instrument with an item analysis of the two tier instrument. This procedure involved identification of major alternative conceptions, analysis of the number and type of alternative conceptions identified, analysis of the curriculum level at which students are working and analysis of the level of difficulty of the instrument items.

Chapter 6 presents a discussion of the efficacy of the instrument in diagnosing student learning needs followed by conclusions, limitations, recommendations and possible future developments in the environment of the 21st century learner.

Chapter 2
Review of Related literature

Overview of chapter

The first part of Chapter 2 provides a review of research literature on cognitive learning theories and the development of constructivist learning theory with its range of versions. There is a review of research into the outcomes of conceptual learning followed by conceptual change theory and its implications for science teaching and learning. The second part of the chapter reviews strategies for ascertaining student alternative conceptions leading on to formative assessment and feedback as significant ways to improve student engagement and learning. This leads on to discussion of diagnostic assessment as a tool to ascertain student alternative conceptions, discern student learning needs and inform the next steps in the learning programme. The final part of the chapter considers the context of the distance learning environment and how information technology can enhance the learning environment for these pedagogical processes to occur in a social learning environment involving a community of learners.

Learning theories and student alternative conceptions

The transmission model for teaching holds that the learner is like an empty vessel to be filled with knowledge transmitted directly by the teacher. The role of the teacher in this model is to repackage knowledge into meaningful units that the learner can absorb. The teacher's knowledge thus becomes the learner's knowledge and transfer of understanding has occurred. All alternative conceptions that the learner hitherto held are simply replaced by the superior scientific knowledge from the teacher. Ausubel (1968) asserted that the student's mind is far from being an empty vessel or *tabula-rasa* but contains a form of indigenous knowledge built up by the learner as a result of sense making processes gained through his/her lifeworld experiences. This knowledge is often at variance with scientific knowledge and has a significant effect on the subsequent learning process. Ausubel used the term preconceptions to describe the non-scientific notions that make up much of the learner's prior knowledge.

David Hawkins (1978) described such preconceptions as critical barriers to science learning because development of scientific concepts can seem counter intuitive to the learner. " ……the discrepancy or unresolved conflict between the scientific and common sense-perceptual models" (p. 7). These unresolved conflicts contribute to the alternative conceptions that students hold in relation to scientific understanding which can act as barriers to further learning.

The notion of prior knowledge and its unanticipated effect on learning was discussed further by Osborne and Whitrock (1985). They asserted that this prior knowledge has a significant influence on the way in which new knowledge is received and incorporated into the learner's conceptual framework. Prior knowledge is an important factor in the constructivist view of student learning. Treagust, Duit and Fraser (1996) stated:

> The many empirical studies provide ample evidence that students hold pre-instructional conceptions in many fields and that these are substantially different from the scientific and mathematical concepts taught in school. Most of these conceptions are strongly held and are hence very resistant to change. (p. 2)

Various terminologies are used for student's pre-instructional notions such as "misconceptions" (e.g. Doran, 1972; Driver & Easley, 1978, Helm, 1980, McClelland, 1985), "children's science" (Osborne & Freyberg, 1985), "world knowledge" (Gunstone, Champagne & Klopfer, 1981), "alternative frameworks" (Novak, 1977, Driver & Easley, 1978) and "naïve conceptions" (Champagne, Klopfer & Gunstone, 1982), "provisional science concepts" (English & Hipkins, 1999; Hipkins & English, 1999). In this thesis, I will use the term "alternative conceptions" in preference to the term misconception. Misconceptionimplies that notions are incorrect, when in fact, they often serve learners adequately in making sense of their experiential world. -(Vosniadou, 2008).

The constructivist theory of learning recognises the significance and effect of the learner's prior knowledge on subsequent learning and is used as a referent for teaching approaches and strategies in many modern science curricula. There are many versions of constructivism (Ernest, 1995; Geelan, 1997) which range from naïve constructivism which has an objectivist epistemology, in which scientific knowledge is seen to reflect reality, through to radical constructivism which asserts that scientific understanding exists in the minds of the knowers and may not reflect reality (Von Glasserfeld, 1990). Generally, the constructivist view of learning is that the learner actively constructs knowledge as he or she seeks to make sense of his or her own experience. Therefore from the learner's perspective, knowledge is not something that is passively received, but is actively built up by the cognising subject (Wheatley, 1991).

Constructions are formed as individuals seek to understand their experiential world. Connections are made with pre-existing knowledge, and hypotheses are formed and tested to explain observations. The learner is in search of viable explanations for his or her experiences and observations as noted by Treagust et al. (1996):

> The constructivist view allows us to explain that students' pre-instructional conceptions are difficult to change by instruction because they guide or even determine the student's sense making process when information is provided by the teacher or textbook. (p. 3)

Revealing students' alternative conceptions can also lead teachers to re-evaluate their own understanding of scientific concepts as well as their view of the student thinking process. This point is reflected by Duit et al. (1996):

> Investigations of students' conceptions reveals important insights into student ways of thinking and understanding in science and mathematics, but also can help researchers and teachers revise and develop their own science and mathematics knowledge. The awareness of alternative points of view, namely, the students' perspectives, allows researchers and teachers to see their own views in totally new ways that can result in major reconstruction of their science and mathematics knowledge or their convictions about how this knowledge should be presented in the classroom. (p. 17)

The fundamental tenets of constructivism are not new. Dewey's (1922) approach to education was to attempt to connect subject matter with the child's experiences. Piaget's cognitive developmental theory contains elements of the constructivist theory of learning (Piaget, 1960; 1963; 1976). Piaget stressed the need for researchers and teachers to be aware of the stage of development of the learner as well as the learner's prior knowledge related to concepts in new material being studied. As a child develops, understanding of the world becomes more sophisticated. Piaget (1963) observed that experience is critical to a child's cognitive development. According to Piaget, a child's perception and understanding of the world emerges in distinct age related stages.

Vygotsky (1962) asserted that learning preceded and contributed to cognitive development in contrast to Piaget's view that cognitive development is dependent on age-related stages. Vygotsky also introduced the social and cultural dimension to the learner's sense-making processes by asserting that the community plays a central role and the people around the student greatly affect the way he or she sees the world. This social interaction is mediated through the use of language which plays a central role in cognitive development.

Vygotsky's viewpoint contributed to the social constructivist learning model in which learning is a social and collaborative activity. The learner constructs his or her own understanding and this understanding is mediated through communication with significant others in the learner's social environment. Vygotsky (1978) proposed a "Zone of Proximal Development", also called "construction zone", which represents the conceptual gap that the student can bridge by performing learning tasks with the appropriate support and guidance. Vygotsky (1978) asserted that if this gap was too large the learner would not be able to make the change without assistance and the support of scaffolding to facilitate the necessary construction of new concepts necessary to be in striking distance of the target conceptual understanding. Alternative conceptions are, therefore, according to the social constructivist model, a conflation of students' sense-making processes through their life-world experiences, their stages of cognitive development and their social interaction (Solomon, 1992).

Situated learning (Lave & Wenger, 1991) involves the generation of scientific knowledge in a community of practice that provides an authentic learning situation in which certain beliefs and behaviours are acquired. Cognitive apprenticeship (Collins, Brown & Newman, 1989) introduces the learner into the culture of the expert through a step-by-step process in an authentic learning situation. Cultural constructivism (Hutchison, 2006) puts learning into a wider context by recognising cultural influences. Taylor (1996; 1998) describes critical constructivism that addresses the socio-cultural context of knowledge construction and adds a dimension whereby knowledge is constructed in a critical environment in which dialogue is orientated towards achieving reciprocal or mutual understandings in a community of learners.

Outcomes of conceptual learning

Many researchers stress the need for the teacher to be aware of stages of development of the learner and also the learner's alternative conceptions associated with what is to be experienced when exposed to new scientific ideas and concepts. Ausubel (1968) discussed the need for teachers to view student preconceptions as alternative ways of looking at experience but also to use them to inform teaching strategies to challenge students and prevent conflicts at a later stage.

The issue of student alternative conceptions and the way in which they can interfere with accepted scientific concept development is discussed by Driver and Easley (1978); Gilbert & Osborne, 1980; Gunstone, Champagne and Klopfer (1981) and Fisher and Lipson (1986). All of these researchers indicate the difficulty of changing entrenched student alternative conceptions and also point out that these alternative conceptions may interfere with new concepts where they conflict with the alternative conception. This situation can result in unsatisfactory outcomes ranging from the student developing two parallel sciences, the everyday one and the school science (Driver & Easley, 1978; Gilbert, Osborne and Fensham, 1982 and Solomon, 1987), to complete rejection of the accepted scientific concept. Also, a range of intermediate outcomes can occur which could be worse for the student than being left with his/her original conception. Gilbert, Osborne and Fensham (1982) described the following possible outcomes:

1. The undisturbed children's science outcome - student continues to hold original idea as the only rational way of explaining experience.
2. The two perspective outcome - two viewpoints held which are unrelated and incompatible.
3. The reinforced outcome - taught ideas are unintentionally misinterpreted as

lending support to the learner's original idea.

4. The confused outcome - learner loses confidence in original idea without better ones being constructed.

5. The unified outcome - coherent scientific perspective which the student can relate to other aspects of what he/she learns.

The nature of the alternative conception can vary in terms of the cognitive level at which the learner is functioning and the mismatch between this and the cognitive level required to understand the particular concept in question. Various taxonomies have been devised for measuring cognitive levels of thinking and these can be applied to the cognitive level required to understand the concept and also to the level of thinking that the student applies in formulating his/her own alternative conception. Examples of these are Blooms taxonomy of educational objectives (Bloom, 1956), the Structure of Observed Learning Outcomes taxonomy (Biggs & Collis, 1982) and the Three Storey Intellect (Fogarty & Bellanca, 1991). There can be a mismatch between the cognitive demands of the scientific concept and the cognitive level at which the student is functioning. The latter may be a combination of maturity (Piaget, 1960) or level of development of the learner through engagement in formal or informal educational processes (Vygotsky, 1978). This conceptual gap could determine whether or not the learner is likely to be able to make the necessary concept shift in order to reach the desired level of scientific understanding.

Black and Simon (1992) used a metaphor of two countries, the science country inhabited by scientists and science teachers, and the pupils' country. Progression involves strategies for constructing and crossing the bridge between the two countries which may involve strategies for conceptual change or conceptual development. The authors point out the possible influence of the intertwining of the developmental sequences of learning that take place in the student's own country over time, irrespective of any science teaching, and the learning that the student does achieve through science teaching. Hipkins, Joyce and Bull (2000) describe the 'cycle of learning' which proposes taking students through a four stage strategy involving mini-concepts, called conceptual foothills, which are stepping stones to reach a major concept or big scientific idea.

From a different perspective Duit and Confrey (1996) describe two complementary kinds of learning in science and mathematics, conceptual growth and conceptual change: “Conceptual growth refers to the enlargement of the conceptual network in such a way that one’s previous knowledge and its connections, for the most part, remain intact” (p. 80). This description is similar to The New Zealand science curriculum statement *Science in the New Zealand Curriculum* which suggests for two of the ways for enhancing achievement:

> Students have an opportunity to clarify their own ideas, to share and compare, question, evaluate and modify their ideas, leading to scientific understanding.
>
> Teachers and students work within a supportive atmosphere of mutual respect where all the experience, ideas and beliefs, which students bring into the learning situation are acknowledged as a basis for learning. (Ministry of Education, 1993, p. 10)

The notion of conceptual growth is equivalent to evolutionary growth described by Kuhn (1970) and to Piaget’s term assimilation (Piaget, 1963). Conceptual change is equivalent to Piaget’s term accommodation and represents a revolutionary change involving a paradigm shift from the student’s alternative conception to the scientific conception.

Applying constructivist principles to teaching science requires a change in the role of the teacher. Learning becomes student-centred and is conducted at the students’ pace. The teacher becomes a facilitator who coordinates student learning. Teachers need to develop skills to respond to individual and group needs by promoting an effective learning environment.

The constructivist view has important consequences for the development of teaching and learning approaches. Such approaches need to take into account students' alternative conceptions which then form the starting point for constructing understanding along the lines of the scientific viewpoint. In order for constructivist principles to be applied to the learning of science, some changes need to be made in terms of the aims of science education, the setup and content of structures, media and teaching/learning strategies.

According to Duit and Confrey (1996), there are five assumptions for the re-organisation of the science curriculum and teaching from a constructivist perspective. These assumptions in summary are:

1. More emphasis on the applicability of science to the students' everyday experiences i.e. science should be related to the world of the student. This gives a more appropriate starting point from which to build connections between prior knowledge and scientific concepts.

2. Students learn about the nature and range of scientific principles and concepts in terms of them being human constructions rather than eternal truths. The term metaknowledge is used to describe an awareness of how knowledge is constructed and consequently an awareness of how we seek to understand our scientific world. Students thus become aware of how they learn.

3. The difficulty and inadvisability of extinguishing students' everyday conceptions while trying to replace them with scientific conceptions. Rather, to allow students to make the necessary concept change only when the scientific conception is more useful to them in explaining their observations and experiences than their original alternative conception.

4. The approach must be student-centred in a specific way. Subject matter is used: "……. as a vehicle for interactive engagement with students. Ideas are embedded in student orientated challenges and the classroom climate supports and encourages active exchange, debate and negotiation of ideas" (p. 85).

Students are required to become active learners - a state which can only be reached with a suitable classroom environment and suitably presented learning material. Students are made more keenly aware of their thinking processes and the process of reflection on their ideas and conceptions is enhanced.

5. Students must learn to value alternative perspectives and reach a: "……… negotiated consensus about how classes are to be conducted and the possible meanings of and agreements about the content being taught" (p. 86).

Implementing these aims requires sound curriculum planning. Any approach to teaching which aims to take into account the ideas of students and the process by which they construct new understandings requires a high level of skill on the part of the teacher. The teacher has to be a motivator, a diagnostician, a guide, an innovator, an experimenter and a researcher. The teacher becomes a facilitator of students' personal and social construction processes by establishing classroom interaction patterns that promote each individual's exploration and resolution of ideas within the social and cultural context. Negotiation rather than imposition characterises teaching. Problem solving is achieved through conceptual understanding rather than application of a prescribed method.

In addition, multi-media resources including computer based learning environments have been developed. Texts are a common medium for science instruction, especially in distance education, and have relatively recently taken students' perspectives into account. There is a need for resources which challenge students' alternative conceptions resulting in cognitive conflict (Hewson, 1996) which is a step towards conceptual change to the scientific viewpoint. Texts alone, of course, cannot always achieve this because students may hold alternative conceptions which are not anticipated by the author and this is where the teacher/facilitator has to provide additional guidance. This last point was an issue for distance education when resources were largely paper based and the pedagogy essentially the structural design model (Gagné, 1987).

Conceptual change

The traditional content structures previously used in schools need to be revised. Approaches involving a continuous passage from students' alternative conceptions to the scientific conception need to be implemented. This approach requires set steps from eliciting students' ideas, through cognitive conflict to understanding, acceptance and application of the scientific conception as a better and more useful way of explaining their experiences. Posner, Strike, Hewson and Gertzog (1982) applied Kuhn’s ideas about scientific revolutions and paradigm shifts (Kuhn, 1970; Chalmers, 1999) to individual learning and derived the conditions necessary for bringing about conceptual change. According to Posner et al. the conditions supporting conceptual change lead the student to dissatisfaction with his/her own conception by offering the scientific alternative which must be intelligible, plausible and fruitful to the student. There have been criticism of this approach from the sociocultural perspective (Saljo, 1999). Conceptual change does not occur by cognitive means alone. It requires extensive socio-cultural support with the learner participating in rich socio-cultural activities (Vosniadou, 2007). Other researchers have pointed out that conceptual change does not occur as a sudden restructuring of an alternative conception, but by a more gradual process. Rather than involving the learner in replacing ‘incorrect’ with ‘correct’ conceptions, the process cultivates the learners’ abilities to take different viewpoints and understand when alternative concepts are appropriate in different contexts (Pozo, Sanz & Gomez, 1999). The more fluid approach to conceptual change is summarized by Vosniadou in the following statement:

> Conceptual change is considered not as the replacement of an incorrect naïve theory with a correct one, but rather, as an opening up of the conceptual space through increased metaconceptual awareness and epistemological sophistication, creating the possibility of entertaining different perspectives and different points of view (2008, p. 279).

It is important for students to understand that science is an evidence based evolving form of knowledge. Scientifically valid understanding is that which is based on evidence currently available and is falsifiable through the actions of further scientific investigation. Contemporary science is therefore not a proved body of truths but evidence based theories that are fallible by falsification (Chalmers, 1999; Kitcher, 1982). Effective teaching strategies are required in order to facilitate the construction of scientifically valid understanding. A number of models for bootstrapping knowledge construction (Resnick, 1991) have been proposed. These include: the conceptual change model (CCM) (Posner, Strike, Hewson & Gertzog 1982), the generative learning model (Cosgrove & Osborne, 1985), the constructivist teaching sequence (Driver & Scott,1996), contrastive teaching (Schecker & Niedderer, 1996), concept substitution (Grayson 1996), analogies (Treagust, 1995b), stories (Raymo, 1992), children’s drawings (Ollerenshaw & Richie, 1997), Venn diagrams and concept maps (Novak & Gowin, 1984), predict, observe explain (White & Gunstone, 1992), computer-based simulations (Maor, 1995; Kearney & Treagust, 2000), web based animations (Tasker & Dalton, 2006), historical models (Ben-Zvi & Hofstein) and reusable learning objects (Allan, 2002). In addition Hipkins, Joyce and Bull (2000) described an iterative four step process for progressing from the worlds of children's science towards scientists' science they call cycles of learning.

These models obviously have their differences but all of them and other strategies have a place depending on the concept being taught and the age and cognitive maturity of the students involved. In all of these models, students ascertaining alternative conceptions is a significant part of the process and the subsequent teaching strategy is designed to provide guidance for students to change from their alternative conceptions to constructing a scientifically valid understanding.

Commencing with a diagnostic survey is a useful way to start in order for the teacher to ascertain the range of alternative conceptions and finishing with an application phase to ensure that students have achieved the unified outcome, namely the coherent scientific perspective which they themselves see as fruitful in terms of its usefulness in explaining their world.

These approaches to teaching and learning that facilitate construction and co-construction of understandings by students in collaborative learning settings are more learner-centred than the traditional transmission method of teaching. That is not to say that learners in the transmission teaching environment do not construct understanding in that setting. Rather, constructivist learning theory explains how learning occurs in any situation.

> Looming over all the concerns, dilemmas and critiques of constructivist pedagogy is the realization that constructivism as a learning, development or meaning-making theory suggests that students also make meaning from activities encountered in a transmission model of teaching such as lectures or direct instruction, or even from non-iteractive media such as television. (Richardson, 2003, p. 4)

However, the process of ascertaining student alternative conceptions and employing strategies for these alternative conceptions to be replaced by the accepted scientific conceptions has been shown to work more effectively in teaching/learning environments where students become more proactive in their learning and accept greater responsibility for the process. This involves students making their ideas explicit and then being engaged in justifying, evaluating and revising them in a supportive environment (Cobb, Wood, Yackel & McNeal, 1992; Davis, 2001). Constructivist learning theory acts as a referent for developing effective pedagogical strategies (Confrey, 1990; Lorsbach & Tobin, 1992). Learning communities in science classrooms function differently from scientific communities because schools are driven by power structures and discourses that need to be taken into account (Duit & Treagust, 1998). Learners in the school system frequently find themselves in a complex psycho-social environment in which there are captive groups, crowded communal settings and imposed agendas. These learning environments have traditionally been dominated by the cultural myths of cold reason, where knowledge is seen as discovery of an external truth, and hard control, which renders the teacher as controller (Taylor, 1996). These myths can be addressed by the creation of an environment in which there is a much less asymmetrical relationship between teacher and learners. Such a relationship, in which the teacher operates as a co-learner in a community of learners, encourages the construction of deep, shared understanding by students in a learning environment in which the learners control what and how they learn (Taylor, 1998). Teachers operating in this type of learning environment need to be aware that multiple socio-cultural perspectives will lead to multiple understandings. Issues arise such as truth versus meaningfulness and the status of knowledge constructions in relation to the accepted scientific viewpoint (Airasian & Walsh, 1997; Noddings, 1990). Teachers operating in this environment in a facilitative role will be guided by postmodern pragmatism (Polkinghorne 1992), and notions of ‘what works’ in a socio-cultural context with an evidence-based approach (Alton-Lee, 2005).

Ascertaining student alternative conceptions in science

Developing a coherent and useful understanding of science often involves construction of understanding of a range of inter-related concepts.

> A problematic feature of the knowledge construction process is that in some domains the construction of the scientific model requires the establishment of a quite extensive

> series of concepts and inter-relationships. . . . . . Although they can only be constructed in bits, such complex ways of seeing may make sense only as a whole – thus presenting a complex problem for pedagogy. (Scott, Asoko & Driver, 1991, p. 10)

It is essential that strategies for ascertaining what students know at the start of a new topic are incorporated into science schemes. There are a large range of methods available, but the strategies most useful to us must survey all students and must not interrupt classes to any great degree. Probably the best way to find out what students think about a particular topic is by talking to them individually. These talks can take the form of interviews, a technique that can be traced back to Piaget (Piaget, 1929). Two interview techniques that have been used to investigate student understanding of science are interviews-about-instances and interview-about-events. Interview-about-instances (Carr, 1996; Osborne & Gilbert, 1980) involve exploration of the concept that the child associates with a particular label, for example, animal. Interview-about-events (Carr, 1996; Osborne 1980) investigates the child's view of everyday phenomena, for example, evaporation. Interviews, however, are time consuming and also require skill and experience on the part of the interviewer. Interviews are not feasible as a regular part of most teaching programmes. Other useful strategies are concept maps (Novak, 1990, 1996), brainstorming (Ministry of Education, 1990), Teacher's questions (Ministry of Education, 1990), post-box (Ministry of Education, 1990), expository writing (Ministry of Education, 1990), models (Dunlop, 2000) and pencil and paper surveys.

Diagnostic tests or surveys of the multi-choice type have certain drawbacks when "they are compiled by teachers with a 'correct' answer in mind, together with a number of 'distractors' designed by teachers to give particular types of error" (Freyberg & Osborne, 1985 p.166). This method has also lost favour because of a strong and negative association between behaviourism and multi-choice items which often do not investigate student understanding and do not always bring out the student's ideas. There has been some improvement on this by researchers who have developed distractors for items based on students' answers to open ended questions (Duit et al. 1996). Although the range of ideas that students hold is large, on a particular concept, their ideas can be grouped into four or five categories (Freyberg & Osborne, 1985). Thus, carefully compiled multi-choice surveys could be useful for ascertaining students' ideas and alternative conceptions. They are quick and easy to mark and quick to analyse, and can be useful for looking at concept change if the survey is administered again at the end of the topic. They have the disadvantage in that if administered under test conditions, students are unable to share ideas and reflect on them as part of the process. Surveys take up a lot of time to design but once established can provide the teacher with useful data. Normally in face-to-face situations, the surveys would be given to students under test conditions, although there is potential to use items selectively and for self-assessment.

Diagnostic tools should relate to the objectives for that topic or to ideas essential to the understanding of more advanced concepts that will be covered in the topic.

Formative and Summative assessments

Governments in many western countries have implemented a range of standardized high stakes assessments in an attempt to raise educational standards particularly in literacy, numeracy and in science (Hill, 2002). International assessments such as the Programme for International Student Assessment (PISA), (2000), and the Trends in Mathematics and Science Study (TIMSS), (1999) have enabled international comparisons to be made between the performances of students of a particular age group (Ministry of Education, 2001). Assessments such the National Education Monitoring Project (NEMP) in New Zealand have provided assessment data on student achievement within particular age groups and curriculum areas (including science) on a national basis. The national and international assessments are summative assessments which serve to measure student achievement after a specific unit of learning or years of schooling.

The constructivist view of assessment is that it should focus on student understanding of essential concepts. Kuhn and Hand (1995) made the following statement:

> A constructivist approach demands that we assess students' understanding of concepts essential to the unit; not their recall of concepts or the practiced application of a science concept to solve a problem. Assessment tools must therefore allow students to

> demonstrate their understanding of essential concepts addressed in the unit. This means assessment items must be conceptually focused, requiring students to apply their new knowledge to new problems in situations not previously encountered. (p. 124)

Conversations about assessment have increasingly become conversations about accountability. Much of the focus on assessment has been on high stakes testing, focusing at the school level. While focus on this type of testing can illuminate potential learning issues, testing alone cannot move learning forward (Ciofalo & Wylie, 2006). This type of assessment is summative assessment which measures the level of achievement reached by the student. In New Zealand high stakes summative assessment takes the form of standards-based assessment consisting of unit standards and achievement standards that are registered on the National Qualifications Framework (NQF). The main certificate for school based students is the National Certificate of Educational Achievement (NCEA) which consists of a combination of internal and external achievement standards.

Formative assessment provides a framework for improved learning and is an integral part of the teaching-learning process, not separate from it. Sadler (1988) identified feedback as the key element in formative assessment and defined it as information on how successfully something has been or is being done. For optimum effect, feedback would occur in a supportive learning environment which incorporates feedback loops that provide for two main audiences, the teacher and the learner. According to Sadler (1988):

> Teachers use feedback to make programmatic decisions with respect to readiness, diagnosis and remediation whereas students use it to monitor the strengths and weaknesses of their performances, so that aspects associated with success or high quality can be recognized and reinforced, and unsatisfactory aspects modified or improved. (p. 121)

Formative assessment is assessment **for** learning whereas summative assessment is assessment **of** learning. Black and Wiliam (2002) produced a research synthesis that focused on formative assessment which they defined as follows: “Formative assessment is a process, one in which information about learning is evoked and then used to modify the teaching and learning activities in which teachers and students are engaged"(p. 122). Nicol and McFarlane-Dick (2006) identified seven principles of good feedback practice:

> 1.Facilitates the development of self-assessment (reflection) in learning.
> 2.Encourages teacher and peer dialogue around learning.
> 3.Helps clarify what good performance is (goals, criteria, expected standards).
> 4.Provides opportunities to close the gap between current and desired performance.
> 5.Delivers high quality information to students about their learning.
> 6.Encourages positive motivational beliefs and self-esteem.
> 7.Provides information to teachers that can be used to help shape the teaching. (p. 201)

Formative assessment therefore has a diagnostic function and student responses to questions provide feedback to the teacher and to the student so that the teaching-learning programme can be modified appropriately to address areas of misunderstanding. Teachers should be able to justify the use of an assessment strategy on instructional grounds (Carr, 2003) and the formative assessment processes need to be embedded in the teaching (Treagust, Jacobowitz, Gallagher & Parker, 2001; 2005). A central part of this teaching is dialogue with students to clarify their existing ideas and to help them construct the scientifically accepted ideas. Formative assessment is seen as a crucial component in teaching for conceptual development. Better learning outcomes include increased enjoyment, social cooperation, ownership, student confidence and motivation. Formative assessment involves students recognizing, evaluating and reacting to their own and/or others' evaluations of their learning. Students can reflect on their own learning or they can receive feedback from their peers or the teacher (Bell & Cowie, 2001).

> In taking into account students' thinking in their teaching, teachers are responding to and interacting with the students' thinking that they have elicited in the classroom. They are therefore undertaking formative assessment whilst teaching for conceptual development. (Bell & Cowie, 2001, p. 4)

Bell and Cowie (2001) describe the process of formative assessment as eliciting information, interpreting information, acting on information. Formative assessment can be on-going and progressive, interactive, contextualized, informal, unplanned as well as planned, proactive or reactive, responsive with individuals and with whole classes, uncertain and risk taking. It is a skilled activity requiring professional knowledge and experience on the part of the teacher, relying on student disclosure and degrees of responsiveness. Student self and peer assessment can be powerful components in the learning process for motivated students in a community of learners (Dix, 2003). Formative assessment is therefore evidence-based practice and a key component in the New Zealand Ministry of Education *Best Evidence Synthesis* (Ministry of Education, 2003a) and the *Making a bigger difference fir all students: Directions fo a schooling strategy 2005-2010* (Ministry of Education, 2004a).

Research informs us that it is the quality of the interaction between teacher and student that makes the biggest difference to student achievement (Hattie,1999; McMahon, 2000). Requirements for accountability at national, local and school level can lead to schools making changes that are detrimental to student achievement by compromising the quality of this interaction. This situation can occur if there is an unbalanced management focus on coverage of the curriculum rather than the needs of the student (Littlewood, 2003). There needs to be a balance between summative and formative assessment and their different purposes and validities recognized (Crooks, 2001, 2004; Harlen, 2005).

Diagnostic Assessment

The terms formative and diagnostic assessment are often used interchangeably but Millar and Hames (2001b) make a distinction between the two terms:

> A diagnostic question is one which can provide evidence of a learner's understanding of a specific point or idea. A good diagnostic question should not only provide evidence that a pupil does or does not have a particular piece of understanding, but should also try to indicate how they are thinking about the matter even where their answer is incorrect. (p. 1)

Diagnostic questions can be used both summatively, to provide externally referenced assessment of the learner's knowledge and understanding, or they can be used formatively as an integral part of the teaching/learning process. The New Zealand

Ministry of Education (2003b, 2005a) has developed a bank of nationally benchmarked diagnostic assessment items for reading, writing and mathematics called Assessment Tools for Teaching and Learning (asTTle). Diagnostic tests in one of these three essential skills can be computer generated for individual students or cohorts of students according to curriculum level range and content coverage. Teachers can computer generate, from the database, a 40-minute pencil and paper test designed for the students' learning needs. Once students have completed the test a report is generated providing rich data that show:

- Curriculum levels - where are students relative to the targets of curriculum levels.
- Individual learning pathways - what are the strengths and weaknesses of students' individual performances?
- Group learning pathways - what are the strengths and weaknesses of students' group performances?
- The console - how are my students doing compared to similar students in New Zealand?
- What next - what is the next teaching learning step and where might I locate appropriate learning materials?
- Value added - how are my students doing compared to earlier reports?

(Ministry of Education, 2003b, p. 23)

The asTTle tool thus provides teachers, students and parents with information about student's level of achievement, relative to curriculum outcomes, for Curriculum Levels 2 to 6 and national norms of performance for students in years 4 to 12.

Two-tier diagnostic instruments

Conventional multi-choice diagnostic instruments have a tendency to probe only the surface levels of student understanding. A deeper probe can be achieved by use of test questions at two levels (Millar & Hames, 2001a; Treagust, 1988, 1991, 1995b; Treagust & Mann, 2000). Respondents first select a response to the first tier question which typically gives a two way choice such as 'true-false' or 'yes-no'. The second tier then provides justification for the first tier choice. The justification choices in the second tier consist of common alternative conceptions typically held by students in the age group of the target group. Design of these instruments is time consuming because of the need to research the range of student alternative conceptions around a particular scientific concept but once set up they provide an economical way of ascertaining student alternative conceptions.

Ciofalo and Wylie (2006) advocate using multi-choice diagnostic items one question at a time as a powerful and economical and flexible tool in the 'evoking' stage of formative assessment. They advocate the use of multiple choice questions connected to a specific content standard or objective, which include answer choices that relate to common alternative conceptions regarding that standard or objective. The multi-choice items that Ciofalo and Wylie advocate using are the conventional one tier type. Two–tier multichoice items could be used in this way and would provide a more powerful tool for this strategy for ascertaining student alternative conceptions to inform the next steps in the teaching-learning process.

Effective diagnostic instruments are grounded in the research on alternative conceptions in science. The systematic evidence based process for developing focused diagnostic instruments was developed by Novak (1990, 1996, 2004). This process involved the development of concept maps which defined the conceptual steps in understanding required by students and the steps in which alternative conceptions can form. From the concept maps, propositional knowledge statements were developed which showed the relationship between the concepts in the process of concept construction by the learner. A whole range of science diagnostic instruments has been developed to elicit student common sense notions in science at secondary and tertiary levels of education.

Two-tier diagnostic instruments have been developed by a number of researchers in a range of scientific topics. Haslam and Treagust (1987), Peterson and Treagust (1989) and Peterson, Treagust and Garnett (1989), developed pencil and paper two-tier diagnostic instruments for ascertaining alternative conceptions in photosynthesis and respiration in plants, and covalent bonding and structure in chemistry. Each item in the instrument consisted of a question in which the student first makes a choice out of two, three or four options. The second tier consisted of a choice of usually four possible alternatives to justify the answer in the first tier. The second tier contains common alternative conceptions identified by research with groups of students of the particular age and stage for which the instrument is designed.

Similar two-tier diagnostic instruments have been developed in particular science topics for students working at specific levels. The topics are diffusion and osmosis (Odum & Barrow, 1995), breathing, gas exchange and circulation (Treagust & Mann, 2000), characteristics of matter (Chiu, Chiu & Ho, 2002), the formation of image by plane mirror, (Chen & Lin, 2002), astronomy, (Zeilik, 2003), plant transport and human circulation (Wang, 2003), flowering plant growth and development (Lin, 2004) and animal classification (Yen, Yao and Chiu, 2005). These two-tier diagnostic instruments were developed to ascertain alternative conceptions in particular scientific topics. Chiu (2005) developed a broader based set of two-tier items for conceptions in chemistry which covered a wide range of chemistry alternative conceptions for students at a range of levels. There have been a large number of on-line diagnostic instruments developed for ascertaining science alternative conceptions. Most of these instruments were developed for ascertaining alternative conceptions in a specific area of science and only a relatively small number using two-tier multi-choice instruments. The Taiwan National Science Concepts Learning Study (Chiu, Guo & Treagust, 2007) involved the design of two-tier diagnostic tests to identify the scientific conceptions of students from large national samples using random sampling procedures (Treagust & Chandrasegaran, 2007). Tsai and Chou (2002) developed a networked test system using three two-tier items. Larrabee, Stein and Barman (2006) developed a 47-item Science Belief Test. This is a two-tier computer based instrument for identification of common science misconceptions in which students make written responses to support their true/false responses to the first tier. This instrument is similar in scope to the on-line diagnostic instrument developed in this research in that it covers a variety of science concepts across a range of scientific disciplines.

Distance learning environments

Distance education pedagogy has been dominated by static media such as paper based modules, videotapes and audiotapes. Telephone and teleconferencing provided opportunities for synchronous teaching and learning but this was limited to individual or small group interaction. The distance learning environment is one in which the cultural myths of cold reason and hard control (Taylor, 1996, 1998) are less influential and the relationship between student and teacher is less asymmetrical than in the traditional face-to-face environment. Computer-based learning provides the distance learner with opportunities for engagement with interactive multimedia ranging from electronic versions of behaviourist teaching machines (Skinner, 1954) to more authentic learning activities simulating real world events (Herrington & Oliver, 1995; Herrington, Oliver & Reeves, 2003). More significantly, information communication technology provides the distance learner with environments for dynamic synchronous and asynchronous interaction and co-construction of knowledge in communities of learners (Brown, 1999). Synchronous interaction of the virtual classroom type enables student alternative conceptions to be ascertained in much the same way as the face-to-face environment enabling appropriate strategies for conceptual change and conceptual growth to be applied in a multimedia learning environment. The internet can also be used to support models of learning based on sound teaching practices by providing opportunities for the distance learner that allow construction of understanding to take place in an environment in which there is active engagement, learner control and student collaboration (Brown, 1999; Churach & Fisher, 1999). On-line diagnostic survey instruments have been designed and used to gather a large range of information including student alternative conceptions. These survey instruments have the potential to provide rapid feedback to teachers and students to inform the next steps in the teaching-learning process whether at the macro level of designing appropriate programmes of learning or at the micro level of informing a strategy for conceptual change or conceptual growth. On-line diagnostic instruments of the two-tier type have the potential to fulfill both of these functions in the multimedia distance learning environment.

Summary of the Literature Review relevant to this study

- Constructivist learning theory holds that learners make sense of their world by building a form of indigenous knowledge consisting of alternative conceptions.Understanding science involves making sense of scientific concepts.

- Learners hold alternative scientific conceptions which they use to make sense of their own life-world experiences.
- These alternative conceptions develop as the learner makes sense of his/her life-world experiences and are frequently at variance with the accepted scientific viewpoint.
- Alternative conceptions may be the result of stage of development, social interaction, a range of informal and formal learning opportunities, belief systems and cultural factors.
- Alternative conceptions can conflict with the scientific concepts and may act as a barrier to the construction of valid scientific understandings.
- Replacing alternative conceptions with scientifically valid understanding involves conceptual change in the mind of the learner.
- Effective teaching strategies involve the learner reflecting on his/her own alternative conceptions and when faced with the scientific conception experience cognitive conflict leading to a change to the scientific viewpoint.
- Ascertaining students' alternative conceptions is an important starting point in the teaching learning process and as part of the discernment process for designing and developing student personalized learning programmes.
- Formative assessment involves gathering evidence of student learning stages that can be used to inform teaching interventions to help students to construct meaningful frameworks of understanding.
- Diagnostic processes can be used to ascertain alternative conceptions that may act as barriers to understanding so that effective next steps in the teaching learning process can be put in place.
- Research has shown that student alternative conceptions relating to a particular scientific idea fall into three to five broad categories (Freyberg & Osborne (1985).
- Multi-choice surveys are an economical instrument for ascertaining student alternative conceptions as part of the formative assessment process for informing the next steps in the teaching learning process, particularly in the distance learning context.
- Two-tier multi-choice items allow teachers and students to probe to deeper levels at which alternative conceptions may operate in the conceptual ecology of the student.

- On-line two-tier multi-choice items provide an economical rapid feedback instruments for ascertaining student alternative conceptions for informing the next steps in the teaching learning process at micro and macro level.
- The literature search found a number of research projects that had developed two-tier diagnostic instruments for specific science topics but none like the broader bank of on-line items to ascertain alternative conceptions linked to curriculum objectives over a range of levels.

Chapter 3 discusses the various methods used to identify student alternative conceptions related to the concepts that underpin the objectives at specified levels in the New Zealand science curriculum and the process employed to build the on-line diagnostic instrument.

Chapter 3
Methodology

Overview of Chapter

Chapter 3 provides a description of the design and development of the two-tier on-line instrument. The first part of the chapter describes the development of concept maps and propositional statements leading to the design of question stems for open ended student surveys. These question stems related to the concepts underpinning curriculum objectives and aimed to ascertain common alternative conceptions held by students in the relevant age groups. The second part of the chapter describes the validation of identified student conceptions by telephone interviews and identification of common student alternative conceptions by experienced science teachers. The third part of the chapter describes the building of the two-tier diagnostic instrument from the stem questions and identified alternative conceptions, putting into an on-line format and trailing with a group of students. The final part of the chapter describes the collection and analysis of student responses.

Introduction

A conceptual diagnostic instrument aims to ascertain students' conceptual understanding of key ideas in the discipline. The multi-choice format can be administered efficiently and economically to large numbers of students and computer scored. The distracters that are designed to elicit student alternative conceptions must be compiled from a research base. In this way common alternative conceptions held by students of a particular age and stage can be anticipated in the distracters. Because conceptual diagnostic instruments can be scored quickly they can be used as rapid feedback formative evaluation instruments as well as for summative assessments. Two-tier multi-choice questions in which students respond on two levels can be used as a deeper probe into student alternative conceptions. The instrument needs to match the course objectives and therefore must be designed specifically, or selected from an item bank of questions that specifically elicit alternative conceptions relating to ideas that underpin the course objectives and learning outcomes. Development of such items requires a process of mapping the scientific concepts that underpin the course objectives and then constructing the proposition statements that link the concepts in appropriate ways for building the necessary scientific understanding of the course concepts, content and context.

Choice of Instrument

The two-tier diagnostic multi-choice instruments provide a method of ascertaining student alternative conceptions in an economical way. Normal multi-choice instruments tend to operate at a more superficial level of understanding than diagnostic strategies that require longer and more in- depth written or verbal answers. The two-tier multi-choice instrument is able to probe more deeply to ascertain the conceptual understanding that the student has (Treagust, 1988). The first tier ascertains whether the student has a primary notion as to whether the statement is right or wrong in the context of contemporary scientific thinking. The second tier requires the student to give a reason for his/her choice. It tests the student’s reasoning and therefore understanding of the underlying concept relating to the particular curriculum objective. Also, with eight possible combinations, from the choice of two in the first tier (in this case True or False) then four in the second tier, it is less easy for students to guess the ‘correct answer’ than with the more conventional four or five choice format.

Research Design

This study involving a series of surveys to ascertain students' understanding of specified concepts in science is described as descriptive or as development research by Cohen, Marion and Morrison (2001). The study has features of both. Descriptive research is concerned with the status of scientific knowledge understanding of individuals at a particular level of schooling and development research is concerned with an analysis of changes in this knowledge and understanding, in this case as measured by the SOLO Taxonomy (Biggs & Collis, 1982).

The items in the diagnostic surveys are referenced to the four contextual strands of The New Zealand science curriculum. Underlying concepts were identified within each of the four objectives in each of the levels 4, 5 and 6 of a strand and mapped on a concept map for that strand. Propositional knowledge statements were constructed linking the conceptual development within the strand. Questions were then devised that focussed on the concepts underpinning each curriculum objective. The items in each survey were designed to ascertain the range of student alternative conceptions in cohorts of students working at particular levels of the science curriculum. The items in the survey covered each curriculum objective in each of the four contextual strands. The items have the format of a question that required the student to choose between two alternatives e.g. true/false, and then write a reason for their choice.

Three surveys were designed, one for each of the Curriculum Levels 4, 5 and 6. Three cohorts of students were selected from the New Zealand Correspondence School full- time roll and three classes in local face-to-face schools. Each group included a range of abilities, representative ethnic composition and gender balance. A sample from the Correspondence School cohort was interviewed by telephone to check whether their written alternative conceptions reflected their mental constructions. The survey questions were given to six teachers asking them to predict the types of reasons students will give reflecting alternative conceptions they have experienced with students at that age and stage. The second tier explanations for each question were selected from the alternative conceptions from the three surveys, the telephone interviews and augmented from predicted alternative conceptions from six science teachers. The three search techniques (student alternative conception survey, telephone interviews and teacher predictions) provided triangulation to ensure that the identified alternative conceptions were authentic in terms of the perspectives of students and of science teachers experienced in teaching students of the relevant age range.

A single instrument containing 52 questions was built in Microsoft Word drop-down menu format and this was then transcribed to a HTML format. The instrument was then placed on the Correspondence School website. Three student cohorts were selected and sent the link to access the instrument by email. Students who completed the diagnostic instrument returned their answers by clicking a send button at the end of the instrument. The returned answers were returned to the author in the form of an answer sheet for processing and analysis. A marker spreadsheet was designed for rapid processing of student responses into scientifically correct and incorrect answers by strand and level. The answers obtained from the three surveys, the telephone interviews and the teacher responses were used to design the items in the second tier of the instrument that provided reasons for the first tier selections. A programme for marking the student answers was built so that the student responses could be processed quickly and returned. The returned analysis gave the student information on which questions contained the scientifically correct answer and also an analysis of correct answers by curriculum level.

Development of Concept Maps and Propositional Statements

The need to ascertain students' alternative conceptions in science has been discussed in Chapter 2. The context in which the items of the instrument were developed is the New Zealand Science Curriculum Statement (Ministry of Education, 1993) with the contextual curriculum objectives having their origin in 16 achievement aims of the science curriculum statement. Four aims are threaded through each learning strand in each of the four objectives at each level in the curriculum. Each objective number has a continuing theme through each level in each strand.

Level 5 was the focus level because this is the level at which the average Year 9 and 10 student is working. Above and below Level 5 would provide for a range of levels for students in the Year 9 and 10 age group that would span the cognitive ability range of the majority of students in this age group. The objectives in The New Zealand Science Curriculum provided the basis for the items to be developed in the instrument. The curriculum levels represent levels of thinking or conceptual development in students. Items in the diagnostic survey are designed to be linked to specific curriculum objectives within Levels 4, 5 and 6. The items in the diagnostic survey were referenced to the four contextual strands of the science curriculum. The curriculum objectives themselves are skill-based signified by key verbs in the objective, for example, investigate, research, carry out etc, but depend on underlying scientific concepts and propositions (Novak, 1990) that need to be understood by students in order to achieve at the level of understanding necessary for meeting the objectives.

The objectives of the four contextual strands for Levels 4, 5 and 6 of *Science in the New Zealand Curriculum Statement are:* Making sense of the living world; Making sense of the physical world; Making sense of the material world; and Making sense of planet Earth and beyond. The objectives of the four contextual strands for Levels 4, 5 and 6 of *Science in the New Zealand Curriculum Statement* are listed within each strand and within each objective line (Appendix B). This meant that for example, the objectives of the strand Making Sense of the Living World were listed for Level 4 Objective 1, then Level 5 Objective 1, then Level 6 Objective 1. These objectives are linked by the theme provided by Achievement Aim 1. Then Objective 2 for Levels 4, 5 and 6 were listed, then Objective 3 etc. This enabled the continuity of scientific themes and concepts to be seen more clearly in moving from Level 4 to Level 6. The making sense of the Physical World strand was the most difficult to drill down to specific learning outcomes because of the very general nature of these objectives. Objectives 1 and 3 at Curriculum Level 5 are:

1. Carry out simple practical investigations with control of variables, into common physical phenomena, and relate their findings to scientific ideas.
2. Investigate and describe the patterns associated with physical phenomena – some patterns may be expressed in graphical terms.

Objectives 1 and 3 at Curriculum Levels 4 and 6 also used the term ‘physical phenomena’. It was possible to meet the objectives with several topics such as electricity and mechanics. This issue was discussed by Hipkins et al. (2000) in their work on the development of ‘big ideas’ in science within the contextual strands of the New Zealand Science Curriculum: “It seemed that each topic within this strand (Physical World) had its own unique set of key understandings” (p. 2). The general nature of the objectives provides for flexibility but the science teachers find a lack of guidance regarding the depth of scope of the content to be taught and learnt (Baker, 1999). Most schools in New Zealand, including The Correspondence School, cover both of these topics at Curriculum Levels 4, 5 and 6. For this reason, separate concept maps were derived for these two topics within this strand.

Bloom’s Taxonomy of educational objectives (Bloom, 1956) provides levels of behavioural objectives that can guide curricular learning goals. The thinking levels of the cognitive domain from lowest to highest - knowledge, comprehension, application, synthesis and evaluation - have been revised and updated by Anderson, Krathwohl, Airasian, Cruikshank, Mayer, Pintrich, Raths & Whitrock (2001). This revision has involved changing these categories from nouns to verbs in line with the view that the taxonomy reflects different forms of thinking that are more appropriately represented as actions. Some categories were changed e.g. knowledge was changed to remembering, since knowledge represents a more complex product of cognitive processes, rather than the accumulative behaviourist view, comprehension has been changed to understanding, and synthesis to creating. In addition, the hierarchy was changed so that the highest thinking levels, synthesis and evaluation, were changed over so that creating is the highest thinking level above evaluating.

The revised thinking levels, from lowest to highest, are now - remembering, understanding, applying, analyzing, evaluating and creating. Key verbs from each of these categories (Adams Center for Teaching Excellence, 2004) were allocated to the curriculum objectives within each objective line to see if there was a hierarchy of thinking levels for the curriculum levels within the objective themes. Bloom's behavioural objectives, however, did not show a consistent trend that correlated with the curriculum objective levels in any of the strands. This was because the key verbs in each of the curriculum objectives tended to denote higher thinking levels in the Bloom taxonomy e.g. the word 'investigate' features prominently as a key verb at all curriculum levels. According to the Adams Centre, 'investigating' is a sub-category of analyzing in the revised Bloom taxonomy. However, the word 'investigating' can be interpreted as finding, comparing, carrying out, finding, experimenting or testing. These actions can be linked to all categories from remembering to analyzing (Appendix C). If the verb 'investigating' is viewed in this way, and the other verbs in the objectives are emphasised e.g. describe, apply, understand, then there is a tendency for higher thinking skills to be appear more prominent in the higher curriculum levels, particularly Curriculum levels 7 and 8. This trend is less pronounced from Curriculum Levels 4 to 6, the focus of this research.

The SOLO taxonomy (Biggs & Collis, 1982) was used for assessing thinking levels in student responses to the surveys described later in this chapter. Bloom's taxonomy is more suitable for selecting 'ready made' items from an item bank rather for determination of the levels of thinking shown in student responses.

> The Bloom taxonomy is designed to guide selection of items for a test i.e a 'before the event' attack on learning quality. This makes it difficult to apply to open ended responses based on judgements on quality which are difficult to apply. They are **a priori.** (Biggs &Collis, 1982, p.13)

Concept maps were developed (Novak, 1990, 1996; Treagust, 1988, 1991; Treagust & Mann, 2000) for each objective line through Levels 4, 5 and 6 in each of the contextual strands (Appendix D). Unlike Novak's concept maps, these concept maps are non-hierachical in the top-down sense. The concepts near the centre of the map are more general whereas the concepts near periphery are more specific. These concept maps have similarities with semantic networking whereby the concepts have a high degree of interconnectivity to form a space-filling ball of knowledge (Fisher, 1990). Propositional knowledge statements were then constructed based on the concept maps (Ausubel, 1968; Treagust, 1988, 1991; Treagust & Mann 2000). These propositions were derived from the sequence of concepts that needed to be understood in order for a student to meet the requirements of the achievement aims and objectives within each strand. This activity was conducted for the three levels, namely 4, 5 and 6 which span the Years 7 to 11 inclusive for the average range of science students in New Zealand (Appendix E).

The construction of concept maps and listing of propositional knowledge statements shows a progression in the level of sophistication, complexity and generality of the concepts with ascending curriculum level. The sequential nature of scientific concept development is clearly shown in the branches of the concept maps for each contextual objective line. The concepts at the lower curriculum level tend to focus on the understanding of more familiar concepts of the observable world (Ausubel, 1968). At Curriculum Level 4, the student deals with macro-observable phenomena, then at Levels 5 and 6 s/he deals with the scientific theory that provides the model to explain the observation. Examples of this progression are given in Table 3.1.

Table 3.1
Progression of scientific concepts with ascending curriculum level

Context/Theme	Curriculum Level 4	Curriculum Level 5	Curriculum Level 6
Land shaping forces	Know about volcanoes and earthquakes	Plate tectonics theory	Rock cycle
Nature of matter	Recognise states of matter	Particle theory of matter	Latent heats of fusion and vapourisation
Structure of matter	Observable properties of substances	Elements, compounds, atomic structure	Chemical formulae and equations
Genetic variation	Recognise inherited traits	Genetic crosses	Natural selection
Organisation of the universe	Star patterns and apparent movements	Organisation of universe into stars, galaxies and planets.	Expanding universe, theory of origin, scale of distance and time.
Electrical energy	Electrostatic charge	Electric circuits	Electrical calculations of voltage, current, resistance.

These examples show how scientific concept development sequence goes from concrete to abstract or from qualitative to quantitative in progressing from Curriculum Level 4 to 6. By ordering underlying scientific concepts in this way, it is possible to see the trends in conceptual development involved in meeting the curriculum objectives at different levels in an objective line (Lee, 2007; Yen, Yao & Mintzes). These trends were shown for each objective line in the concept maps.

Design of stem questions for diagnostic instrument

The next step in developing the items was to design or compile questions that would test the understanding of selected underlying propositions. These questions described a situation in words or diagramatically and then asked the student to make a two-way choice such as true/false or yes/no. The questions for this level needed to relate to everyday life-world experiences of the learners such as washing drying on a line, use of TV remote control devices or the occurrence of earthquake tremours. Many of the questions were based on themes used in Correspondence School science activities such as pendulum swing-time or use of a planisphere. Another source of question stems was the Assessment Resource Banks (ARBS) which are tailored to particular curriculum strands, levels and objective lines (New Zealand Council of

Educational Research, 2004). This is a collection of assessment resources developed by The New Zealand Council for Educational Research from 1993 to 2003, to match New Zealand Curriculum Statements in mathematics, English and science.

A specification table was constructed to ensure that each of the objectives and sub-objectives was covered for each of the curriculum levels 4, 5 and 6 (Appendix F). For curriculum objective 5-2, two questions were selected, one with an electrical theme and the other with a mechanics theme. Some curriculum objectives have two sub-objectives that have different underlying concepts for which different questions were designed and selected. There are four objectives at each level in each strand. In some strands at some levels one objective statement covered two of the four objectives at that level. Overall, 53 questions were selected to cover all of the objective statements at the three levels one for each curriculum objective and sub-objective.

Three pencil and paper surveys were developed, one for each curriculum level. The Level 4 survey consisted of 17 questions, Level 5 consisted of 20 questions and Level 6 consisted of 16 questions (Appendix G).

Identification of common alternative conceptions by student survey

The second tier consisted of possible reasons for the answer to the first part of the question. These possible reasons consisted of conceptions held by students working at the curriculum level of the objective against which the question is set. Three surveys were set up, each consisting of the questions for one of the three curriculum levels across all 4 contextual strands. There was therefore a survey for Level 4, one for Level 5 and one for Level 6. Each consisted of questions requiring a two-way choice e.g.' true' or 'false' followed by the word 'because', followed by a space for the student to write an answer.

The surveys were then given to students working at the appropriate level of the survey. Level 4 surveys were given to a class of 29 Year 8 students at School A, Porirua. The Level 5 survey was given to a class of 31 Year 10 students at School B, Lower Hutt and the Level 6 survey was given to a class of 16 Year 11 students at

School B. Both of these schools had students of similar socioeconomic and ethnic composition. Both schools were designated by the Ministry of Education to Decile 3. The decile rating is the indicator used to measure the extent to which schools draw pupils from low socio-economic communities. A decile is a 10% grouping. Decile 1 schools are the 10% of schools with the lowest proportion of these students (Ministry of Education, 2006c p. 19).

The answers given by these samples of students were then analysed and classified into main categories of alternative conceptions for the underlying concept being tested. The same survey was also sent to three cohorts of Correspondence School students. These cohorts were from programmes at each of the three curriculum levels being surveyed, 15 at Level 4, 21 at Level 5 and 14 at Level 6. These students were in classes taught by the same science teacher. Because students at The Correspondence School enroll throughout the year, and can be at various stages of course completions, these groups consisted only of students who had enrolled from the beginning of 2003 and had completed their courses.

Validation of identified student alternative conceptions by telephone interviews

At the end of each survey sent to the Correspondence School students, there was a question that asked the student whether s/he would be prepared to be involved in a follow-up telephone interview. In the returned surveys containing student responses, a minority of respondents signaled ‘yes’ to the telephone interview. Of these, six students were selected, two from each curriculum level. The selected students were sent photocopies of the surveys with their answers to enable them to refer directly to their original responses. The students were reminded that they were not being tested and that the researcher was interested in their thinking in response to the questions and that it was the questions themselves that were under investigation. The students were asked about questions where they had given alternative conceptions in order to ascertain whether or not these alternative conceptions were indicative of genuine alternative conceptions that had been identified in the survey.

Procedural guidelines described by Carr (1996) were used in the interviews with care taken to ensure that the students were given sufficient wait time to answer the questions (Rowe, 1974). Students also were asked how confident they were about their response and explanation given in the survey (Zeilik, 2006). The telephone interviews were recorded with the permission of the students and their supervisors.

Identification of common student alternative conceptions by experienced science teachers

The surveys were also given to six practicing teachers with extensive experience in teaching science. Three of these teachers had been teaching at The Correspondence School (TCS) for more than five years and three had been teaching at TCS for less than one year and therefore had recent experience with students in face-to-face schools. All were teachers of science but with different specializations at senior level and had developed the pedagogical content knowledge of typical student alternative conceptions (Veal & MaKinster, 1999). Balance in senior subject specialisations was achieved by having two teachers who taught senior biology, two who taught senior physics and two who taught senior chemistry. Each of the teachers was asked to predict and write down the common alternative conceptions they have experienced with students around the underlying concept being tested in each question.

Building the Diagnostic Instrument

The responses were classified according to the Structure of Observed Learning Outcomes (SOLO). This taxonomy is designed for use in "distinguishing distinct levels of quality ranging from the almost incoherent, through to the stereotypical and conventional to the richly expressive" (Biggs & Collis, 1982, p. 124). The alternative conceptions obtained from the three surveys for students fitted broadly into three or four main types. There were also some miscellaneous responses that were at SOLO Level 1 outside the realms of scientific thinking. The aim was to obtain four second tier items for each of the questions to provide one correct answer and three distracters. The three distracters consisted of alternative conceptions of the type held by students at the particular age and stage of the students from the survey samples. Ideally, two of the alternatives would support one answer in the first tier, e.g., 'false' and the other two alternatives would support the other answer in the first tier, e.g. 'true'.

For each item**,** four alternatives were designed, based on the alternatives provided by the students' samples in the three surveys and the follow-up telephone interviews. Where there were more than three distracters, the ones with the highest SOLO rating were used. In some cases, three alternatives were not obtained and in these cases, appropriate alternative conceptions provided by the six science teachers were selected to design suitable items. One question in the Level 4 survey was removed. This was Question 15 because the sub-objective this question was linked to was, "Use simple technological devices to observe and describe the night sky e.g. binoculars, simple star maps." This sub-objective was better tested in a practical activity so its exclusion resulted in 52 items in the instrument. Four alternatives were designed for each of the 52 items (Appendix I).

The 52 items needed a reliability check. Unlike mathematics and English where *Assessment Tools for Teaching and Learning* (Hattie et al., 2004; Ministry of Education, 2003b) had been developed, providing a benchmark for external referencing, no such benchmark test existed for science. However, there are exemplar items from three main sources that can be used to benchmark the three levels covered by the diagnostic instrument. These are:

- National Exemplars (Ministry of Education, 2004b) that cover Curriculum Levels 4 and 5.
- Assessment Resource Bank items (New Zealand Council of Educational Research, 2003) that cover Curriculum Levels 4, 5 and a few at Level 6. Some of these were items originally developed for the National Education Monitoring Project (University of Otago, 2003)
- National Certificate of Educational Achievement (New Zealand Qualifications Authority, 2004) items from National Qualifications Framework assessment examples for NCEA Level 1. NCEA Level 1 is matched to Curriculum Level 6; hence instrument items set at Curriculum Level 6 can be benchmarked against NCEA Level 1 exemplars.

These resource banks were used to ascertain whether or not the items of the science diagnostic instrument were pitched at the correct conceptual level for the curriculum level they were designed to test against. This was done by matching each diagnostic instrument item to one or more items from these resource banks with adjustments being made where necessary to ensure reliability (Appendix J). This external referencing process together with the feedback received from the six experienced science teachers provided triangulation to ensure the instrument items were pitched at the appropriate conceptual level. There were now 52 two-tier multi-choice items covering the four contextual strands of the New Zealand Science Curriculum at Levels 4, 5 and 6.

Putting the instrument into an on-line format

The surveys, originally in the form of three separate surveys, one for each of Levels 4, 5 and 6 in the NZ Curriculum Statement in Science, were combined into a single instrument of 52 two-tier multi-choice items ordered by curriculum level so that items 1-16 were at Curriculum Level 4, items 17 to 36 were at Curriculum Level 5 and **items** 37 to 52 at Curriculum Level 6. The instrument was first built in a Microsoft Word format (Appendix I) and was set up with drop-down menu buttons for both tiers of each item**.** The first tier had a drop down menu of 3 choices: a dot '.' meaning no selection or 'I disagree with true or false', an option of 'A' and an option of 'B'. The 'A' and 'B' options corresponded with answers 'True' or 'False', 'Yes' or 'No' or other appropriate two-way choice. The second tier had a drop-down menu for the four possible explanations of the first tier answer. These were labelled 1, 2, 3 or 4 in all items**.** Generally, two of these choices supported one of the first-tier choices e.g. true, and two of the choices supported the other first-tier choice e.g. false. The choices in the second tier were in no particular order. Much work was done working on digital formats for the indicators and various systems were tried from the simple HTML version to more complicated Micromedia Flash generated versions. The simpler HTML version was decided upon because it could be set up on a form handler relatively easily. The Word format was then converted to the HTML format and placed on The Correspondence School Website. Major considerations for workability in the current situation with students at The Correspondence School were student ICT capability, technical specifications and connectivity. The proportion of students with email addresses and Internet access at the time of using the instrument was about 60%.

Student cohort selection

Three cohorts of students with email access were selected, cohorts taught by a teacher in the science department at TCS who taught science to all three curriculum levels targeted by the instrument. These were cohorts of Year 9, Year 10 and Year 11 students who were working at Curriculum Levels 4, 5 and 6 respectively. The cohorts were selected at the end of the year, in November, so that each student had completed his/her programme for the year. This procedure ensured that all students had covered the same content for their year group and curriculum level. At The Correspondence School students are enrolled in programmes appropriate for their learning needs and adjustments are made if the level of work is found to be inappropriate. It can therefore be assumed that the students are working within the curriculum level of the science course in which they are enrolled. The total number of students who responded was 47 out of the 60 who were sent the instrument. The number of students from each year level and curriculum level is shown in Table 3.1.

Table 3.2
Student number in sample by year level and programme curriculum level

Year level	Curriculum level of programme	Number of students
9	4	16
10	5	16
11	6	15

The students were sent a letter by email inviting them to participate in the survey by completing and returning the diagnostic instrument. The purpose of the instrument was explained and a link was provided to enable the students to access the survey on The Correspondence School website. The indicator gave instructions on how students were to select their answers to the two-tier questions and an example was provided. Instructions were also given to click a ‘send’ button that returned their responses back to the teacher (the author) via email.

Collecting student responses

The returned answers were returned to the teacher/marker (the author) as an email attachment in the form of a list of answers by question number e.g. Question 1: A2, Question 2: B3 (Appendix K). Any optional written responses were also recorded. A marker spreadsheet was designed for rapid processing of student responses to the two-tier items into scientifically correct and incorrect answers (Appendix L). A second table gave the number of scientifically correct answers by strand and level (Table 5.10, Chapter 5)..Scientifically correct answers are given in Appendix M.

Analysis of student responses

Student responses returned as email attachments were analysed as follows:

- The percentage selection of each alternative was calculated.
- Alternative conceptions were identified and categorised by type.
- The number and range of types of alternative conceptions of were analysed.
- Individual responses in comment space were analysed for new alternative conceptions not offered as alternatives in the item. They were also analysed for indicators of difficulty related to factors such as interpretation of text, diagrams, context or language.
- The percentage of scientifically correct responses by the total student sample was calculated for the each item to provide indications of level of difficulty a basis for calculating indices of difficulty and discrimination.
- Difficulty and description indices were calculated for each item.
- The efficacy of the instrument for ascertaining conceptual scientific understanding by curriculum level was analysed.

Ethical considerations

The research complied with the Privacy Act 1993 and the health information privacy Code 1994 concerning the collection, use and disclosure of personal information. Parental consent was obtained prior to the involvement of students in the research (Appendix O). There were no consequences for not supplying information as participation in any aspect of this research is voluntary. Anonymity of all participants was preserved in all written summaries and reports of the research. The research proposal was signed off by the CEO of The Correspondence School and Principal of the Secondary Division of The Correspondence School.

Chapter Summary

- The items in the diagnostic indicators are referenced to the four contextual strands of the New Zealand science curriculum.
- The objectives themselves are skill based signified by first word in the objective e.g. investigate, but depend on an underlying scientific concept that needs to be understood.
- The fundamental underlying concepts were identified within each of the four objectives in each of the levels 4, 5 and 6 of a strand and mapped on a concept map for that strand.
- Propositional knowledge statements were then constructed linking the conceptual development within the strand.
- Questions were then devised that focussed on the concepts that underpinned each curriculum objective.
- Research has shown that student alternative conceptions fall into three to five broad categories (Osborne & Freyberg, 1985).
- The items in each survey were designed to ascertain the range of student alternative conceptions in cohorts of students working at particular levels of the science curriculum.
- The items in the survey covered each curriculum objective in each of the four contextual strands.
- The items have the format of a question requiring the student to choose between two alternatives e.g. true/false, and then write a reason for their choice.
- Three primary surveys were designed, one for each of the Curriculum Levels 4, 5 and 6.
- Each survey consisted of 16 to 20 questions. The range was due to the fact that some objectives in the curriculum have two distinct parts, each part effectively being a separate sub-objective.

- The survey items were numbered for clarity and instructions including a worked example were inserted.
- Three cohorts of students were selected from the Correspondence School full time roll and three classes in local face-to-face schools.
- The Correspondence school cohorts included the range of students in terms of gender balance, ethnic composition, reason for enrolment and level of engagement.
- The face-to-face school samples included a range of abilities, representative ethnic composition and gender balance.
- A sample from The Correspondence School cohort was interviewed by telephone to check whether their written alternative conceptions reflected their mental constructions.
- The survey questions were given to six teachers for them to predict the types of reasons students will give reflecting alternative conceptions they have experienced with students at that age and stage.
- The second tier explanations for each item were selected from the alternative conceptions from the three surveys, the telephone interviews and augmented from predicted alternative conceptions from six science teachers.
- A single instrument containing 52 items was built in Microsoft Word drop-down menu format and this was then transcribed to a HTML format.
- The instrument was placed on The Correspondence School website.
- Three student cohorts with email addresses were selected and by email were sent the link to access the instrument.
- Students who completed the diagnostic instrument returned their answers by clicking a send button at the end of the instrument.
- The returned answers were returned to the marker in the form of an answer sheet for processing and analysis.
- A marker spreadsheet was designed for rapid processing of student responses into scientifically correct and incorrect responses by strand and level.

Chapter 4 provides analyses the data collected from the three types of survey and identifies commonly held student alternative conceptions for use in the construction of the on-line two-tier diagnostic instrument.

Chapter 4
Student understandings identified from three techniques

Overview of chapter

The first part of Chapter 4 provides an analysis of student alternative conceptions identified from the surveys that were given to student samples in face-to-face and distance learning environments. The surveys consisted of stem questions with two–way responses but the students were asked to write reasons for the choices they made. The student responses were grouped into similar ideas categories and classified into SOLO taxonomy levels of thinking. The second part of the chapter analyses student responses to telephone interviews given to a sample of students to test the validity of the alternative conceptions identified in the surveys. This is followed by analysis of surveys given to six experienced science teachers to predict the types of alternative conceptions that students in the target age group were likely to hold. The final part of the chapter provides a list of alternative conceptions identified from three search techniques for use in building the on-line two tier diagnostic instrument.

Introduction

The three surveys, one for each of the Curriculum Levels 4, 5 and 6, that had been given to classes of students in face-to-face schools were analysed separately. The student responses were categorised using the SOLO taxonomy according to levels of thinking and reasoning. The reason for including the curriculum objective in the analysis was to provide the reference point for the question and the range of the responses given.

Analysis of surveys

The responses made by students to each of the questions were systematically listed and the categorised using the SOLO Taxonomy which describes the level of complexity of the student's understanding of the concepts relating to the question

(Atherton 2003; Biggs and Collis 1982; & Biggs 1999). The levels of complexity in the SOLO Taxonomy are as follows:

1. Pre-instructional level – students have simply acquired bits of unconnected information, which has no organization and makes no sense.
2. Unistructural level - students have made simple and obvious connections but have not grasped their significance.
3. Multistructural level - students have made a number of connections but have missed meta-connections and missed the significance as a whole.
4. Relational level - students are able to appreciate the significance of the parts in relation to the whole.
5. Extended abstract level – students make connections not only within the given subject, but also beyond it and are able to generalize and transfer the principles and ideas underlying the specific instance.

The student responses were listed and classified according to the first tier answer e.g. True or False and the reasons were classified according to the SOLO level of complexity. The word 'level' was avoided in the SOLO classification to prevent confusion with curriculum level so a respondent's reason would be classified as SOLO, 4 for example, meaning that it had a complexity on the SOLO scale of level 4.

Each question has a count of the number of respondents who selected each Tier-1 choice. An asterisk signifies the 'scientifically correct' answer
e.g. True False*.

Each question has a code to indicate curriculum strand and objective number e.g. CO LW4-1 codes for Curriculum Objective in Living World strand, Curriculum Level 4 objective number 1. The coding system is described below.

CO = Curriculum Objective.
LW = Living World strand.
PW = Physical World strand.
MW = Material World strand.

PEB = Planet Earth and Beyond strand.

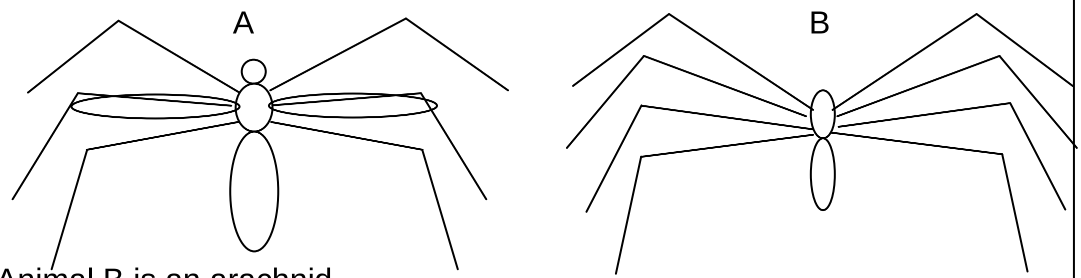
4-1 = Curriculum Level 4 objective number 1.

Curriculum Level 4 Survey

Question 1

CO LW4-1 Investigate and classify closely related living things on the basis of easily observable features.

Insects have 6 legs, most of them have wings and their body divided into 3 sections. Arachnids have 8 legs, no wings and their body is divided into 2 sections.



Animal B is an arachnid.

A True B False

Because:

Tier 1 answers: True* 29 False 4

The overwhelming majority of students were able to classify animal B as an arachnid by applying the information given. Of these, 3 respondents gave three valid reasons at SOLO Level 4:

> Because animal B's body is divided into 2 parts and not 6 legs but 8 and no wings.
> It has 8 legs, no wings and is divided into 2 parts of its body so it is a spider.

There were eight 'True' respondents who gave two valid reasons at SOLO Level 3:

> It has 8 legs and no wings.
> It has 8 legs and the body has only 2 sections.

There were 18 'True' respondents who gave one reason at SOLO Level 3:

> Because arachnids don't have wings.
> Because it has 8 legs.
> It has 2 parts to its body.

In this case, one reason is enough, although in a greater range of animals, more than one reason would be required.

Some 'True' respondents gave a less definitive answer for one feature, SOLO Level 2.

> It doesn't have 3 sections.

Of the students who were 'False' respondents, none gave reasons above SOLO Level 1. Several respondents showed an alternative conception for the word animal:

> Spiders are not animals.

Others misinterpreted the information given:

> All spiders have 3 body bits.
> They have wings.

With several 'False' respondents there was confusion over how to answer the question:

> Because arachnids don't have wings

Conceptual issues identified from this analysis are:

- A significant misconception that emerged was the scientific definition of the word 'Animal'.
- The ability to use information given to classify an organism into a broad group.

Question 2

CO LW4-2 Investigate and describe special features of animals or plants which help survival into the next generation.

Adaptations are features of a living thing which help it to survive and reproduce. Many plants produce brightly coloured and scented flowers. This is an adaptation. A True B False Because:

Tier 1 answers: True* 16 False 17

Of the 'True' responses, only three showed SOLO Level 4 reasoning by identifying the purpose of a flower as a reproductive organ that is therefore necessary for the survival into the next generation as stated in the objective:

> An adaptation is a feature of a living thing, plants produce flowers to help them reproduce and survive.
> Flowers are needed to form seeds that grow into new plants.

Some 'True' respondents understood the attractive function of brightly coloured flowers but did not link this with reproduction, therefore showing SOLO Level 2 reasoning:

> Brightly coloured flowers attract bees.

Most of the 'True' respondents simply stated that flowers were brightly coloured without linking this to any reproductive process therefore reasoning at SOLO Level 1:

> Most plants have brightly coloured flowers.
> Many plants produce flowers that are brightly coloured and some make flowers that aren't.

Several students thought that the brightly coloured flowers had a camouflage function:

> Yes, because it camouflages its baby and the baby grows.

Of the 'False' responses, many refuted any link between brightly coloured flowers and reproduction of the plant and it was therefore only achieved SOLO Level 1:

> It got nothing to do with it (reproduction).
> Coloured flowers is genetic but not how it survives and reproduces.

Other 'False' respondents gave vague or irrelevant SOLO Level 1 reasons:

> Flowers grow from seeds.
> It needs water.

Conceptual issues identified from this analysis are:

- Adaptations helping survival of species.
- Flower as a reproductive organ.
- Brightly coloured flowers have an attractive function e.g. insects to effect pollination.

Question 3

CO LW4-3 Investigate and describe patterns in the variability of a visible physical feature found within a species.

> In a class of 30 students, 26 were right handed and four were left handed. Three of the left handed students had at least one left handed parent. Five of the right handed students had a left handed parent but 21 right handed students had both parents right handed.
>
> Left and right handedness is:
>
> A Genetic B Environmental
>
> Because:

Tier 1 answers: Genetic* 16 Environmental 17

Of the 'Genetic' respondents, one correctly linked the reasoning to the data provided reaching SOLO Level 5:

> It's more likely to be genetic because most of the right handed students have right handed parents and most of the left handed children have left handed parents.

Several 'Genetic' respondents gave SOLO Level 4 reasons:

> If the mum and dad are left handed probably their child is left handed.
> They all have at least one parent that's the same.

The rest of the 'genetic' respondents supported their choice with a statement that may have been gleaned from the information given:

> It (the information) shows it runs in the family.

Some gave a general statement affirming their choice with SOLO Level 2 reasoning:

> You won't get it from the outside, you get it from your mum and dad.

Some SOLO Level 2 respondents personalized their reason, relating it to their own family:

> Because my mum and dad are left handed like me.

Of the 'Environment' respondents, some showed SOLO Level 3 reasoning using the information given to deduce that handedness is environmental:

> Some of the parents were the exact opposite of the child.

Environmental respondents with SOLO Level 2 thinking provided reasons from their own knowledge and beliefs:

> It depends which is easier for you.
> Because you learn to write.
> It's whatever you think feels better.

Other 'Environmental' SOLO Level 2 respondents used their own family characteristics to support their choice:

> Because my mum's right handed and my hand is left.
> My older sister is left.
> Your parents could be the exact opposite.

These are valid arguments from the students' perspectives, given that at this stage the concept of dominance and recessiveness has not been taught. If this question is used, the choices will have to be carefully worded to indicate that the reason should relate to the information supplied in the stem of the question.

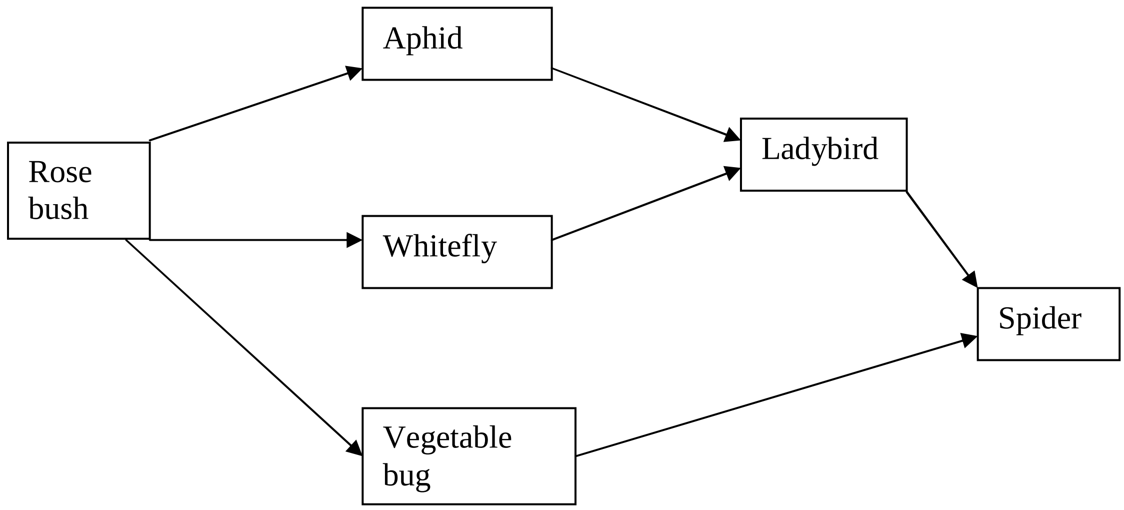
Many students relate to their own situation to make a choice rather than interpret the text. The Mendelian nature of the inheritance of handedness confuses students at this level because some students give family differences as a reason for the characteristic being non-inherited. (The word 'environmental' also confused. This became apparent in interviews because many students only think of environment in an ecological context rather than meaning non-inherited).

Conceptual issues identified from this analysis are:

- Environmental means non-inherited.
- Genetic characteristics run in families.
- If a behaviour is learned e.g. writing, there are no genetic factors in the way it is done.

Question 4

CO LW4-4 Use simple food chains to explain the feeding relationships of familiar animals and plants, and investigate effects of human intervention on these relationships.



In the food web above, reducing the number of ladybirds would help the rosebush:

A True B False

Because:

Tier 1 answers: True 18 False* 15

Of the 'False' respondents two gave a valid SOLO 5 reason:

> Because ladybirds eat the insects that eat the rosebush.
> If the ladybird didn't eat the aphids, whitefly and vegetable bug, the rose bush would be eaten.
> Several respondents gave SOLO 4 reasons:
> The ladybird eats the pests.
> The whitefly lives on the rosebush and the lady bird would eat the whitefly.

Some respondents gave SOLO 3 reasons:

> They are not the closest food level like aphids are ladybirds are not the main target to eat the rosebush.
> Because it would help other animals to eat the rosebush.

Some 'False' respondents indicated that because the ladybird did not eat the rosebush directly, a reduction in its number would not affect the rosebush. These were SOLO 2 reasons.

> It (ladybird) is far from the rosebush (in the food web).

These students did not understand the carnivore-herbivore-producer number relationship.

Many ‘False’ respondents gave an invalid reason in relation to their choice attaining only SOLO 1 reasons:

> Ladybirds eat the rosebush.

Of the ‘True’ respondents, some gave reasons that were invalid but showed some understanding of part of the interdependent relationship therefore SOLO 3:

> Because you get rid of ladybirds, you get rid of spiders.
> The spiders would die without food.

Most of the ‘True’ respondents did not relate to the information given, giving SOLO 1 reasons:

> They might blend in with the rose bush.
> The ladybird eats the rose bush.

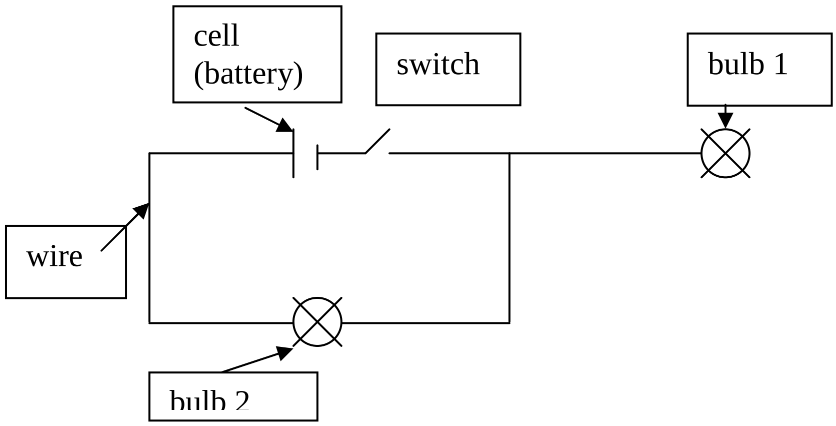
Some misunderstanding of a food web as a chart for conveying information. Most respondents had an idea of ‘what eats what’ but had difficulty with effects of changes one step away from the changed variable.

Conceptual issues identified from this analysis are:

- Food chain.
- Food web.
- Producer-herbivore-carnivore interdependence.

Question 5

CO PW4-1 Investigate and offer explanations for commonly experienced physical phenomena and compare their ideas with scientific ideas.



In the electric circuit above, when the switch is closed, bulb 1 will light up:

A True B False

Because:

Tier 1 answers: True 9 False* 23 No answer 1

Of the 'False' respondents, one gave a SOLO 5 reason conveying an understanding that an electric current needs to flow in a continuous conducting pathway – a circuit.

> It's got no wire carrying out. (drawing of line to complete circuit for bulb 2) The electric current needs to go through the bulb and back to the battery.

A number of False' respondents gave SOLO 4 reasons for bulb 2 not lighting up:

> There is only one wire leading to the bulb.
> Only bulb 2 will light up because the light bulb needs 2 wires.

A number of the 'False' respondents wrote less precise SOLO 3 reasons implying that bulb 1 would not light up because it was not connected into the circuit:

> Because it's not connected to the circuit.
> Because bulb 1 is not part of the circuit.
> Because bulb 2 is in the circuit, not bulb 1.

Of the 'True' respondents who thought bulb 2 would light up, a number argued that it was connected to the circuit showing SOLO 2 thinking, realising that there needed to be a connection or the need for a circuit, without understanding the need for the current to flow through the bulb in a circuitous route:

> The switch will complete the circuit for the bulb (bulb 2) to light up.
> Because when the switch goes down the circuit will be completed.

A number of 'True' respondents gave SOLO 1 reasons simply stating that bulb 2 was connected:

> It's connected to the switch.
> Bulb 2 is connected to the wire.
> It's connecting the cells to the bulb.

Conceptual issues identified from this analysis are:

- Electric current requires a complete circuit for current to flow.
- Current will only flow through a device that is part of the circuit (a continuous conducting pathway).
- An electric light bulb will only light up if the current can flow into it and back out by a different route to complete a circuit.

Question 6

CO PW4-2 Investigate and offer explanations for commonly experienced physical phenomena and compare their ideas with scientific ideas.

When washing dries on the washing line, liquid water in the wet clothes turns to water vapour in the air: A True B False Because:

Tier 1 answers: True 32 False* 0 In between 1

Almost all of the students sampled thought the statement was true, although their reasoning revealed misconceptions. Only six of the 'True' respondents gave a valid reason showing an understanding of change of state:

SOLO 5 reasoning would require recognition of the change of state involved in the process of evaporation. None of the 'True' respondents reached this level. There were some SOLO 4 reasons giving by some of the 'True" respondents:

> Water always evaporates and makes more rain.
> The heat in the air evaporates the water and the liquid.

Most of the 'True' respondents had the idea that the water went somewhere due to the action of the sun, but were not clear about its form in the air, with SOLO 3 reasons:

> Water drops go up into the air because heat makes it go up.
> Because the sun dries it up into the rain clouds.
> The water doesn't fall to the ground it evaporates into the air because the sun soaks it up.
> It dries up and evaporates into millions of oxygen.
> When the sun comes out it sucks the water up and the clothes dry.

Some respondents gave SOLO 2 reasons stating that the washing dries without any reference to what it becomes:

> It dries up and the wind blows on it, it will vanish.
> The sun dehydrates it.
> It will melt and fly into the air.

Some of the reasons at SOLO levels 1-2 had the notion that the sun sucked or soaked up the water.

> When the sun comes out it sucks the water 8up and then clothes dry.
> The sun sucks it up.
> The sun soaks it up.

The role of the wind was recognized by some students at this level:

> The air blows it all so they become dry.

Conceptual issues identified from this analysis are:

- Water dries by droplets going into the air.
- The sun 'sucks' water up.
- Wind blows water drops from clothes.

Question 7

CO PW4-3 Process and interpret information to describe or confirm trends and relationships in observable physical phenomena.

The following table gives car speeds and stopping distances.

Speed (kilometers per hour)	Stopping distance (metres)
30	20
40	31
50	42
60	53
70	64
80	75

The figures on this table tell you that the faster the car is going the longer the distance needed for the car to stop:

A True B False

Because:

Tier 1 answers: True* 27 False 6

The majority of the student sample could see the causal relationship between speed and stopping distance. Only a small proportion of 'True' respondents could express the relationship in terms of the stopping distance increasing with speed. One student gave a mathematical pattern for the relationship between stopping distance and speed, which would have to be a SOLO 5 level of thinking:

> The faster you go 1 metre gets taken off e.g. 30 – 10 = 20, 40 – 9 = 31, 20 – 8 = 42.

The rest of this group of respondents gave SOLO 4 reasons:

> The faster you go the larger the stopping distance.
> As the car speeds up it needs a longer space to stop.

Most of the 'True' respondents gave SOLO 3 reasons that did not relate the stopping distance to the speed,

> It's going to take a certain time to stop.
> When you need to stop, you need good distance.
> Because the more it will slide when you slam on the brakes.

The 'False' respondents gave invalid reasons for their choice indicating a misunderstanding of the meaning of the question. One respondent showed SOLO 3-2 thinking with a mathematical pattern deduced:

> It takes 10 metres less than how fast you are going.

Some ‘False’ respondents gave SOLO 2 reasons:

> Because you can stop faster.
> It would be too sudden to stop.

Some students gave reasons from their own knowledge or experience showing that the question related to their life-world experiences although they did not interpret the information given:

False	Some one has done it to us.
True	It was on a documentary on TV.

Conceptual issues identified from this analysis are:

- Stopping distance increases with speed.
- The faster an object moves, the harder it is to stop.

Question 8

CO PW4-4 Investigate and offer explanations of how selected items of technology function and enhance everyday activities of people.

> Remote controls for TV sets give out a signal which switches the TV on or off, changes channels and the sound volume. Two students were talking about how they thought it might work. Jeremy thought that the remote gave out a small electric current that passed through the air and Wendy thought it gave out a kind of invisible light.
>
> Who do you think was correct?
>
> A Jeremy B Wendy
>
> Because:

Tier 1 answers: Wendy* 13 Jeremy 19 No answer 1

Nearly all of the students who thought Wendy’s explanation to be correct gave an answer with an explanation that fitted the information given and used their own logic to support their choice. For a SOLO 5 reason the respondent would need to use the evidence that the signal traveled in straight lines and could be reflected, plus the fact that electricity needs a conducting pathway to conclude that it was most likely to be a form of light. Two respondents gave SOLO 4 reasons:

> Because electricity needs to travel in something.
> Because if you get in the way it doesn’t work in order to change the channel, you have to aim directly.

One respondents gave a SOLO 3 reason:

> When I switch on the TV and Jason is in the way he would probably get an electric shock. (If the signal was electrical).

Some 'Wendy' respondents linked the fact that a small light could be seen to go on when operating a remote, therefore the signal must by a form of light. These were SOLO 2 reasons:

> The control has a little light at the front of it.
> Because there are little lights at the end of the remote that turn the TV on.
> Because when you press the button you see a little light go on.

A significant number of 'Wendy' respondents simply repeated information stated or implied in the question to justify their choice with SOLO 1 reasons.

> It sends out an invisible light.
> There is a sensor in the TV.

The 'Jeremy' respondents gave a range of answers to justify their choice in deriving the conclusion that the signal was electrical. Most respondents used the fact that the remote control needed electricity to operate to infer that the signal must be electrical, a SOLO 2 level of thinking.

> Remote is electrical and the TV is electrical therefore electric signal.
> Because a little electric light (in the remote) switches it (the TV) on.
> The remote needs a battery to make it work so it's a current.

Conceptual issues identified from this analysis are:

- Light travels in straight lines.
- Light can be reflected.
- Electricity needs a conductor to travel through (cannot pass through air).
- There are 'invisible' forms of light.

Question 9

CO MW4-1 Investigate and group common materials in terms of properties.

Graphite is a fairly soft, grey substance that is shiny and brittle (it snaps if you try to bend it). It conducts electricity and can withstand very high temperatures. Graphite is most likely to be a: A Metal B Non-metal Because:

Tier 1 answers: Metal 1 Non-metal* 21 No answer 1

Three of the respondents who decided that graphite was a non-metal chose the brittle (non-bendy) property as the main reason for their choice. For a SOLO 5 reason there would need to be mention that the metal-like properties shown by graphite, such as shininess and conduction of electricity were outweighed by its brittleness. Respondents who realized the significance of brittleness reasoned at SOLO 4 level:

> It snaps when bended.
> Metal bends not breaks.

Some respondents interpreted brittle (non bendy) to mean not strong, exhibiting SOLO 3 thinking. Because the students' perception of metals is that they are strong, they decided that graphite was not a metal:

> Because it's non-metal if it was metal it can't break.
> Because metal isn't brittle and is strong.
> Because it is not as strong as a metal.

Of the 'Metal' respondents, SOLO 3 reasons were shown by selection of one of graphite's properties associated with metals i.e. conduction of electricity and high melting point:

> Because metal conducts electricity.
> Because it can let current go through
> It is the best at withstanding very high temperatures.

Some respondents used alternative knowledge with SOLO 1 reasons:

Non-metal	Graphite is a rock not a metal.
Metal	Graphite is a powder and needs to be mixed.

Conceptual issues identified from this analysis are:

- All substances that conduct electricity are metals.
- Metals are all strong (too strong to break).

Question 10

CO MW4-2 Investigate and explain how uses of everyday materials are related to their physical and simple chemical properties.

Over the last 50 years plastics have replaced metals in many items such as food containers. Metal cans (tins) are still widely used but plastics are being used more and more for packaging foods and drinks. At present, metal cans are better for packaging many food types: A True B False Because:

Tier 1 answers: True 10 False 22 No answer 1

For a SOLO 5 reason respondents would need to refer to mechanical strength and high melting point as the significant factors mentioned in the stem of the question. Only two of the 'True' respondents referred to the greater strength of metal but none mentioned the need for high melting point so that food could be cooked and sealed in the container. SOLO 3 was therefore the maximum level reached in the reasons:

> Because it can withstand a lot of weight and it keeps air out.
> It doesn't break when you drop it.

Several 'True' respondents showed misconceptions about degradability of metal and plastic, SOLO 2 level of reasoning:

> Plastics make food go off quicker e.g. most plastics are biodegradable.

A follow-up interview showed that this student was attempting to make the valid assertion that food in cans was preserved for a longer period of time than in sealed plastic; by biodegradable the student meant that plastic allowed food to deteriorate more quickly.

Most of the 'False' respondents alluded to properties of plastics that have advantages over metal such as non-rusting, lightness, heat insulation, softness, durability and ease of opening, with SOLO 3 reasons:

> Because plastics are strong, cool, lighter.
> Metals can expose and get rusty.
> Plastics are more lighter and durable.
> It will be too heavy and plastic is lighter.

One candidate referred to a functional utility of the package using own knowledge, SOLO 2:

You can't put metals in the microwave.
Tin cans hold food sealed inside for 12 months or more.

Conceptual issues identified from this analysis are:

- Interpretation and application of the information given.
- Metal rusts (only iron does, which in the case of tinplate is valid but only when the tin layer is penetrated).
- Interpretation of **some** as **all.**

Question 11

CO MW4-3 Investigate and describe ways of producing permanent or temporary changes in some familiar materials.

> When a spoonful of salt is added to water, it disappears after stirring and forms a solution. The salt cannot be filtered out of the solution and it does not settle out if the solution is left to stand. If the solution is left to dry out, solid salt is left.
>
> Salt dissolving in water is a **temporary** change:
>
> A True b False
>
> Because:

Tier 1 answers: True* 26 False 6 No answer 1

Of the 'True' respondents, six gave a reasoned explanation for this being a reversible change. A SOLO 5 reason would need to make the point that dissolving salt in water is an easily reversible change by evaporation of the water from the solution leaving the salt behind. Two 'True' respondents were close to a SOLO 5 reason:

Because it dissolves into water but when the sun evaporates the water, the salt is left salt can't evaporate.
Because when the water evaporates the salt is left because salt is heavy.

SOLO 4 'True' respondents gave less explicit reasons:

Salt is a mineral and will remain after the solution has dried out.
It dissolves when it is stirred and turns back to its form when it's dried out.

Some explanations of 'True' respondents revealed some misunderstandings of processes, confusing drying with setting with SOLO 3 explanations:

> Because it dissolves into the water but when it dries it turns solid.
> Because it can go for a little while then come back when it dries so it disappears for a little while.
> Because it gets hard after drying.

Some 'True' respondents used their own knowledge in their reasons, at SOLO level 2:

> Sea salt is left in ponds and water dries out.

The 'False' respondents doubted the information given and showed misunderstanding of the concept of dissolving in their SOLO 2-1 reasons:

> It won't just come up like that.
> Because salt won't stay in the pot.
> Salt is left only when you stop stirring.

Conceptual issues identified from this analysis are:

- Salt will not reform from solutions on evaporation.
- Salt will settle from solution in time.
- Evaporation confused with drying or setting in the context of concrete.

Question 12

CO MW4-4 Investigate the positive and negative effects of substances on people and on the environment.

Two students were doing an experiment with different types of plastics. Susan said that most plastics are made from fossil fuels such as oil. Tania said she didn't think that plastics could be made from oil. Who do you think is correct? A Susan B Tanya Because:

Tier 1 answers: True* (Susan) 28 False (Tanya) 4 No answer 1

Of the 'True' (Susan) respondents, only two gave a valid reason for their answer. At this curriculum level an understanding that plastics can be made from oil by processes involving change to form new substances is sufficient so the following reasons reach SOLO 5:

> Because oil is heated and formed into plastics with other chemicals.
> Plastic is made from crude oil which is mixed with a chemical to make it.

Most of the other ‘True’ respondents gave SOLO 3 reasons indicating the notion that plastics are extracted from oil rather than made from it:

> Some plastics are in oil.
> Crude oil is in plastic.

Or, that oil is an additive in the process of making plastics:

> Because crude oil is added into the mixture to make plastics.

Some ‘True’ respondents simply stated that plastic was made from oil because they were taught this without justifying with any other reason derived from the information given, thus SOLO 2-1:

> Susan is right because it does come from oil.
> We watched a video that showed people making plastic from oil.

Of the ‘False’ (Tanya) answers, some pointed out the physical difference between plastic and oil to support their choice, at SOLO level 2. In some cases, respondents had the notion that oil is an additive used in making plastics:

> Oil is a slippery substance (plastic is not).
> Oil is dangerous and toxic (plastic is not).
> Oil would eventually burn through (from the plastic and reveal itself).

These three answers indicate a lack of understanding of the fact that a chemical change results in substances with different properties. The notion that plastic can be made simply by mixing up ingredients, like making a sauce, was prevalent.
Conceptual issues identified from this analysis are:

- Plastic is an ingredient in crude oil.
- Plastic could not be made from crude oil because it is so different.
- If oil was part of plastic, it would show itself somehow.

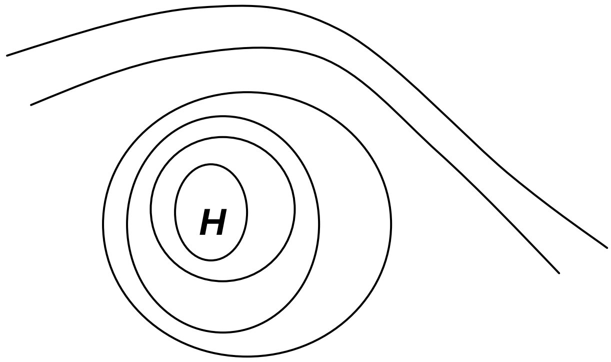
Note: Distinctions between physical and chemical change are not expected outcomes at this curriculum level.

This question does not relate directly to the objective. However, students need to be aware of the usefulness of crude oil in our way of life in terms of its use as fuels and as raw materials for other products such as plastics which also have positive and negative effects on people and the environment. This relationship is an important **underlying** concept for students seeking to investigate the positive and negative effects of fossil fuels and/or plastics on people and the environment.

Question 13

CO PEB4-1 Investigate major factors and patterns associated with weather, and use given data to predict weather.

The weather map below shows a high pressure zone in the atmosphere.



The area under this weather system will have fine weather:

A True B False

Because:

Tier 1 answers: True* 23 False 9 No answer 1

Of the 'True' respondents, five stated that a 'high' indicated fine weather. There was no indication as to why this was, which would not be expected at this level. The objective is simply to recognize a pattern associated with weather – a 'high' or anticyclone being one such pattern, but also to understand that 'high' or 'low' refers to atmospheric pressure. Association of high atmospheric pressure with fine weather merited a SOLO 4 reason, even though the term 'trough' is inappropriate.

> Because it is a high pressure trough.

The association of a 'high' with fine weather without reference to air pressure therefore reflected a level of thinking no higher than SOLO 3.

> Because most lows have rain around them.
> I think hot weather will move from this area.

Most of these respondents associated the 'high' with fine weather without any qualification. Most of these students knew that the 'high' referred to atmospheric pressure although some clearly thought that the 'H' stood for 'hot'.

> The hottest weather is in the centre.
> Because hot weather from above comes down.
> Because it's near the hot weather.

Of the 'False' answers, most had misunderstood the code or pattern and its weather related associations, many of these thought that 'H' meant 'hot' therefore no higher than SOLO 1:

> Because the layer on top is to keep heat out.
> It's just in the middle (the heat).

Or simply disagreeing with the statement.

> It will be cold underneath.

Conceptual issues identified from this analysis are:

- Atmospheric pressure pattern represents a layered section of a structure.
- The 'H' represents high atmospheric pressure.
- The 'H' represents high temperature.

No understanding is expected at this level of why a high pressure zone is often associated with fine weather.

Question 14

CO PEB4-2 Collect and use evidence from landforms, rocks, fossils, and library research to describe the geological history of the local area.

Many of the rocks found on a hillside contained fossil sea shells. This indicated that the area was once part of an ancient seabed. A True B False Because:

Tier 1 answers: True* 28 False 4 No answer 1

The majority of respondents thought that the assertion that the area was once part of an ancient seabed was the correct explanation. Most of these respondents provided the fact that sea shells come from the sea therefore the rocks must also have a marine origin.

A few respondents gave an indication of how a seabed became a hill side, showing SOLO 4 reasoning:

> Because the sun dried up the water and all the rocks still had shells stuck in them.
> Because sea shells were under the sea, not a hill side. Evolution changed it.

Straight association of the shells with marine origin merited SOLO 3 reasoning:

> Because shells only come from water.

Other SOLO 3 respondents provided alternative explanations. One student mentioned the possibility of human intervention:

> Unless someone dropped them (the shells) there, it's more likely to be true.

A couple of respondents referred to the biblical flood.

> The whole world was underwater when Noah built his ark.

One respondent advanced an astronomical explanation:

> The world was underwater after the big bang.

Of the 'False' answers, alternatives were offered:

> Because shells came from rocks on land.
> It could have been a river.
> People could have put them (the shells) there.

Conceptual issues identified from this analysis are:

- Sea shells in a rock indicate a marine origin.
- Sea shells had become fossils indicating age.
- The Earth's surface has changed over time.
- Time scale big bang to Earth to life-forms to humans.

Question 15

CO PEB 4-3 (a) Use simple technological devices to observe and describe our night sky, *e.g. binoculars or simple star maps.*

> A student found a star map from a newspaper that was a year old. She noticed the planet Mars on the map and decided to use it to try to see if she could see Mars in the sky at night time.
>
> This old map could be used to find Mars in the night sky
>
> A True B False
>
> Because:

Tier 1 answers: True 8 False* 25 No answer 0

Of the ‘False’ answers, no respondents gave a valid SOLO 5 reason for not being able to use an old map to find Mars in the night sky: A SOLO 5 reason would mention the planets orbiting Sun and Earth orbiting Sun as resons for the changing position of Mars in the night sky during the year. Several respondents gave SOLO 4 reasons:

> Mars being a planet orbits the sun, therefore changes positions during the year.
> Because the world moves around the sun.

SOLO 3 reasons were less explicit.

> All the planets move around the sun so you can’t find it.
> Because planets move.
> Because the world moves around the sun.

One student knew that an old map of this type could be used again after a set time period because Mars position would recur periodically (even though the time span is on the short side!), but merited SOLO 3 reasoning:

> Mars would be moving unless it was exactly a couple of years.

SOLO 2 ‘False’ responses included:

> The world moves round.
> Earth is moving.

Responses such as ‘the world moves around’ were not clear as to whether the intended meaning was Earth rotating on its axis or orbiting around the sun. The first would not be valid whereas the second would be. However, this is a difficult distinction at this level.

Most of the ‘False’ respondents gave the reason that Mars would have moved without giving a deeper reason for this, meriting SOLO 2 reasoning:

> Because Mars would have changed in the year and you couldn’t tell if it was Mars.

Other answers confused Mars the planet with stars:

> The stars are in a different place.

Of the ‘True’ answers, some implied that Mars would be in the same place because it orbited with Earth, meriting SOLO 2:

> Mars is in line with the Earth.

> Because Mars only circles, it doesn’t move away.

One ‘True’ respondent gave the reason that the atmosphere moved Mars.

> Because the atmosphere would have moved Mars.

Conceptual issues identified from this analysis are:

- Planets are stars.
- Planets orbit the sun therefore positions in the night sky change from year to year.
- Earth orbits the sun.
- Mars moves independently of Earth.
- Mars is beyond Earth’s atmosphere.
- Earth rotates on its axis and orbits the sun.

Due to the complexity of the systems involved in answering this question it was decided to remove this question. Similar concepts are more appropriately tested at Curriculum Level 5.

Question 16

CO PEB4-3(b) Investigate and use models which explain the changing spatial relationships of the Earth, the Moon, and the Sun, and the way different cultures have used these patterns to describe and measure time, and position.

> Hemi and Aaron were talking about the moon. Hemi said that the moon travels around the earth and the sun. Aaron said that the earth travels around the sun, the moon travels around the earth but the moon doesn’t travel around the sun. Who do you think is correct?
>
> A Hemi B Aaron
>
> Because:

Tier 1 answers: Aaron 22 Hemi* 10 No answer 1

Of the students who selected Hemi’s reasoning, one gave a fully satisfactory SOLO 5 reason:

> Because the moon goes around Earth it will also go around the Sun.

This student accompanied this statement with a diagram clearly showing the correct movement of the moon around Earth and of Earth around the sun.

Other 'Hemi' respondents simply selected the part of the statement that they could relate to as true, with SOLO 3 reasoning:

> Because the Moon travel around the Earth.
> The moon goes around us and we circle the Sun.

One 'Hemi' respondent gave a SOLO 2 reason containing correct idea but did not directly explain the choice.

> The gravity of the Earth pulls the Moon which keeps the Moon connected to earth.

Some of the 'Hemi' respondents showed misconceptions about Sun, Earth, Moon system:

> The Sun does orbit the Earth.

Of the students who selected Aaron's reasoning, some showed a basic understanding of the Sun, Moon, Earth relationship, with SOLO 3 reasoning:

> Because earth orbits only around the Sun but the Moon does not orbit the Sun.
> Earth circuits the Sun.
> I know that the Moon orbits the Earth.
> The Moon travels around the Earth, that's how the Moon comes up at night.
> The Moon orbits the earth, not the Sun.

Some of the 'Aaron' respondents revealed misconceptions about the Sun, Earth, Moon relationship:

> The Earth travels around the Sun and around the Moon.
> They both travel around the Moon at night and the Sun at day time.

Conceptual issues identified from this analysis are:

- Earth orbits moon.
- Sun orbits earth.
- Moon orbits Earth but not sun.

The notion that the moon orbits Earth and that Earth orbits the sun therefore, the moon orbits the sun also was that extra step in logical reasoning that only one of the respondents achieved.

Question17

CO PEB4-4 Investigate a local environmental issue and explain the reasons for the community's involvement.

In a tree planting project, students from the local intermediate school spent a day planting New Zealand native trees on a hillside in a reserve. One student, Sandra, said the main reason for planting New Zealand native trees is because they are cheaper than trees that are not native to New Zealand. Do you think she is correct? A Yes B No Because:

Tier 1 answers: Yes 14 No* 18 No answer 1

Of the 'No' respondents, only 1 gave a SOLO 4 reason relating to the desirability of recreating the natural environment and restoring natural heritage:

> Planting trees make you realize the importance of native trees and plus you breathe with trees so their doing it for their own sake to survive.

Other 'No' respondents questioned the cost motive, showing SOLO 3 reasoning:

> It should be to grow more native trees.
> It might be to help the environment.

One 'No' respondent gave an educational reason:

> It was a project.

A few suggested that native trees might grow better in the NZ environment, SOLO 3 reasoning:

> Natives are used to NZ.

Most of the other 'No' respondents gave economic reasons for planting native trees, SOLO 3 reasoning:

> Because NZ trees are precious to NZers and they won't be cheap.
> They are natural over here and would be much cheaper.

Of the 'Yes' answers, most argued the other way from the economic standpoint, with SOLO 2 reasons:

> Native trees are more than normal trees.
> You won't pay for transport because the natives come from NZ.

Conceptual issues identified from this analysis are:

- Community involvement in environmental projects helps people to appreciate it more.
- Use of NZ native trees to recreate a natural community helps to preserve NZ natural heritage.

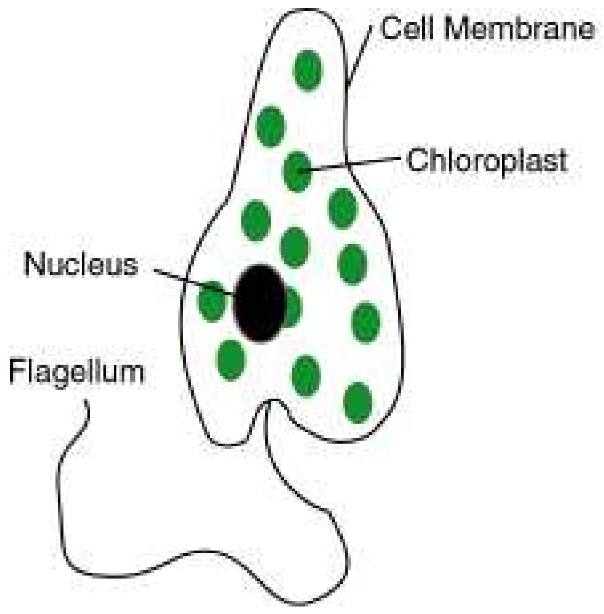
This question needed to be modified so that students are not distracted by the economic connotations, but think in terms of the community involvement in preserving New Zealand's natural heritage. This question aimed to see if the students appreciated that planting New Zealand native trees would help to recreate a natural community to help conserve New Zealand's natural heritage.

Curriculum Level 5 Survey

Question 1

CO LW5-1 Investigate, and classify in broad terms, the living world at a microscopic level.

Euglena is a microscopic single celled organism which lives in ponds. It swims by the action of a flagellum which pulls it along. Its cell consists of cytoplasm, nucleus, chloroplasts and is surrounded by a flexible membrane. It feeds by carrying out photosynthesis but it can also absorb organic nutrients from the water.



Euglena is:

A A plant cell B An animal cell

Because:

Tier 1 answers: Plant* 27 Animal* 12 No answer 2

There were no answers at SOLO Level 5. This would require a reason stating that Euglena showed both plant and animal characteristics, but on balance the respondents choose say, plant because it can photosynthesise, or animal because it can move.

Of the 'Plant' respondents, some gave photosynthesis as the main reason for their choice. This type of response represented SOLO Level 4:

> Has chloroplasts it uses for photosynthesis.
> Has chlorophyll for photosynthesis.

Some 'Plant' respondents gave chloroplasts as the reason, SOLO 3-4:

> It has chloroplasts.
> Animal cells don't have chloroplasts.

Some 'Plant' respondents mentioned photosynthesis but also stated that Euglena absorbs organic nutrients which is more an animal characteristic than plant.

> Photosynthesis and absorbs organic nutrients.

This type of response showed SOLO level 3 thinking.

A high proportion of students gave level 1 reasons for their choice:

> It lives in ponds.
> It's an organism.

Of the 'Animal" respondents, some level 4 reasons were given:

> Doesn't have a cell wall.
> Has a flagellum so it can move.

Some simply stated a structure as the reason for their 'Animal' choice:

> It has a tail.
> Flagellum.

It is hard to allocate a level of thinking to these students. If by naming the structure, there are implying the ability to move then their reason is at SOLO level 3 or 4. If they are just naming the structure because it is unusual, they are reasoning at Level 1 or 2.

There were some 'animal' respondents who gave Level 1 answers:

> It has a nucleus.
> Single cell.

Conceptual issues identified from this analysis are:

- Plants absorb **organic** nutrients.
- An organism is a plant.
- Animals don't live in water.
- Organic and inorganic nutrients.
- Only animal cells have a nucleus.
- Plants cannot be single celled.

Question 2

CO LW5-2 Investigate and describe structural, physiological, and behavioural adaptations which ensure the survival of animals and flowering plants in their environment.

> Adaptations are features that help a living thing to survive. There are 3 kinds of adaptations:
>
> **Structural** which is a body part which helps the living thing to survive
>
> **Behavioural** which is something the living thing does to help it to survive
>
> **Physiological** which is a chemical the living thing produces to help it to survive
>
> Plants grow towards light. This helps the plant to carry out photosynthesis better. This growth is caused by the action of a chemical produced in the stem.
>
> A plant growing towards light is a **behavioural** adaptation:
>
> A True B False

Tier 1 answers: True* 25 False 16 No answer 0

A SOLO Level 5 answer would state true with a reason stating that it is something the plant does in order to photosynthesise better and therefore survive better.

Two reasons were close to Level 5

> It grows towards light in order to photosynthesis and survive.
> Because they will never run out of light for photosynthesis.

A larger number gave the survival value without stating why they thought it was a behavioural adaptation of reasons were at the level 4

> It is heading for the light to help it grow.
> Plants need light to help them grow.
> It faces the sun, so it faces it to help it survive.
> It helps to survive by sunlight.

Others stated the value of the behaviour stating that it was behavioural but not linking to why it was of survival value hence SOLO level 3:

> Growing towards light is a behaviour
> It is something it does to survive.
> Photosynthesis is something it does to survive.

Of the 'False' responses, a number reasoned this was a physiological adaptation because it involves a chemical.

> Chemical so physiological.
> Growth caused by chemical.
> It is physiological that makes it grow towards light.

These 'False' response students clearly linked ideas showing Level 3 reasoning but missed the significance of something the plant does to link the actual process to a behavioural adaptation of movement towards light.

Conceptual issues identified from this analysis are:

- A growth response brought about by a chemical is physiological.

Question 3

CO LW5-3 Investigate patterns in the inheritance of genetically controlled characteristics and explain the importance of variation within a changing environment.

A pure black guinea pig and a pure white guinea pig were mated. The first generation were all black. When two of the black offspring were mated, the second generation were seven black and two white guinea pigs. This shows that the black gene is dominant and the white gene recessive. A True   B False Because:

Tier 1 answers: True* 31 False 9 No answer 1

Only one respondent gave a level SOLO 4-5 reason.

> Gene that produced the white coat was not seen until the 3rd generation.

There was one Level 3 reason:

> Offspring all black in first generation so black must be dominant.

This is a higher level reason than simply stating more black than white. Most of the reasons for the 'True' notion were at the low end of the SOLO taxonomy.

> There were more black than white.
> There were 7 black and only 2 white.

One 'True' answer indicated a lack of understanding of a gene as a particle of inheritance.

> Shows that black gene may be created more easily.

Of the 'false' responses, a number were at SOLO Level 3:

> Not a big enough sample. Two black offspring could give white, so false.

An erroneous reason indicated a similar level of understanding:

> It can have any colour because of genes e.g. white and white could = black

Conceptual issues identified from this analysis are:

- The way in which dominance and recessiveness operate in determining physical characteristics of organisms.
- The relationship between genetic probability as a predictor of offspring characteristics and the actual results obtained.
- The effect of sample size on the closeness of actual results to genetic prediction.
- Genetic characteristics are the result of the interaction of discrete units of inheritance, the particle nature of inheritance.

Question 4

CO LW5-4 Investigate and understand trophic and nutrient relationships between producers, consumers, and decomposers.

A living community contains producers, consumers and decomposers. Decomposers are essential to life on planet Earth: A True B False Because:

Tier 1 answers: True* 33 False 7 No answer 2

Of the 'True' responses, only 1 student gave a SOLO Level 4 reason in which s/he saw the activity of decomposers as part of a natural recycling process:

> Remove dead creatures and recycle. Balanced cycle of life.

Some of the 'True' respondents gave a SOLO level 3 answer with the realization that decomposers' activities were good for soil and plant growth:

> Helps get rid of waste from animals and plants and helps grow plants
> Decomposers make things grow.
> Create good soil to grow things.
> Give something back to earth.

The majority of the 'True' respondents gave unistructural reasons at SOLO level 2 for the role of decomposers:

> Things get broken down.
> They rot dead things.
> Consume waste, planet free of it.

Of the 'False' respondents, most did not give a valid reason. One 'False' respondent did not see the importance of decomposers despite some understanding of trophic levels:

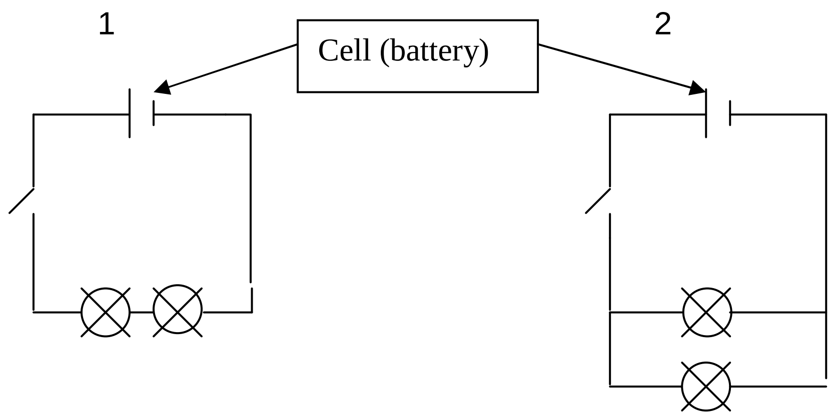
> Don't help us like producers and consumers.

Conceptual issues identified from this analysis are:

- Decomposers remove dead remains from planet.
- Decomposers recycle nature's resources.
- Decomposers return nutrients to soil to benefit plants
- Decomposers are an essential part of the biosphere as nature's recyclers of limited resources.
- Decomposers perform an essential function for other life forms.

Question 5

CO PW5-1 Carry out simple practical investigations, with control of variables, into common physical phenomena, and relate their findings to scientific ideas.



The above circuits have cells of the same voltage and bulbs of the same size.
When the switch is closed the bulbs in circuit 1 will be brighter than the bulbs in circuit 2:

A True B False

Because:

Tier 1 answers: False* 18 True 24

Of the 'False' respondents, few gave a valid reason. Only two students reached the multistructural level of understanding at SOLO level 3:

> The bulbs in circuit 1 get an uneven amount of power because they have to share each other's power.

Given that power = current x voltage, this is true but the resistance factor was not mentioned by this student or any other in the sample. Most of the 'False' respondents gave a unistructural reason maintaining that the two circuits contained the same components therefore bulb brightness would be the same in both:

> Same voltage and same light bulbs.
> Both same apart from where bulbs are placed.

Of the 'True' respondents, two reached a multistructural level of thinking at SOLO 3, but assumed that the power would be split between bulbs in the parallel circuit instead of each bulb receiving all of the power:

> Circuit 2 joined in parallel, so doesn't have power of 2 cells.
> All electrons flowing past in circuit 1 only half in circuit 2.

Most of the other 'True' respondents gave reasons relating to the amount of wire the electric current in the circuit had to travel:

> Bulbs in circuit 1 closer than circuit 2.
> Less wiring, light bulbs in one area.
> The lights are closer.

There was a relatively high proportion of respondents who did not give a reason or just did not know.

Conceptual issues identified from this analysis are:

- Electric circuits in parallel circuit shared (split half and half) the electric current.
- Circuits with the same components will have the same current flowing irrespective of series or parallel connections.
- The length of wire in a circuit has a significant effect on the current through a bulb.

Question 6

CO PW5-2 describe various ways in which energy can be transformed and transferred in our everyday world.

When an electric current lights a bulb in a circuit, electrical energy is turned into light energy which is lost from the circuit: A True B False Because:

Tier 1 answers: True* 17 False 18 No answer 6

Of the 'True' respondents, only two gave reasons showing understanding at the relational level in which they stated that energy is lost from the circuit as light:

> It gets emitted from the light. The energy is no longer in the circuit.
> When electrical energy is turned into light energy it is given off as light and is therefore lost from the circuit.

Some ‘True’ respondents acknowledged that some electrical energy was converted to light energy but did not infer that this meant that it was lost from the circuit system.

> Because changes from electrical energy to light energy.
> You need electrical energy to turn circuit on to produce light energy.

Some ‘False’ respondents gave multistructural reasons at SOLO level 3 for their choice, acknowledging energy conversion and loss from the circuit system but the word ALL became the issue:

> Some lost but not all, but it does lose heat energy.

Others indicated that they doubted the energy was lost because electricity continued to flow in the circuit:

> It is continuous and also generates heat.
> Because there is still both electrical and light energy.

Other false respondents showed a misunderstanding of the electrical circuit:

> The electricity just goes through the wire to the bulb.

Others did not accept that electrical energy is turned to light:

> Because light energy does not come from the electric current.
> Because light energy just comes from the bulb.

One respondent did not accept the involvement of the electric current at all:

> Light energy runs on batteries.

Conceptual issues identified from this analysis are:

- Electrical energy is converted to light energy.
- Light energy given out by a light bulb is lost from the circuit.
- Electrical energy in a circuit is a continuous circular flow of current.

Question 7

CO PW5-1 Carry out simple practical investigations, with control of variables, into common physical phenomena, and relate their findings to scientific ideas.

If the two objects below are dropped at the same time:

The 1 kg and 10 kg masses will hit the ground at the same time:

A True   b False

Because:

Tier 1 answers: True* 10 False 30 No answer 2

Of the 'True' answers, only two respondents showed multistructural understanding at SOLO level 3. None reached above this level:

> The amount of gravity acting down on them adjusts to make them fall in the same amount of time.
> Everything falls at the same rate of speed.

One respondent mentioned terminal velocity.

> Terminal velocity the same because of air resistance.

One respondent gave an erroneous explanation but knew the outcome:

> The pull of gravity is the same on both objects.

Of the 'False' respondents, some reasoned at the multistructural level despite selecting the wrong outcome:

> 10 kg is much bigger than so more gravitational force, therefore it falls faster.

Most reasoned at SOLO Level 1 or 2:

> 10 kg will hit the ground first.
> The 10 kg will fall faster.

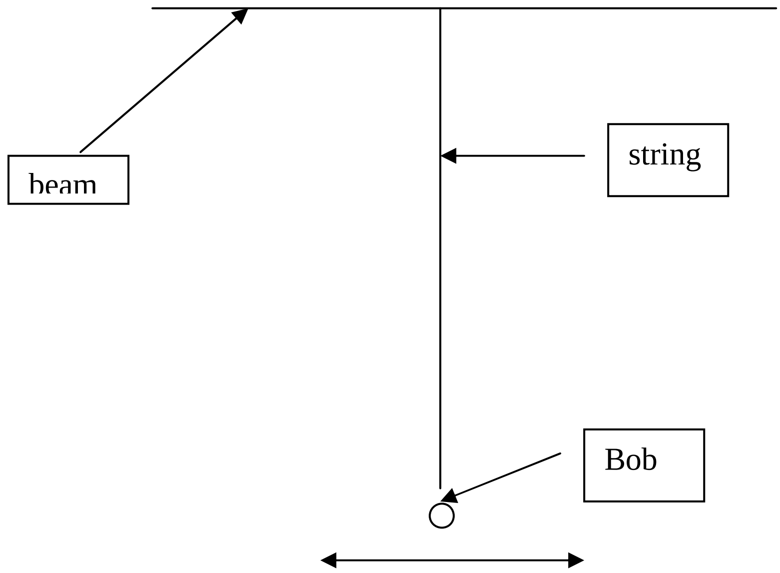
Conceptual issues identified from this analysis are:

- Larger masses fall faster than smaller masses.
- Masses fall at same rates because gravity evens out.
- Masses fall at same speed because they have the same terminal velocity due to air resistance.

Question 8

CO PW5-3 Investigate and describe the patterns associated with physical phenomena some patterns may be expressed in graphical terms.

2 students set up a pendulum made from a length of string hanging from a beam in a door way and a mass hanging on the end (the bob). They were investigating the effect of the bob mass and the string length on the swing time.



The pendulum was set swinging and the student measured the time for 10 swings (each swing was back and forth). The students then divided the time by 10 to get the average time for one swing. They then repeated the experiment a number of times but changed the mass of the bob on the pendulum or the length of the string. Here are the results:

Bob mass (grams)	String length (cms)	Average swing time
50	50	1.2
100	100	2.0
50	100	2.0
100	50	1.2

From these results it can be concluded that swing-time is increased when the mass of the bob is increased **and** when string length is increased:

A True B False

Because:

Tier 1 answers True 28 False* 11 No answer 3

Of the 'False' responses, two showed understanding of the data at extended abstract level:

> The results show that the mass of the bob does not affect the swing-time, the longer the string length, the longer the swing-time.
> 100 grams on 50 cm of string has the same swing-time as 50 grams on 50 cm of string so it is length of string that increases swing-time.

Another respondent at multistructural level at SOLO 3 tried to explain why the longer string led to longer swing-time.

> The longer the string the further it has to travel, the weight doesn't do anything.

Of the 'True' respondents, a few reached multistructural SOLO level 3 of understanding by making a valid association, but not giving the whole story with respect to both mass and string length.

> It will sway more if string longer.

Others gave a generalised answer but had not made a valid correct association:

> They are different, some are increased, some aren't.

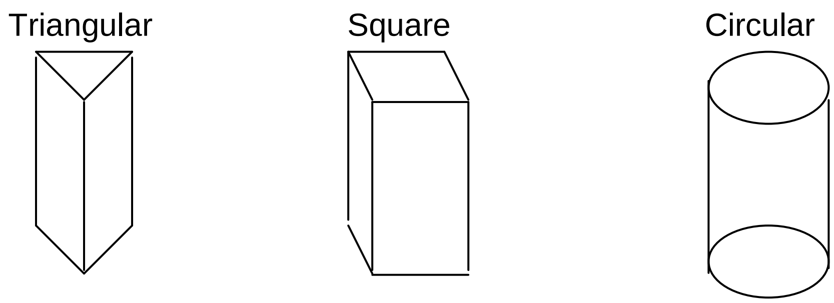
Conceptual issues identified from this analysis are:

- Mass affects swing-time of a pendulum.
- Length of string affects swing-time.

Question 9

CO PW5-4 Investigate how physical devices or systems can be used to perform specified functions.

3 students did an investigation to find out which shape of pillar was the strongest. The 3 shapes tried were triangular, square and a cylinder. Each model pillar was made of the same sized piece of cardboard.



Masses were placed on top of each pillar until it collapsed. The mass under which the pillar collapsed was recorded. Each student did their own investigation and the results were all recorded on the table below.

	Mass which caused pillar to collapse (grams)		
Student	**Triangular**	**Square**	**Circular**
Leon	250	250	300
Jenny	300	300	350
Don	250	350	350
Average	267	300	333

The pillar with the circular end was the strongest:

A True B False

Because:

Tier 1 answers True* 29 False 7 No answer 5 Both 1

Of the 'True' respondents two gave SOLO level 4 reasons:

> On average it held the most weight and at least as much as if not more in 2 cases than the square.
> It has the highest average.

Other 'True' respondents did not refer to the table giving reasons at unistructural level:

> It seems stronger without edges.
> It has no corners, the circle is more stronger because it has no corners.

Of the 'False' answers, most did not give a reason. One respondent used life-world experience/knowledge to support his/her choice:

> Triangular is the strongest maybe not this one (circular), but if made correct it is. That's the shape they use to hold up trains when they go over lakes etc.

One 'False' respondent thought the square and circular pillars were equally strong because they both held the same highest mass.

> It has equaled the square and both held 350g.

Conceptual issues identified from this analysis are:

- Average or mean mass held is a better indication of strength than maximum mass held.
- Ignoring of evidence and drawing on personal knowledge

Question 10

CO MW5-1(a) Investigate familiar substances and describe, using the concept of the particle nature of matter, how they may exist as solids, liquids, and gases.

A small amount of a liquid called ether is poured into a plastic bag, the air is squeezed out and the bag is tied tightly at the top. The plastic bag is then placed in a tray and hot water is poured over it. The bag inflates and there is no longer any liquid ether in the bag. This can be explained using the theory that all matter is made up of tiny particles that are too small to see. A True B False Because:

Tier 1 answers: True* 17 False 10 No answer 4

Of the 'True' respondents, two provided relational level reasons:

> Particles further apart in a gas and they are moving more quickly than they were.
> Particles separated so there is gas instead of liquid.

Other 'True' respondents gave reasons at the unistructural SOLO 2 level:

> Ether can't disappear, so tiny particles are still in bag although too small to see.
> Because it heats up and turns to gas.
> Because it would form into a gas where therefore we can't see the particles.
> Because it has evaporated and you can't see it is still there.

Of the ‘False’ respondents, some rejected the notion of particles, simply implying that liquid turning to gas was the explanation for the inflation of the plastic bag.

> The ether would have evaporated into gas which would inflate the bag.
> This can be explained using the method of evaporation, liquid to gas.

One ‘False’ respondent thought that the inflation of the bag is caused by particles enlarging in size:

> Because the particles are bigger when heated.

Conceptual issues identified from this analysis are:

- The notion that matter consists of moving particles too small to see.
- Solid, liquid and gas states can be explained in terms of speed and nature of particle movement and degree of separation.
- Particle movement and separation dependent of temperature.
- Particles expand when heated.

Question 11

CO MW5-1(b) distinguish between elements, compounds, and mixtures, using simple chemical and physical properties, and describe a simple model of the atom.

Water is a pure substance made up of hydrogen and oxygen. Hydrogen is an explosive gas and oxygen is a gas that helps burning. Scientifically speaking water is: A an element B a compound Because:

Tier 1 answers: Element 16 Compound 23 No answer 2

Of the respondents who selected ‘Element’, reasons given that were incorrect or erroneous alluding to the four elements of medieval times popularized in some contemporary TV cartoon programmes.

> Water is pure and one of the four elements.
> It is natural and it is not a chemical substance.
> It has gas in it.
> It can’t be separated and has 1 type of atom in it.

Of the ‘Compound’ respondents a number of reasons showing relational understanding were given at SOLO 4:

It's made up of more than one element.
More than one element required to make water.
Water can't be an element because it is made up od 2 elements, hydrogen and oxygen.

Some 'Compound' respondents used the word 'mixture' showing a lack of understanding that the elements of a compound are a special combination.

It's a mixture of 2 elements.
It is a mixture of 2 hydrogen atoms and 1 oxygen atom.
An element is a pure substance and a compound is made.

Pre-instructional level reasons at level 2 were given by some of the 'Element' respondents:

Because water is a liquid.

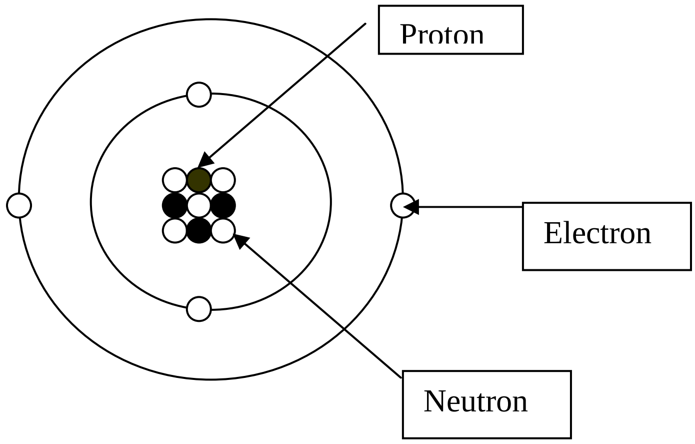
Conceptual issues identified from this analysis are:

- Compounds are made up of two or more elements combined together.
- The elements combine in a fixed ratio.
- A compound is a pure substance.
- The state of matter is not an indicator of element or compound.

Question 12

CO MW5-1(b) distinguish between elements, compounds, and mixtures, using simple chemical and physical properties, and describe a simple model of the atom.

Look carefully at the drawing of an atom below.



The number of protons, neutrons and electrons in this drawing of an atom indicate that it is an atom of a naturally occurring element:

A True B False

Because:

Tier 1 answers: True* 14 False 18 No answer 9

Of the 'True' answers, no respondent gave the scientifically correct reason that the number of protons was equal to the number of electrons. The nearest response was a statement at relational level SOLO 4 that also included neutrons (albeit the wrong number of neutrons quoted).

> They all have 4 protons, 4 electrons and 4 neutrons.

Most 'True' respondents gave reasons at pre-structural level at SOLO level 1.

> Because it is up to 3 elements.
> Because it is a naturally occurring element.
> There are more natural than non natural.

Many true respondents did not give a reason with responses like:

> I don't know.
> I haven't learnt this.

Of the 'False' answers, some referred to numbers of fundamental particles with reasons at multistructural SOLO level 3:

> The number of protons and neutrons is not the same.
> The protons and neutrons are different amounts and it's not natural.
> The number of protons, electrons and neutrons are not equal.

Several 'False' respondents referred to the outer shell electrons:

> The outer shell isn't full.
> The outer shell isn't filled with 8 electrons.

Conceptual issues identified from this analysis are:

- Neutrons are present in the same number as protons and electrons.
- Outer shell of eight electrons in natural atoms.
- Element, compound, atom – mixing up of ideas around these.

Question 13

CO MW5-2 Apply their knowledge of chemical and physical properties of substances to investigate their safe and appropriate use in the home and the community.

Oven cleaner is a strong base called caustic soda which breaks down fat and grease. If some oven cleaner is sprayed accidently on to the floor, a safe way to deal with it would be to sprinkle it with citric acid (a weak acid powder used in baking) and then clean up with a wet mop: A True B False Because:

Tier 1 answers: True* 18 False 15 No Answer 8

Of the 'True' respondents, only two gave a scientifically valid reason at SOLO Level 5 and 4, respectively:

> Adding acids to base makes it neutral so it makes it safer to just clean up with a wet mop.
> The acid and base cancel each other out.

Other 'True' respondents gave answers at SOLO Level 3 but indicating less understanding of neutralization:

> Citric acid will break the oven cleaner down.
> It will absorb and breakdown the caustic soda.

Some 'True' respondents with SOLO Level 3 reasons showed some correct ideas together with a micconception:

> It will break up the acid in the spray.

Acid in this context is used to mean any hazardous substance.

> Citric acid will stop the chemical reaction in the oven cleaner.
> Whatever damage the oven cleaner might do to the floor or you, will be prevented by the citric acid.

SOLO Level 1 answers were given by a significant number of 'True respondents:

> Oven cleaner might burn you.
> Because acid burns.

Of the 'False' respondents, some had SOLO level 3 reasons:

> That makes it even more acidic. You need something non acidic to neutralize it.

In the above response oven cleaner is considered acidic due to the fact that it is a hazardous, so the student asks why add more acid? This student knows about neutralization but has confused the concepts of hazardous substance and acid despite being told in the question that oven cleaner contained a strong base.

> You could use vinegar, it should cancel the caustic soda out.

This student seemed to have a correct understanding but just did not think that citric acid being acid, being an acid, would have the same action as vinegar. This student knew from own knowledge base that vinegar would be effective but had not grasped the concept of acid-base neutralisation.

SOLO Level 1 and 2 reasons given by both ‘True’ and ‘False’ respondents were general statements about this being a safe way to clean up oven cleaner, without making any reference to the acid base reaction.

> Sometimes it is a safe way to clean up with a mop.

Conceptual issues identified from this analysis are:

- Acid is the name for any hazardous substance.
- Substances that burn you are acids.
- All acids burn you.

Question 14

CO MW5-3 Investigate some important types of substances and the way they change chemically in everyday situations.

When dilute sulfuric acid reacts with sodium hydroxide, a **salt** is formed: A True B False Because:

Tier 1 answers: True 16* False 12 No answer 12

A high proportion of respondents did not give an answer to this question indicating a relatively high degree of difficulty for students at this level. The acid-base word equation is nevertheless expected to be known at this curriculum level together with the concept of neutralisation.

Of the ‘True’ answers one respondent gave a SOLO Level 5 reason.

> An acid (sulfuric acid) and a base (sodium hydroxide) make a salt when they join together.

A SOLO Level 3 reason was:

> Dilute sulfuric acid with sodium hydroxide forms a solid.

SOLO level 2 answers were given that were based on experience of performing neutralisation reactions in laboratory practical activities:

> Salt is made from sodium hydroxide and acid.

Of the ‘False’ respondents, one SOLO level 5 reason was given:

> A salt forms when an acid is added to a metal.

This student understood the idea of a salt forming when and acid reacted with a metal but did not understand the concept of a base.

A SOLO Level 2 reason was:

> It will turn sulfuric acid and will eat at the hydroxide and form a liquid.

SOLO Level 1 reasons were common amongst false respondents:

> It wouldn’t make salt because salt is sodium chloride.
> Salt is not made up of a compound sulfuric acid.

These respondents did not appreciate that the chemical definition of a salt as a family of compounds, but as the name for table salt, sodium chloride. This is of course an instance of everyday versus scientific language.

Conceptual issues identified from this analysis are:

- Salt just means table salt, sodium chloride.
- A salt can only be said to have formed when it is a solid.
- Sulfuric acid and sodium hydroxide would not react.
- Salts only form when acids react with metals.

Question 15

CO MW5-4 Research and describe how selected materials are manufactured and used in everyday goods and technology.

> A positive effect of burning fossil fuels such as petrol and diesel is that it gives us fast transport of people and goods in vehicles such as cars, trucks, trains and aircraft. Burning these fuels also releases millions of tonnes of carbon dioxide into the air.
>
> This is a negative (bad) effect:
>
> A True B False
>
> Because:

Tier 1 answers: True* 25 False 12 No answer 5

Of the 'True' respondents, there were no SOLO Level 5 reasons given which would have related carbon dioxide release to the greenhouse effect, global warming, climate change, rising sea levels etc. There was one SOLO Level 4 reason given:

> It is bad for the atmosphere, fossil fuels are fast running out and we need to breathe oxygen not carbon dioxide.

Several 'True' respondents gave level 3 reasons in mentioning the polluting effect of carbon dioxide but linked it to ozone depletion:

> Too much carbon dioxide is not good for living things. It also wears out the ozone layer.
> It causes it to break down the ozone layer.

Other 'True' respondents gave Level 1 reasons, overstating the toxic effects of carbon dioxide:

> It can kill us and the Earth with pollution.
> It is polluting and damaging to the atmosphere.
> It is bad for people and animals' health.
> Well, it destroys the atmosphere.

Of the 'False' reasons, some were at a higher SOLO Level (Level 4) than most of the 'True' respondents. One linked the increase in carbon dioxide to climate change but derived a positive, perhaps personal, benefit:

> Increase in carbon dioxide will cause warmer weather.

Other 'False' respondents linked increase in carbon dioxide to increased photosynthesis in plants, therefore deriving a good effect:

> Good for trees as they give us oxygen as they breathe carbon dioxide. It is bad for own health and for our atmosphere.
>
> Really good I guess because don't trees breathe carbon dioxide then release oxygen?

Most of the 'False' respondents gave reasons at SOLO Level 2 or 1:

> Carbon dioxide is needed.
> Well, I say carbon dioxide is good for trees.

Conceptual issues identified from this analysis are:

- Carbon dioxide leads to greenhouse effect and global warming.
- Carbon dioxide damages the ozone layer.
- Carbon dioxide increase in atmosphere will have some positive effects but overall it is negative.

Question 16

CO PEB5-1 Investigate and describe processes which change the Earth's surface over time at local and global levels.

New Zealand has more earthquakes than Australia:
A True B False
Because:

Tier answers: True* 28 False 10 No answer 4

Of the 'True' respondents, one reason was at SOLO Level 5, linking earthquakes to tectonic plate movements:

> New Zealand is on top of 2 tectonic plates and Australia is over one, so the plates move under New Zealand creating earthquakes but don't do this in Australia.

Students who referred to or alluded to New Zealand straddling two plates were reasoning around SOLO Level 4

> There is a fault line splitting New Zealand in half through the Cook Straight.
> New Zealand is situated where two plates meet.
> Because we are on the crack (with a sketch map of New Zealand with the fault line drawn through it).

‘True’ respondents who simply mentioned the fault line were thinking at SOLO Level 4:

> There is a fault line through New Zealand.
> Because we are on a fault line and they are not.

SOLO Level 2 reasons mentioned a fact related to the occurrence of earthquakes in New Zealand:

> We are on the Pacific Plate.
> Because New Zealand has volcanic activity.

SOLO Level 1 reasons simply stated a fact about earthquakes in New Zealand:

> We have little ones every day.

Of the ‘False’ reasons given were at SOLO 1 Level, facts unrelated to the occurrence of earthquakes:

> Australia has a hotter climate than New Zealand.
> Australia might have more because it is a bigger country.
> Australia is closer to the equator.
> Australia is closer to the main countries for earthquakes than New Zealand is.
> New Zealand has more rain causing land slips.

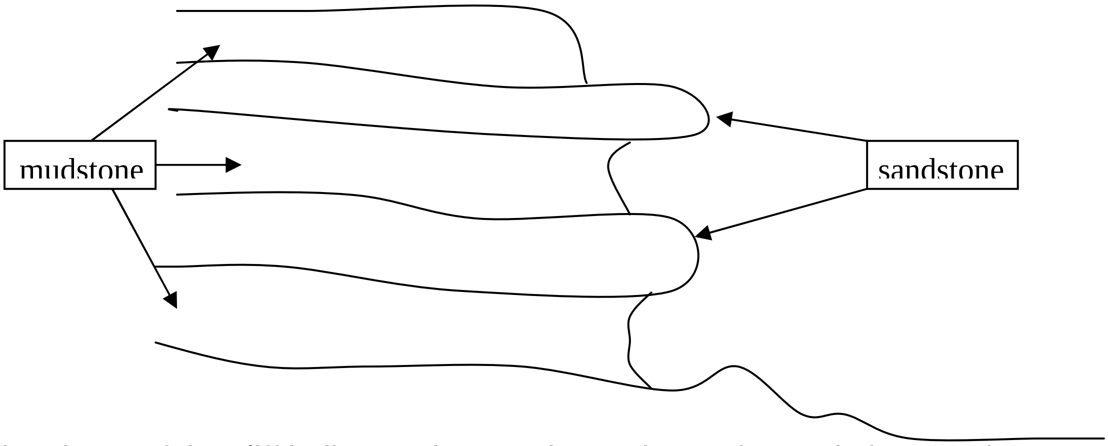
Conceptual issues identified from this analysis are:

- Earthquakes are linked to climate.
- Earthquakes depend on the size of the land mass.
- Earthquakes are related to landslips

Question 17

CO PEB5-2 Investigate and describe processes which change the Earth's surface over time at local and global levels.

The diagram below shows a cliff section made up of layers of 2 rock types, sandstone and mudstone.



The shape of the cliff indicates that sandstone is a softer rock than mudstone:

A True B False

Because:

Tier 1 answers: True 9 False* 16 No answer 7

Of the ‘False’ responses, there were none at SOLO Level 5, linking the profile to erosion and the factors causing it – wind, rain and weathering. There were some SOLO Level 4 reasons given:

> Mudstone must be the softer rock as it is worn off more than the sandstone.
> Mudstone has washed away at the edges.
> The sandstone has not worn away as much as the sandstone.

SOLO Level 3 reasons stated difference between sandstone and mudstone that was related to the hardness of the rock.

> Sandstone is holding itself up.
> The sandstone is overlapping the mudstone.
> Because the mudstone is shorter than the sandstone.

Of the ‘True’ responses, some reasons were at SOLO Level 3, interpreting the profile in terms of sandstone being squeezed out by the pressure of the rock above it, hence softer than mudstone.

> Because mudstone is not bulging yet the sandstone is like oozing out the side in solid form.

> The sandstone is protruding. This shows that the mudstone is heavier and softer than the mudstone.

Conceptual issues identified from this analysis are:

- Erosion.
- Sedimentation, uplift.
- Soft rock behaving like cream.
- Geological timeframe.

A lack of knowledge of how the layered structure of sedimentary rock formation occurs i.e. sedimentation in layers followed by uplift followed by faulting followed by erosion. The notion of softer rock bulging out due to pressure is logical but based on the analogy of a chocolate gateau where the cream squeezes out between the chocolate layers. This kind of analogy may be useful to the student to explain rock formations but is divorced from a timeframe of millions of years over which time erosion would have worn/washed the 'cream' away.

Question 18

CO PEB 5-3 (a) Use simple technological devices, such as telescopes and simple star maps, to observe and describe changing patterns in our night sky.

On a clear night the southern cross can be seen to change its position in the night sky from the evening through to early morning. This is because the stars that make up the Southern Cross are moving. A True B False Because:

Tier 1 answers: True 18 False* 18 No answer 5

Of the 'False' answers, one was at SOLO level 4-5.

> Other stars don't move, Earth rotates on its axis.

Reasons from 'True' respondents at SOLO Level 4 stated that it is Earth that moves as opposed to the stars, but did not distinguish Earth's rotation from its orbiting around the sun as the main reason for apparent movement of the Southern Cross.

> The Earth is moving, not the stars.

SOLO Level 3 reasons simply stated or implied that earth moves.

> We move.
> The Earth is moving.
> Our stars don't move, only planets.

Level 1 reasons included vague reasons such as:

> It depends how and where you are looking.

Of the 'True' respondents, some gave SOLO level 4 reasons. They interpreted 'stars moving' as appearing to move:

> Earth rotates and moves so will the positioning.
> Earth is spinning.

These students understood the relationship in movements of earth in relation to the sun and the stars but simply interpreted movement of stars as changing position in the night sky.

Some 'True' respondents gave SOLO Level 3 answers:

> The Earth is moving, so stars don't stay in one place.

'True' respondents gave SOLO Level 2 or 1 reasons such as:

> The Southern Cross is moving.
> All stars move.
> Stars will be at different positions at different times.

Although these statements are correct from the astronomical point of view they are not the reason for the situation described in the stem of the question. Other reasons given were:

> Some stars come out at different times.

Perhaps there is a horoscope influence in the above response.

> The world goes around the moon.

A relative motion argument could vindicate this as a statement, but not at Curriculum Level 5!

Conceptual issues identified from this analysis are:

- Circular movement of heavenly objects in night sky due to Earth's rotation.
- Stars do move but because of their distance, this is barely noticeable over years, let alone during the night.

- Galaxies rotate, so the stars within them move. The Sun as a star, Earth orbits the Sun along with other planets and moons orbit planets, including our moon orbiting Earth. In addition, planets rotate. This presents a fairly complex system in terms of what an observer on Earth sees. Alternative conceptions around the Solar System abound. Set all of this against everyday language such as sunrise, sunset, rising moon and it is easy to see how alternative conceptions arise.

Question 19

CO PEB5-3(b) Use information obtained from technological devices, such as radio telescopes and satellites, to clarify, challenge, and extend their ideas about the general characteristics of some near and far space objects.

Our sun is an average sized star like many thousands of others in the night sky. A True B False Because:

First tier answers: True* 18 False 18 No answer 6

Of the 'True' reasons some were at SOLO Level 5 showing an appreciation that the sun is an average star, but only appears large because it is so much closer to Earth.

> It's just that it is much closer to Earth.
> The sun's just a closer star.

A Level 4 reason was:

> It's a medium star because it's not as big as some stars and it is not really small.

Level 3 reasons were:

> It is at the centre of the solar system, and burns, just like all other stars.

Level 2 reasons were:

> It is a dwarf star.
> It is a ball of gas at the centre of the solar system.
> The other stars are ages away.

Of the reasons given by 'False' respondents, many were only at SOLO Level 1 believing that the sun is bigger than stars, because it appears larger.

> It is really, really big.
> It's bigger.
> It's the centre of all planets and really big.
> Our sun is the biggest star.

Conceptual issues identified from this analysis are:

- The Sun is a star.
- The Sun is the largest star.
- Each star is like our sun (A mass of hot gases).
- Apparent larger size of the Sun due to relative nearness to Earth.
- Stars consist of burning gases. (Burning can just mean hot in everyday language of these students, but it is important to dispel the notion that combustion is taking place).

Question 20

CO PEB5-4 Research a national environmental issue and explain the need for responsible and co-operative guardianship of New Zealand's environment.

> Huia and Kate were talking about protecting New Zealand's environment. Huia said that New Zealand's environment was the responsibility of all New Zealanders. Kate said that there wasn't much ordinary people could do and that it was the job of the government to protect New Zealand's environment. Who do you think is right?
>
> A Huia B Kate
>
> Because:

Tier 1 answers: Huia* 20 Kate 14 No answer 5 Both 2

Of the 'Huia' answers several gave SOLO Level 4 reasons:

> Because if everybody did their bit, New Zealand wouldn't be a disgrace.
> All New Zealanders should take part.
> Kate said ordinary people couldn't do much but they can. They can do everything to improve New Zealand's environment.

'Huia' respondents with SOLO Level 3 reasons gave either general reasons or specific ones without relating the two:

> It's up to everybody, not just New Zealand government.
> Otherwise all New Zealand's native plants and birds will die out.
> It is important for survival of Earth. Resources are rapidly running out.
> If you put your rubbish in the bin and recycle your trash, you can help without doing anything really big.

SOLO Level 2 reasons were given by some ‘Huia’ respondents:

> Everyone drops rubbish, they should pick it up.

The ‘Kate’ respondents who gave reasons were at SOLO Level 3:

> Ordinary people can’t stop the pollution from machines.

Or SOLO Level 2:

> The government is responsible for New Zealand.

Conceptual issues identified from this analysis are:

- The desirable attitudinal position in relation to this curriculum objective is that we all have responsibility for our environment, not just the government.
- Individual responsibility of ‘Think globally, act locally’ is central to this notion, where actions such as responsible disposal of waste and recycling are desirable outcomes.

Curriculum Level 6 Survey

Question 1

CO LW6-1 Investigate and describe examples of different types of helpful and harmful micro-organisms.

Viruses are minute particles that can only be seen with an electron microscope. They are able to reproduce only in living cells of a host. Viruses consist of nucleic acid surrounded by a protein coat and they can be crystallized like chemicals. They cannot be grown on agar plates as bacteria can. Viruses are: A Living B Non-living Because:

Tier 1 answers: Living* 9 Non-living* 11

Either answer could be correct with the appropriate reason.

Of the ‘Living’ respondents, one gave a SOLO Level 5 response:

> They reproduce by taking over a cell and then they destroy that cell when they move on to infect other cells.

A Level 4 response was:

> They can reproduce in living cells of the host.

There were a number of level 3 reasons related tp the particular characteristics of living things:

> They cannot live by themselves.
> Because they can reproduce.
> They reproduce in living cells.

There were no reasons given at SOLO Level 2 or 1 among the ‘Living’ respondents. Of the ‘Non-living’ respondents, one gave a Level 4 reason:

> They can only live when they have taken over a host cell.

Some ‘Non-living’ respondents gave SOLO Level 3 reasons, relating to a particular characteristic of living things:

> They don’t grow.
> They cannot be grown even though they can reproduce.
> They only move by connection to other organisms.

Other Level 3 ‘Non-living’ respondents gave reasons relating to the inability of viruses to live independently:

> They need living cells from something else to survive and reproduce.
> They can only live in a host cell not on their own.

A SOLO Level 2 reason given was:

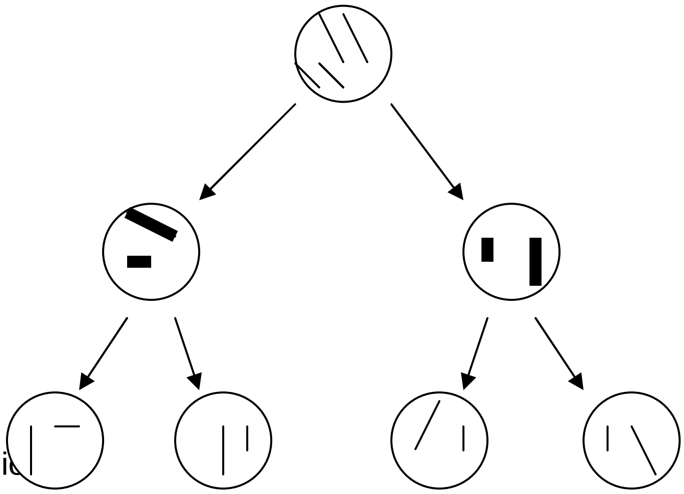
> It’s something that infects your body’s insides. When mixed they spread.

Conceptual issues identified from this analysis are:

- Characteristics of living things.
- Ability to decide living or non-living and to justify.
- Viruses on the borderline between living and non-living things.

Question 2

CO LW6-2 (a) describe cell division and explain how genetic information is passed from one generation to the next.

> The diagram below shows the stages of a cell dividing. The number of chromosomes in the cells is given.
>
> 
>
> This cell divisi
>
> A Mitosis B Meiosis
>
> Because:

Tier 1 answers: Mitosis 6 Meiosis* 9 No answer 5

Of the ‘Meiosis’ respondents, non gave a SOLO Level 5 reason which would have required reference to the purpose of meiosis in halving the number of chromosomes to produce gametes so that normal chromosome number is restored on fertilization.

Some respondents gave Level 4 reasons:

> There is only half the number of chromosomes as the parent cell and this is for reproduction.
> The cells produced have half the number of chromosomes needed.

Level 3 reasons were given by some respondents:

> Each new cell splits into two.
> Each gamete as two chromosomes but the gametes are not identical.

SOLO Level 1 reasons included:

> It splits in two.
> Because the two parallel black lines represent meiosis.
> Three ‘Meiosis’ respondents gave no reason.

Of the 'Mitosis' respondents, one gave a Level 3 reason:

> Where they split they half and are the same.

The other 'Mitosis' respondents did not give a reason.

Conceptual issues identified from this analysis are:

- Mitosis is the single division for the exact duplication of genetic material during growth and repair.
- Meiosis is a process consisting of two divisions in which genetic material replicates once resulting in daughter cells with half the normal number of chromosomes. Its purpose is to produce haploid gametes so that the normal diploid chromosome number is restored on fertilization.

Question 3

CO LW6-3 (b) Investigate examples of the contemporary application of genetics.

> Potato plants can reproduce by growing more potatoes (tubers) underground. Each tuber forms a new plant. This is an asexual method of reproduction. Potato plants can also reproduce by producing flowers, fruits and seeds. This is a sexual method because it involves gametes and fertilization.
>
> Sexual reproduction is necessary to ensure the survival of the potato species over time.
>
> A True B False
>
> Because:

Tier 1 answers: True* 7 False 11 No answer 2

Of the true respondents, none was at SOLO Level 5 with reasoning. One was at Level 4:

> So the potatoes can slowly grow immune to some new diseases and bugs that attack the plants so you may make a stronger hybrid.

Some of the 'True' respondents gave SOLO Level 2 reasons:

> It produces more.
> So that more of them can reproduce.
> Because there would be no potatoes in the future.

Of the ‘False’ respondents, some showed SOLO Level 3 reasoning:

> Potatoes do not need sexual reproduction to reproduce, they reproduce themselves with tubers.
> Potato plants can also reproduce asexually by growing more tubers underground which can form new plants.
> Asexual reproduction is producing more plants so the species will continue to reproduce.

These respondents failed to grasp the concept that sexual reproduction produces variety in the offspring, thinking of it merely as another way for potatoes to increase their numbers.

Responses at SOLO Level 2 and below gave reasons that were erroneous showing basic misconceptions:

> Potatoes don’t have seeds.
> Potatoes are not living.

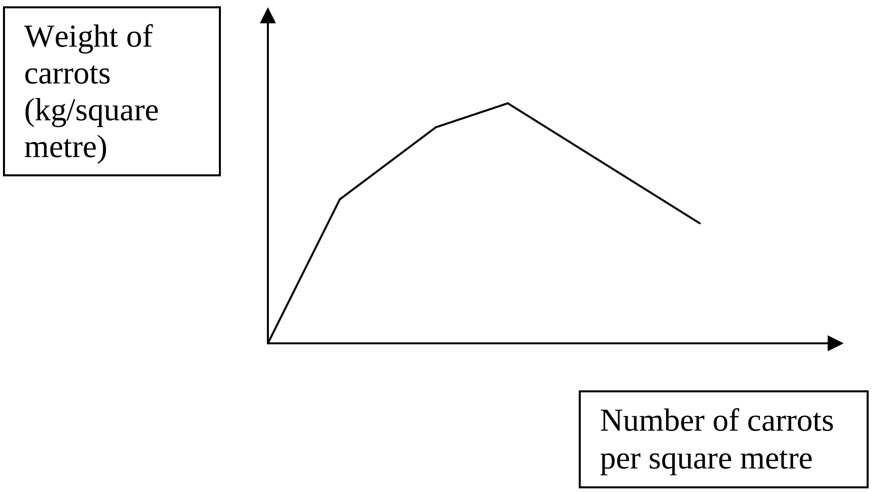
Conceptual issues identified from this analysis are:

- Potatoes are living things.
- Potatoes are flowering plants and can therefore reproduce sexually by producing seeds as well as asexually with tubers.
- Seed reproduction is a sexual method.
- Sexual reproduction gives variation.
- Variation is necessary for survival of a species over time.
- Variation enables species to adapt to environmental change.

Question 4

CO LW6-4 Investigate a New Zealand example of how people apply biological principles to plant and animal management.

A horticulturist experimented with growing carrots to get maximum yield. She found that by growing carrots closer together they reach a smaller size than carrots grown further apart, but she could grow more carrots in a given area. A graph showing the weight of carrots harvested per square metre is shown.



The drop off in the total weight of carrots grown per square metre of soil is competition:

A True B False

Because:

Tier 1 answers: True* 12 False 4 No answer 4

Of the ‘True’ respondents, none were at the extended abstract Level (SOLO Level 5).

One respondent gave a SOLO Level 4 relational reason:

> There are more plants competing for the same amount of moisture and nutrients.

A number of SOLO Level 3 multi-structural reasons were given:

> There are lots of carrots in this area fighting to survive.
> The heavier carrots grow further apart which gives them more space.
> Because the more space and soil they have, the larger they will grow.

Some SOLO Level 2 reasons included:

> If you grow them too close, you get small ones.
> People who grow carrots are trying to get more ot to shops.

A significant number of ‘True” respondents gave no reason.

Of the ‘False’ respondents, several gave SOLO Level 2 reasons:

Carrots need to be far apart.
You need more carrots to be in competition.

Several ‘False’ respondents gave no reason for their choice.

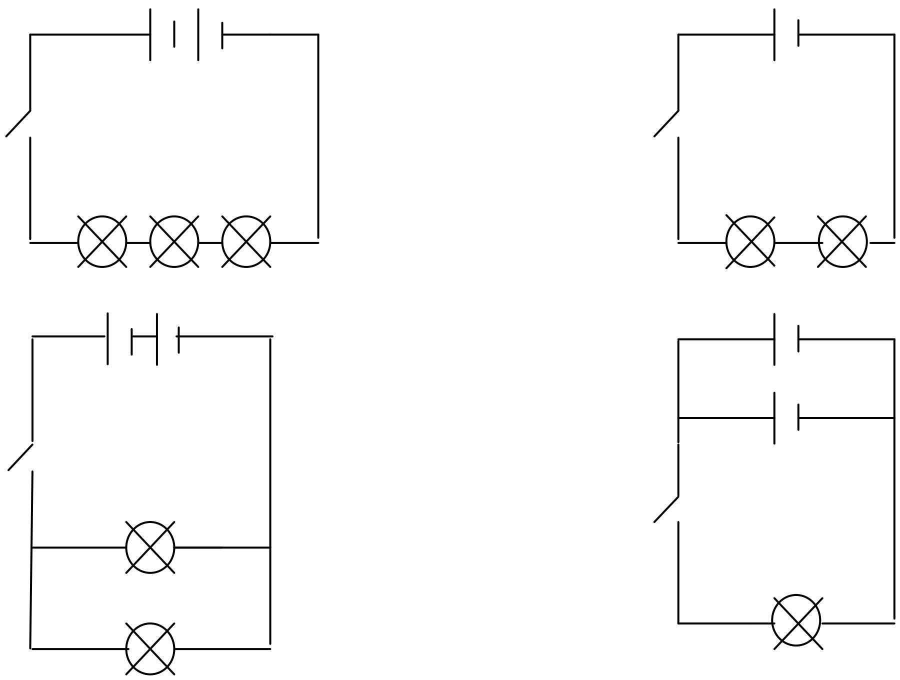
Conceptual issues identified from this analysis are:

- Competition is for any resources a living thing needs – nutrients, water, light, soil.
- These factors affect (carrot) growth and size.
- Competition is more than just a space factor.
- Competition for resources by a crop occurs above ground as well as below.
- Competition can be used to control crop size and overall yield.

Question 5

CO PW6-1 Carry out practical investigations, with effective control of variables, into common physical phenomena, and relate their findings to scientific theories.

A student set up these circuits to investigate the effect of increasing the number of **cells** in the circuit on bulb brightness.



The circuits will enable the student to make a valid conclusion from the results:

A True B False

Because:

Tier 1 answers: True 8 False* 8 No answer 4

Of the ‘False’ respondents, none gave a SOLO level 5 reason. There were several SOLO Level 4 reasons given:

> The student as set up parallel and series circuits. These will give different results. The student should have chosen one type to test bulb brightness.
> More than one variable has changed, they used a different number of lamps each time.

The first is a specific reason and the second a more generalized reason. A SOLO Level 5 reason would have been a combination of these.

A SOLO Level 3 reason was given by one ‘False’ respondent:

> The student changed the number of lamps used and whether the circuits were in parallel or series.

Some SOLO Level 2 ‘False’ reasons were:

> It’s not a fair test.
> They are in parallel and series.
> Each investigation should have the same amount of equipment but set up differently.

Some SOLO Level 1 reasons were:

> They can’t get their conclusion.
> Some of the circuits are not set up right.

Of the ‘True’ respondents, one reached SOLO Level 3 reasoning

> Because they have varied the number of bulbs and batteries.

A number gave Level 2 reasons:

> There are 4 circuits and they are all different.
> They are in parallel and series.
> He can see with the different amount of light bulbs results are in the circuits.

Examples of ‘True’ respondents with reasons at SOLO Level 1 are:

> If the student sets up the circuit correctly and gets the right result that student can then make a conclusion.
> Because there is a lot of details to be taken into account.
> He set up so many types of circuits.
> Several ‘True’ and ‘False’ respondents gave no reason for their choice.

Conceptual issues identified from this analysis are:

- A fair test with the same variable kept constant and one variable changed.
- Variables are the components of the circuit and the way that they are connected.
- Investigations of this type are to find out rather than to get some predetermined ‘right’ result. Students indicated this misconception in some of

their reasons, possibly the result of the 'cookbook' approach to practical work.

Question 6

CO PW6-2 Demonstrate an understanding of the applications of energy and its transfer and transformation.

Water flows through a hydro-dam. The water flow is used to generate electricity. A student thought that if the water flowing through the dam could be pumped back up to the lake, it could be used to make more electricity when it flowed back through the dam. This would be a sensible way of making a lot more electrical energy: A True B False Because:

Tier 1 answers: False* 14 True 5 No answer 1

Of the 'False' respondents, none was at SOLO Level 5 (Extended abstract). One respondent was on the SOLO Level 4-5 borderline.

> It would take more energy to pump it back up than it would be making.

A 'False' respondent at SOLO Level 4:

> The energy created would be used in getting the water uphill.

A 'False' respondent at SOLO Level 3:

> It would make more electrical energy but it's not sensible because a large amount of energy is needed to pump the water back up.

Some 'False' respondents gave SOLO Level 2 reasons:

> It would not work because water only flows one way.
> Water doesn't flow backwards.
> When he pumps it back to the top, it is losing energy.

Some 'False' respondents used from the point of view of needing to maintain water flow in the river which is valid from the environmental point of view but does not stem from a tacit understanding of the laws of energy.

> If you pump all the energy back to the lake what is going to happen to all of the other water. Is it all just going to sit in the lake and not go anywhere?
> There needs to be water on both sides of the dam.

Of the 'True' respondents, SOLO Level 2 reasoning was used by some from the environmental perspective

> It's environmental and by using it over again you can save the environment.

SOLO Level 1 reasons given by 'True' respondents were:

> Reusing it.
> More water still flowing.

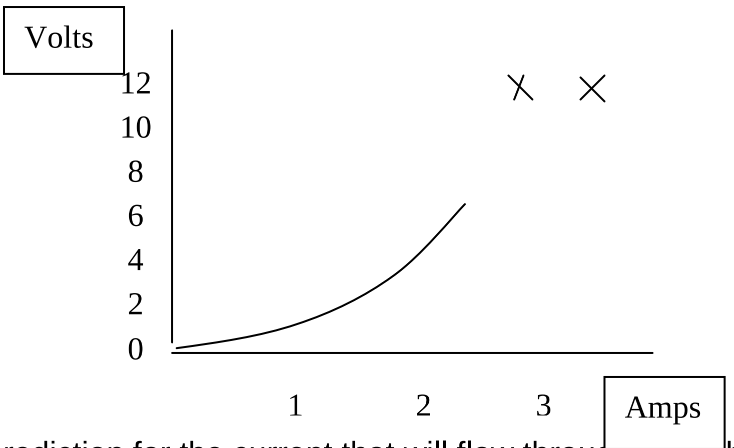
Conceptual issues identified from this analysis are:

- When energy is converted from one form to another, some energy is always lost to the surroundings in a non-useful form e.g. heat, sound. The total energy remains constant, but the capacity to perform work is reduced with every convertion.
- Environmental considerations would be valid if recycling the water resulted in reduction of water flow in the river, but not an issue here because pumping water back up to the lake to generate more electrical energy is not energetically feasible.

Question 7

CO PW6-3 Investigate and establish patterns in physical phenomena and make useful predictions.

The graph below shows the amount of electric current flowing through an electric light bulb at different voltages.



A valid prediction for the current that will flow through the light bulb when the voltage is 12 volts is:

A 2.5 Amps B 3.0 Amps

Because:

Tier 1 answers: 2.5 Amps* 11 3.0 Amps 9

Of the ‘2.5 Amps’ respondents, one was a SOLO Level 4 reason:

> The graph is going off the page as it passes about 2.5 Amps. (Line drawn through point).

Some ‘2.5 Amps’ respondents gave SOLO Level 3 reasons:

> The current is moving at a constant speed (line drawn through point).

Several others simply extrapolated the line through 2.5 Amps by continuing the curve of the graph.

A SOLO Level 2 reason was:

> It makes sense and when the aperage is increased, so is the line.

Of the ‘3 Amps’ respondents, some SOLO Level 3 reasons were given;

> More volts mean more amps.
> The current is nearly 2.5 Amps at 7 Volts.

SOLO Level 1 reasons included:

> It increases.
> It can be divided equally.

A high proportion of respondents gave no reason for their choice of 2.5 or 3.0 Amps. Response without reasons indicated a lack of understanding of the process of using a graph to make predictions outside the range of recorded values.

Conceptual issues identified from this analysis are:

- A graph can be used to make **predictions** by extending a curve.

Question 8

CO PW6-4 Investigate and report on how physical principles are used in some common household appliances.

> Optical fibre cable has replaced copper wire cables in many of the world's telephone systems. In optical fibre, the signals are transmitted by pulses of laser light instead of electricity. Light travels much faster than electricity and many more signals can be transmitted at once, making high band-width internet transmission possible. The energy loss over long distances, due to the electrical resistance of copper, is much lower with transmission of light pulses along optical fibre. Optical fibres are made out of very pure glass which requires expensive high precision technology for manufacture. This expense is offset by the fact that the raw material for making the glass fibre is sand, which is much cheaper than copper.
>
> Optical fibre cables have revolutionized telecommunications:
>
> A True B False
>
> Because:

Tier 1 answers:	True* 12	False 4	No answer 4

Of the 'True' respondents, one gave a reason at SOLO Level 4:

> The energy loss over long distance is much lower than copper wires. Cost is offset by greater volumes of traffic along the cables.

Most 'True' respondents gave SOLO Level 3 reasons:

> It's now faster and easier to send more.
> More signals are transmitted at once.
> Optical fibre cable is cheap to make. They have made the internet work and it does not use much energy over long distances.

'True' respondent SOLO Level 2 reasons included:

> Copper has more resistance than optical fibres which are more practical.
> More connections because of more cables
> Because of its more transmissions.

'True' respondent SOLO Level 1 reasons included:

> It gave us the Internet.
> Sand can be used to make the optical fibres.

Of the 'False' respondents, most gave noreason for their choice. One reason at SOLO Level 1 showed a misunderstanding of the information given in the question:

> We are replacing the optical fibre because copper is a better conductor of electricity.

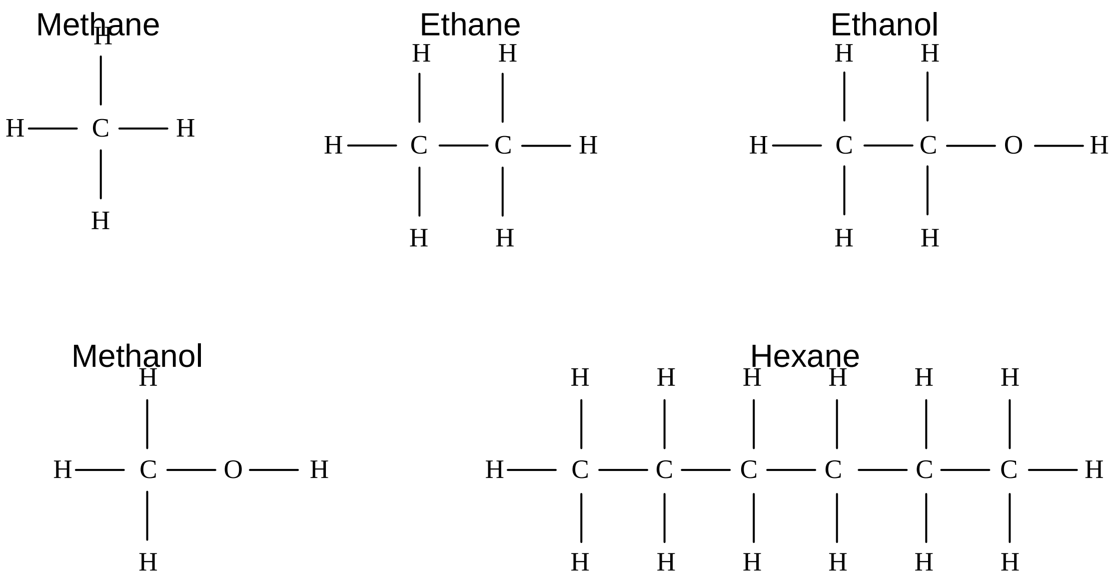
Conceptual issues identified from this analysis are:

- Optical fibre transmits signals by light pulses.
- Transmission of signals by optical fibre is more efficient.
- More signals are transmissible with optical fibre.

Question 9

CO MW6-1 Investigate and understand how familiar chemical substances can be grouped into families which have characteristic chemical properties; (Metals and common metal compounds such as oxides, hydroxides, and carbonates; non-metallic oxides; hydrocarbons and simple alcohols should be studied).

Here are some structural formulae of some organic compounds.



These organic compounds belong in 2 groups in terms of their chemical properties. Ethane and ethanol belong in the same group:

A True B False

Because:

Tier 1 answers: True 9 False* 7 No answer 4

Of the ‘False’ respondents, one was at SOLO Level 5:

> Ethanol is a member of the alcohol family. Also, ethanol has a –OH group attached to a carbon atom whereas ethane hasn’t.

Some SOLO Level 4 reasons were:

> Ethanol has oxygen and is an alcohol, ethane is not.
> Ethane is an alkane and ethanol is an alcohol.

SOLO Level 2 reasons were:

> Ethanol contains oxygen.
> The O is just thrown in, it doesn't match.

Of the 'True' respondents, some showed SOLO Level 3 reasoning:

> Because they have the same number of H's and C's.
> Same amount of C and H.

SOLO Level 2 reasons among the 'True' respondents included:

> If they have the same type of compound then they do belong in the same group.
> They have similarities between the two.

Four 'True' respondents gave no reason.

Conceptual issues identified from this analysis are:

- Alkanes consist of carbon and hydrogen only whereas alcohols consist of carbon, hydrogen and oxygen.
- Alcohols contain a –OH functional group whereas alkanes do not.
- The –OH functional group in alcohols confers different properties to the compound.
- The –OH group is more significant than the number of carbon and hydrogen atoms in the molecule.

Question 10

CO MW6-2 Investigate and relate the physical and chemical properties of a family of substances to their use in the home and the community.

> A gardener found that his soil had a pH of 5 and he knew that cabbages do not grow well in acid conditions. He added lime (calcium carbonate) and found that his cabbages grew much better.
>
> The lime improved the growth of the vegetables because it is an essential food for plants.
>
> A True B False
>
> Because:

Tier 1 answers: True 7 False* 13

Of the False' respondents, none gave a SOLO Level 5 reason which would have required stating that soil pH is raised by addition of lime. Several respondents gave SOLO Level 4 reasons:

> Lime improved the cabbages because they don't grow well in acidic soil and the lime neutralized the soil.
> The lime only improved the growth of the vegetables as it made the soil less acidic.
> It improved the growth because it made the soil less acidic for the cabbages.

A number of SOLO Level 3 reasons were given by 'False' respondents but with a misconception about the change of pH level, equating reducing pH with reducing acidity:

> The lime lowered the pH of the soil making it ideal for the growing conditions for cabbages.
> It reduces the pH of the soil making it better for the plants.
> It lowers the pH of the soil.
> The lime made the pH level of the soil drop to 0 which is what the plant needs to grow in.

Other 'False' respondents gave SOLO Level 3 reasons about acid breakdown without reference to pH Level:

> It improved the growth because it made the soil less acidic for the cabbages.
> The lime only improved the growth of the vegetables as it made the soil less acidic.
> Because lime is an alkali and alkalis break acids down.

Some 'False' respondents gave SOLO Level 2 reasons which were less specific in terms of acid base chemistry:

> It breaks down the chemicals and makes it grow.
> It isn't essential to plants, it protects them but can be used for other substances.

Of the 'True' respondents, some gave SOLO Level 3 reasons. The error of reducing pH rather than raising it as with many of the 'False' respondents, but failure to see lime as a non-nutrient:

> It reduces pH making it better for plants.
> It reduces acid compounds.

A SOLO Level 2 reason was:

> It provided calcium carbonate and worked well in acid conditions.

There were several SOLO Level 1 reasons among 'True' respondents simply restating their notion that lime functions mainly as a plant nutrient:

> It is an essential food.

Conceptual issues identified from this analysis are:

- Lime is basic.
- Lime neutralizes acids in soil.
- Lime increases soil pH.
- Neutralisation of acids involves raising pH.
- Lime functions mainly as a soil conditioner not as a plant nutrient.

Question 11

CO MW6-3 Investigate and understand factors that affect chemical processes, e.g., factors affecting changing rates of reactions.

Marble lumps in hydrochloric acid fizz, giving off carbon dioxide. If the marble lumps are ground up to a powder, then mixed with hydrochloric acid, the fizzing would be much faster:
A True   B False
Because:

Tier 1 answers: True* 10 False 8 No answer 2

Of the 'True' respondents, one gave a SOLO Level 5 reason:

> The surface area has changed, the hydrochloric acid can attack small particles of the powder at once, instead of slowly fizzing through the lump.

A 'True' SOLO Level 4 reason was:

> Because there is more surface area of marble exposed.

A 'True' SOLO Level 3 reason was:

> It turned into a powder which is easier to dissolve.

A 'True' SOLO Level 2 reason was:

> It is no longer a solid so as a powder it would be broken down faster.

A 'True' SOLO Level 1 reason was:

> Because when marble lumps were in hydrochloric acid they weren't really doing much fizzing.

Of the 'False' respondents, none gave reasons beyond SOLO Level 1:

> The lumps would give off more bubbles than the ground powder.
> The lumps will give more bubbles than the powder.
> It (powdered marble) doesn't fizz fast, it fizzes slow.
> The fizzing would react slow.

Conceptual issues identified from this analysis are:

- Lumps have more surface area than the powder.
- Powder is not solid.
- More marble is available for reaction with acid in powder form because in lump form the acid 'can't get to the inside'. The mathematical concept of surface area increasing with granularity is often problematic at this curriculum level. There is an 'indirect' understanding without the surface area concept.

Question 12

CO MW6-4 Investigate and describe the applications and effects of chemical processes in everyday situations.

Iron can be prevented from rusting by coating it with zinc (galvanizing). Zinc protects iron from rusting even if it does not cover the iron completely: A True B False Because:

Tier 1 answers: True* 5 False 14 No answer 1

None of the reasons gave a level of understanding more than SOLO Level 3. There was no understanding of sacrificial protection of iron, the reactivity series or electron donation. The highest level of reasoning was SOLO Level 3 and this came from the 'False' respondents with reasons such as:

> Water and oxygen will break through the zinc.
> Water can still touch the iron.

These respondents had a functional understanding of the role of oxygen and water in rusting but no understanding or familiarity with sacrificial protection given by a metal that is more reactive than iron in close contact with it.

'False' respondents with SOLO Level 2 reasons made no mention of oxygen or water:

> Zinc will only protect the iron from rusting if it completely covers it.

'False' respondent SOLO Level 1 reasons had a misconception that rust was like a disease that attacked the iron:

> Rust can attack the uncoated zinc.
> The rust can still spread where it can get out.

The second reason hints that rust attacks from the inside and 'gets out'.

The 'True' respondents showed little understanding of the factors involved in the rusting reaction therefore misconceptions abut its prevention. This SOLO Level 1 reason did have a hint of the sacrificial role of zinc in rust prevention albeit an incorrect one.

> It attracts water from things causing rust to itself (It attracts water away from the iron, preventing rusting).

Most 'True' respondents gave no reason for iron rusting.

Conceptual issues identified from this analysis are:

- Rust occurs from inside the iron.
- Rust can only be prevented by covering the iron completely and sealing out the oxygen and water.
- Rusting is a chemical reaction involving electrons. Iron reacts by losing electrons therefore any metal that loses electrons more easily than iron will corrode preferentially to iron (sacrificial protection).
- Zinc protects by attracting water away from iron.

Question 13

CO 6-1, 6-2 (a) Investigate and classify some common minerals and rocks according to their easily observed properties and relate to their common use.

The table below shows 4 minerals with their 3 properties compared. The properties are:

- hardness (on a scale of 1 = soft to 10 = very hard)
- colour
- reaction with dilute acid.

Mineral	Hardness	Colour	Reaction with acid
calcite	3	colourless, yellow, orange, brown, green	fizzes
gypsum	2	Colourless, white	no reaction
apatite	5	white, brown, green, yellow, violet	no reaction
quartz	7	colourless, white, pink, blue, black	no reaction

If you were given a piece of mineral and told that it was one of the four listed above, you could find out which by noting its colour and testing with acid.

A True B False

Because:

Tier 1 answers: True* 11 False 8 No answer 1

Of the 'True' respondents no reason was at SOLO Level 5. There was one 'True' SOLO Level 4 reason:

> Test it in the acid, if it fizzes, it must be calcite. If it doesn't you can find out by the colour and hardness of it.

Some 'True' SOLO Level 3 reasons were:

> If you could note its colours then test it with acid and it either reacts or doesn't you know what it is.
> 1 reacts, 3 don't but have different colours and hardness.

A ‘True’ SOLO Level 2 reason was:

> Every mineral has different properties and that’s how you tell them apart.

Some ‘True’ SOLO Level 1 reasons were:

> They are all a bit different in colour.
> Each has its own reaction and colour.

Of the ‘False’ respondents, the highest level of reasoning was SOLO Level3:

> 3 of the 4 rocks has no reaction with acid and many of the colours they come in are the same so you wouldn’t be able to tell which it was.
> Gypsum, apatite and quartz are all too alike in their properties, so would be too difficult to know which it is.

This is true for acid reaction and colour but if hardness is taken into account, each mineral type can be distinguished.

A ‘False’ respondent with a SOLO Level 2 reason:

> Because there are too many with no reaction with acid.

‘False’ respondents with SOLO Level 1 reasons:

> Not enough information.
> Not enough description.

Conceptual issues identified from this analysis are:

- Ability to think in terms of a combination of properties to distinguish the 4 minerals.
- Colour alone is not enough, comparative hardness is not enough and acid reaction can only identify calcite.

Question 14

CO 6-1, 6-2(b) Investigate how the three major types of rocks are formed (igneous, metamorphic, and sedimentary) and describe how rock sequences provide evidence for past events through geological time.

> Rocks that form from volcanic larva are igneous rocks whereas rocks that form on the ocean bed from sediments that cement together are called sedimentary rocks.
>
> Over millions of years igneous rocks can become sedimentary rocks:
>
> A True B False
>
> Because:

Tier 1 answers: True* 12 False 7 No answer 1

Of the 'True' respondents, two gave reasons at SOLO Level 5 (extended abstract).

> Igneous rocks are thrown up in volcanoes and they are weathered down into small pieces. When erosion occurs, the rocks are taken to low lying places. Many are carried out to sea and settle on the seabed. As more rock pieces fall on top they all squeeze together and harden into sedimentary rock.
> The volcanic rocks grind down into smaller pieces that find themselves in a river which would take it out to sea where as a sediment it would compact down forming sedimentary rock.

There were no 'True' respondents who gave SOLO Level 4 or 3 reasons. Some Level 2 reasons were:

> By eroding.
> Sea level constantly changes so where some igneous rocks lie, the sea might rise and change it into sedimentary rock.

Some 'True' respondent SOLO Level 1 reasons were:

> Because over the years they got pushed together by such things as earthquakes.
> They all come from water when they have slipped away.
> Lava goes into sea then it can change.

Of the 'False' respondents, none was above SOLO Level 1:

> They can't change their structure.
> Because they are not in the sea.
> No they can't because lava is still producing more and more.

Conceptual issues identified from this analysis are:

- Rocks cannot change over time.
- Sedimentary rocks form when igneous rocks are submerged by sea.

- Erosion and deposition lead to sediments in the sea which over time form sedimentary rocks. Sedimentary rocks thus form from other rock types including igneous.

Question 15

CO 6-3 Use information from a range of sources, including their own observation, to explain spatial relationships of objects in the night sky and the challenge such spatial relationships present to space exploration.

Astronomical measurements show that the galaxies in the universe are moving apart and that the universe is expanding. This evidence supports the 'big bang theory' of the origin of the universe. A True B False Because:

Tier 1 answers: True* 12 False 6 No answer 2

Of the 'True' respondents, none reached SOLO Level 5 reasoning. There was one reason at Level 4:

> It is still moving after the explosion.

Some 'True' respondents SOLO Level 3 reasons were:

> Everything is still expanding.
> The galaxies continue to move apart.
> The universe is still expanding.

Some 'True' respondents showed SOLO Level 1 reasoning due to confusion around some concepts:

> As the universe continues to expand the big bang comes into play.
> Because all the solar system is slowly expanding.

Of the 'False respondents, some were at SOLO Level 3:

> This does not support the big bang theory. It is just stating that the universe is moving apart.

This statement is, of course, true although the expanding universe does provide evidence that the big bang may have occurred which is what the question is really asking. However, students' belief systems are likely to affect the student's ability to see the logic of the argument.

The rest of the 'False' respondents gave no reason to support their choice.

Conceptual issues identified from this analysis are:

- The galaxies moving apart suggests that they could have started from an initial mass of matter and energy which exploded i.e. it **supports** the big bang theory. It does not **prove** it, however.
- The solar system is only the system around one star, the Sun, in the Milky Way galaxy. The Milky Way galaxy is one of millions of galaxies in the universe. The concept of organization and scale of the universe is the issue here.

Question 16

CO 6-4 Report on an important natural resource in New Zealand, including its method of formation, location, and extraction, as appropriate, and any issues associated with its use.

New Zealand's fossil fuels such as coal, oil and gas are non-renewable and should be managed carefully: A True B False Because:

Tier 1 answers: True* 16 False 3 No answer 1

Of the 'True' respondents, none was at SOLO level 5 with their reasoning. This would have required recognition of the need to conserve resources for future generations. There were some SOLO Level 4 reasons:

> They are non-renewable and therefore can't regenerate by themselves through nature. Once they run out, we have no more.
> Once they run out they are gone. We should be using reusable fuels to save our coal, oil and gas.

Some 'True' respondents gave SOLO Level 3 reasons:

> We cannot replace these things. Once we use them up they are gone forever.
> There is only a limited supply. Once we run out there is no more left.
> Once they have gone we can't get any more. They will have to find new reserves.

The last of these reasons has the implication that there are untapped reserves to be discovered.

Some ‘True’ respondents gave SOLO Level 2 reasons:

> One day we’re going to need as many fuels as possible.
> Because it will all run out over time and we’ll have to find a new source of fuel.
> They will run out otherwise.

Some ‘True’ respondents gave SOLO Level 1 reasons relating to safety, pollution and wastage:

> As not to waste them.
> It is making pollution.
> Could explode.

Of the ‘False’ respondents one respondent gave a SOLO Level 3 reason:

> They will be replaced by sustainable sources that don’t pollute.

A ‘False’ respondent gave a SOLO Level 2 reason:

> New reserves will be found to replace the ones used up.

These last two reasons show optimism that solutions will be found to the problem of scarce energy resources in the future.

Conceptual issues identified from this analysis are:

- There are unlimited reserves of fossil fuels on Earth.
- Fossil fuels will be replaced by sustainable, non-polluting forms of energy.
- To use up Earth’s energy resources without careful management and planning is irresponsible and unfair to future generations.

Summary of survey analysis

Analysis of student responses to the questions revealed a number of alternative conceptions related to the curriculum objectives. These alternative conceptions would act as barriers to understanding concepts that underlie the objective. The SOLO classification provided a means of identifying levels of understanding of concepts related to the objectives and hence the conceptual levels of the types of alternative conceptions held by respondents that may act as barriers to scientific understanding.

Summary of interview analysis

A sample of students was selected for telephone interviews. These students had agreed on the survey to participate in a follow-up telephone interview on some of their responses to the survey. In the interviews the students were asked specific questions related to particular responses to questions on the pencil and paper survey and some general questions relating to the style of the questions and the level of literacy, numeracy and comprehension level. Altogether, six students were randomly selected, two from each curriculum level.

The student responses to interview questions indicated that the alternative conceptions indicated from their responses to particular questions were alternative conceptions that they truly held. This was the case for 28 of the 33 alternative conceptions investigated by the telephone interview process. In four cases, the students interviewed elaborated upon their initial response to provide reasons that were aligned with the correct scientific view. Two of these reasons were due to new learning that had occurred between the survey questionnaire and the interview and the other two were able to give a more rigorous explanation than they had in the survey. One student had confused one question with the previous question in the survey. Based on the interviews, 94% of the conceptual issues or alternative conceptions identified in the surveys were also evident in the telephone conversations. The high level of correspondence between alternative conceptions identified in the surveys and the follow-up interviews provided validity for the notion that the student responses to the surveys reflected their thinking in terms of alternative conceptions. Feedback from the student interviews led to some changes to wording. For example, the word ‘environmental’ in Question 3 was changed to ‘non-inherited’ and in Question 25 the term ‘average’ was changed to the word ‘mean’.

Summary of teacher response analysis

Six science teachers from the Correspondence School Science Department were selected for interview using the following criteria:

- Teachers with at least 10 years science teaching experience.
- Three of the teachers had taught at The Correspondence School for over 5 years and three who had been recently appointed to The Correspondence School but who had had recent experience teaching students face-to-face in schools.
- Teachers had taught general science up to curriculum level 6 and had taught to senior level in physics or chemistry or biology.
- In the teacher group, there were two physics specialists, two chemistry specialists and two biology specialists to ensure a range of backgrounds and perspectives.

The teachers were given the same questionnaires as the students. Two teachers were given the Level 4 questionnaire, two the level 5 and two the level 6. The teachers were asked to read each question and write in the type of answers that the students were likely to give from their knowledge of students of the appropriate level. Earlier discussions with the teachers had shown that they had a good knowledge, from their teaching experience, of the types of alternative conceptions held by students at each level.

The responses of the teachers were analysed according to the types of alternative conceptions they predicted in student responses. These were then compared with the alternative conceptions identified from the student responses.

Alternative conceptions anticipated by the teachers largely replicated the alternative conceptions identified in the student responses. There were some new alternative conceptions that the teachers gave that had not been identified in the student responses. These were added to the list of alternative conceptions to be used for designing the second tier of the items in the diagnostic instrument. With the nature of the structure of the two-tier diagnostic instrument, there were, for a number of questions, under three student alternative conceptions from the student questionnaire responses. Teacher responses provided additional distracters to make up the four preferred number of reason choices required for each question. The teachers were also asked to comment on whether the questions focused on concepts related to the appropriate curriculum objective. They were also asked to comment of the style of the questions and the level of literacy, numeracy and comprehension. The teachers also made some suggestions to remove difficult concepts from several of the questions e.g. change graphite to sodium in Question 9 and remove physiological adaptation from Question 18.

Collated student alternative conceptions identified from the three search techniques

Alternative conceptions related to objectives at levels 4, 5 and 6 in the four contextual strands of the New Zealand science curriculum were identified from three search technique. *The three search techniques provided triangulation to ensure that the identified alternative conceptions were authentic and reliable. The identified alternative conceptions are listed below.* The alternative conceptions in non-Italics are those identified from the student surveys and follow up telephone interviews. The alternative conceptions in Italics are alternative conceptions predicted by science teachers. The alternative conceptions are linked to proposition numbers in Appendix H.

Curriculum Level 4

Question 1

- Insects are not animals.
- The ability to use information given to classify an organism into a broad group. Students mixed up the combinations of number of legs, number of body sections and presence of wings.

Question 2

- Brightly coloured and scented flowers do not help the plant to survive any better.
- *Brightly coloured and scented flowers are attractive to people who pick them helping the plant to survive.*
- *Flowers make food for the plant helping it to survive.*

Question 3

- Left handed parents teach their children to be right handed.
- *Right handedness is more common than left handedness.*
- *We live in a right handed world so most people choose to be right handed.*

Question 4

- Fewer ladybirds would feed on less of the rose bush.
- The number of ladybirds has no effect on the rose bush since they don't feed on it directly.
- *Reducing the number of ladybirds would reduce the number of aphids helping the rose.*

Question 5

- The electric current will flow round the circuit and out to bulb 1.
- No electric current will flow in the circuit.
- *The electric current will flow to bulb 1 and back to the battery.*

Question 6

- Water dries by droplets going into the air.
- The sun 'sucks' water up.
- Wind blows water drops from clothes.
- *The washing dries mainly because water drips out of the wet clothes ('drip dry').*
- *Heat from the sun boils the water into steam*

Question 7

- Stopping distance increases with speed.
- *As speed goes up the driver's reaction time increases.*
- *It will depend on the type of car the person is driving.*

Question 8

- It must be light because a light goes on the TV when the remote is used.
- It must be electricity because the remote contains a battery.
- It can't be light because you can't see it.
- *It must be electricity because a TV works using electricity.*

Question 9

- Graphite is a metal because it conducts electricity.
- Metals are all strong (too strong to break).
- Metals are hard.

- Metals can withstand high temperatures.

Question 10

- Metal rusts (only iron does, which in the case of tinplate is valid but only when the tin layer is penetrated).
- Metals are stronger and can withstand heat.
- *Metals conduct electricity.*
- *Plastics are cheaper.*

Question 11

- Salt does not/will not reform from solutions on evaporation.
- Salt will settle from solution in time.
- *Mixture cannot be separated by passing it through a filter.*

Question 12

- Plastic is an ingredient in crude oil and can be separated out.
- Plastic could not be made from crude oil because it is so different.
- If oil was part of plastic, it would show itself somehow.
- *The elements that make up plastics are different from the elements in fossil fuels.*

Question 13

- Atmospheric pressure pattern represents a layered section of a structure.
- The 'H' represents high atmospheric pressure.
- The 'H' represents high temperature.
- The 'H' means high winds.

Question 14

- The sea in the area dried up leaving many sea shells.
- *The land was flooded and the seashells were left when the flood receded.*
- *Sea shells put there by humans.*

Question 15

- Planets are stars.
- Planets orbit the sun therefore positions in the night sky change form year to year.
- Earth orbits the sun.
- Mars moves independently of Earth.
- Mars is way beyond Earth's atmosphere.
- Earth rotates on its axis and orbits the sun.

Question 16

- Earth orbits the moon.
- The sun orbits Earth.
- The moon orbits Earth.

Question 17

- *Using students gets the job done quickly and cheaply.*
- *Students would learn how to plant trees.*

Curriculum Level 5

Question 1

- Plants absorb organic nutrients.
- An organism is a plant.
- Only animal cells have a nucleus.
- Plants cannot be single celled.
- Cell membrane and cell wall are the same thing.

Question 2

- A growth response brought about by a chemical is physiological.
- *Growing towards light uses up energy.*
- *An adaptation involving the stem must be structural*

Question 3

- The dominant trait is the more common one.
- *Black is the dominant trait because it is the stronger colour.*
- *If black was dominant then the white trait would not have reappeared.*

Question 4

- Animal life could continue because animals do not use minerals directly from the soil.
- *Decomposers recycle energy in a community.*
- *Life could continue without decomposers because there are enough minerals to keep life going.*

Question 5

- Electric circuits in parallel circuit shared (split half and half) the electric current.

- Circuits with same components will have same current flowing. irrespective of series or parallel connections.
- The length of wire in a circuit has a significant effect on the current through a bulb.
- *Two bulbs in parallel have more resistance than two bulbs in series.*

Question 6

- Electrical energy is converted to light energy.
- Light energy given out by a light bulb is lost from the circuit.
- Electrical energy in a circuit is a continuous circular flow of current.
- *Electrical energy turns to light energy in the bulb and changes back to electrical energy to continue round the circuit.*
- *Electrical energy turns to light energy but the light turns back to electrical energy when the light is switched off.*

Question 7

- Larger masses fall faster than smaller masses.
- Masses fall at same rates because gravity evens out.
- Masses fall at same speed because they have the same terminal velocity due to air resistance.
- *The 10 kg mass has more air resistance so both masses fall at the same speed.*

Question 8

- Mass affects swing-time of a pendulum.
- Both mass and string length affect the swing time.
- *The swing time increased when the mass of the bob and the string length had the same value (numerical).*

Question 9

- The pillar that held the biggest mass was the strongest.
- The result was inconclusive because of overlap between the 3 shapes.
- Ignoring of evidence and drawing on personal knowledge.
- *Lack of understanding of the significance of mean mass.*

Question 10

- Particles expand when heated.
- Particle number increases when heated.
- Particles cannot be seen so theory doesn't make sense.

- *Heat makes the bag softer so it swells.*

Question 11

- Water is a pure substance so is not made up of anything else.
- Water cannot be a mixture of two gases.
- Water is one of the 4 elements, earth, wind, fire and water.

Question 12

- Neutrons are present in the same number as protons and electrons.
- Outer shell of 8 electrons in natural atoms.
- Element, compound, atom – mixing up of ideas around these.
- *Electrons are in the nucleus.*

Question 13

- Acid is the name for any hazardous substance.
- Substances that ‘burn you’ are acids.
- All acids ‘burn you’.
- *Citric acids would not affect caustic soda.*
- *The caustic soda should be left to evaporate dry.*

Question 14

- Acids react with metals to form hydrogen.
- Salt just means table salt, sodium chloride.
- A salt can only be said to have formed when it is a solid.
- Salts only form when acids react with metals.
- *Sulfuric acid and sodium hydroxide would not react.*

Question 15

- Carbon dioxide damages the ozone layer.
- Carbon dioxide increase in atmosphere will improve the weather.
- Carbon dioxide will help plants because they need it for photosynthesis.

Question 16

- Earthquakes are linked to climate.
- Earthquakes depend on the size of the land mass.
- Earthquakes related to landslips.

Question 17

- Soft rock is squeezed thinner and bulges out behaving like cream in a gateau.
- *The shape of a rock formation is because that is how it was created.*

Question 18

- Stars go around the Earth.
- Stars appear to move in the night sky because Earth is orbiting the sun.
- The Milky Way is revolving so the stars are moving.

Question 19

- The Sun is much larger than the star.
- The Sun is the largest star.
- *The sun shines during the day and stars shine at night.*
- *The stars reflect light from the sun.*

Question 20

- Ordinary people can't do anything to help the environment.
- Only the government can help the environment by passing laws.
- New Zealand has a small population so the environment is not threatened.

Curriculum Level 6

Question 1

- Viruses consist of cells.
- Viruses are too small to be alive.

Question 2

- Chromosomes replicate in both divisions.
- The cells formed have the same number of chromosomes as the parent cell.
- *Chromosomes pair up but do not replicate.*

Question 3

- Asexual reproduction is more reliable therefore no need for sexual reproduction.
- Asexual reproduction occurs more quickly therefore no need for sexual reproduction.
- Potatoes are not living.
- Potatoes do not flower.
- *Sexual reproduction is a more complex process therefore less likely to take place.*

Question 4

- All carrots receive the same amount of light, minerals and water so they are not competing with each other.
- The carrots will only be in competition if the are in contact with each other.
- *Pests and diseases are more likely to cause the drop off in weight.*

Question 5

- The student can use these circuits to draw conclusions of the effect of changing the number of cells in series or parallel and on bulb brightness.
- Some of the circuits are not correctly connected.
- *Any change in bulb brightness will be caused by the change in the number of cells in the circuit.*

Question 6

- The water would all get used up and there would not be enough left in the river.
- Water could just be made to flow round and round making electricity *every time it flowed back through the dam because energy cannot be destroyed.*
- *Water is not used up as it passes through the dam therefore more energy could be made this way.*

Question 7

- By extending the graph with a straight line this point (3.5 Amps) is passed through.
- An average figure is calculated using V/I = R.
- *It is not valid to make this prediction from this type of graph since the reading is outside the range of values recorded.*

Question 8

- Optical fibre is cheaper to produce than copper.
- Optical fibre conducts electricity much faster than copper.
- *Optical fibre is easier to manufacture.*

Question 9

- Ethanol and ethane both contain two carbon atoms.
- *Ethanol belongs with hexane because both are liquids.*
- *Ethanol belongs with propane because they have similar molecular masses.*

Question 10

- Vegetables need to absorb calcium carbonate for healthy growth.
- Lime powers soil pH to a level more suitable for plant growth.
- *Lime destroys pest and diseases that retard plant growth.*

Question 11

- Lumps have more surface area than the powder.
- *Powdered marble only seems to react faster because it gives off a large number of small bubbles.*
- *Hydrogen ions in the acid would collide more often with lumps of marble than with the powder.*

Question 12

- Rust occurs from inside the iron.
- Rust can only be prevented by covering the iron completely and sealing out the oxygen and water.
- Zinc protects by attracting water away from iron.
- Zinc protects iron by removing electrons from the iron preventing the iron from rusting.

Question 13

- The white colour meant that it could have been any of the minerals in the table.
- Calcite is usually brightly coloured.
- *Calcite is softer than gypsum.*

Question 14

- Rocks cannot change over time.
- Igneous rocks form from volcanoes and sedimentary rocks form under the sea so one cannot form into the other.
- Sedimentary rocks form when igneous rocks are submerged by sea.
- If larva from volcanoes flows into the sea, they will form sedimentary rock.

Question 15

- The universe is expanding so this proves that it started form one huge lump of matter and energy.
- *The galaxies are not moving away from each other, they only appear to be.*
- *The universe had no beginning, it has always existed.*

Question 16

- There are unlimited reserves of fossil fuels on Earth, they just have to be found.
- Fossil fuels will be replaced by sustainable, non-polluting forms of energy.
- *Fossil fuels are slowly replaced so if they are used carefully they will have time to replace what we use.*

Chapter summary

- Three surveys were designed, one for each of the Curriculum Levels 4, 5 and 6.
- Each survey consisted of 16 to 20 stem questions.
- Each question required the respondent to make a two-way choice e.g. 'true' or 'false' and then provide a reason for this choice.
- Cohorts of students working at curriculum Levels 4, 5 and 6 were given the appropriate survey. The cohorts were from local face-to-face schools and from the Correspondence School full time roll.
- The student responses for each question were collated and categorised into groups according to the types of alternative conceptions given.
- The level of thinking of each type of alternative conceptions was evaluated using the SOLO taxonomy.
- A sample of survey respondents were interviewed by telephone to assess whether alternative conceptions reflected their thinking.
- Six science teachers were given the surveys and asked to predict alternative conceptions that would be identified in each curriculum level group.
- Alternative conceptions identified in the student surveys, telephone interviews and teacher predictions were used to construct items for the second tier of each of the questions in the instrument.

Chapter 5 provides analysis of the student responses to the on-line two-tier instrument for identification of student alternative science conceptions and in ascertaining student conceptual development in relation to curriculum level.

Chapter 5

Results of administration of on-line diagnostic instrument

Overview of chapter

The first part of Chapter 5 provides an analysis of student responses to the diagnostic instrument and categorises major alternative conceptions identified by the instrument. This leads on to discussions of the alternative conceptions identified from student multichoice selections and from individual remarks in the comment space. The second part of the chapter contains analysis of the accuracy of the instrument in ascertaining the curriculum level at which students were working. The final part consists of analysis of the level of difficulty of the items of the instrument and discussion of indices of difficulty and discrimination.

Introduction

An on-line two-tier diagnostic instrument was created from the data gathered from the questionnaires, interviews, experienced teacher surveys and the literature. The diagnostic instrument was then given to three experienced teachers of science to identify any problems in the areas of literacy, numeracy clarity, ambiguity and scientific inaccuracies and their feedback resulted in some final amendments.

The answers provided by the students from each of the groups Year 9, Year 10 and Year 11 were processed and tabulated. This allowed for analysis of the responses given by the different groups and the efficacy of each item in discerning the types of common alternative conceptions held by students in the range of age groups being researched.

The analysis of the responses made by the cohort of students selected aimed to ascertain the following:

- Did the data from the test results enable alternative conceptions to be diagnosed?

- Could the responses to the instrument be used to ascertain the curriculum level at which a student is functioning to enable allocation to a personalized science learning programme?
- Did the two-tier diagnostic instrument function effectively in an on-line environment?

Item analysis of the two-tier diagnostic instrument

The instrument was administered to students ranging from Year 9 to 11. Average Year 9 and 10 students work at Curriculum Level 5 although Year 9 students are in the Curriculum Level 4 to 5 range. The target group for the instrument is Year 10 students who are working in the range of Curriculum Levels 4 to 6, with the majority would be working at Curriculum Level 5. The Year 9 students in the cohort of 57 students are on a programme pitched at Curriculum Level 4-5, the year 10 students at Curriculum Level 5, and Year 11 students at Curriculum Level 6. The programmes for these students were initially determined and adjusted by internal discernment processes.

The students were grouped into their year levels and the responses of students to each item were analysed by a method used by Treagust (1988). Each item was scored according to the number of respondents who selected each alternative in the first tier, e.g. True or False, and the number who selected each of the possible reasons in the second tier. These numbers were converted to percentages.

Students were asked to attempt all items and the vast majority of respondents answered both tiers of every item. A few respondents did not attempt the first tier, while a few attempted the first tier but did not select a reason from the second tier. The very few respondents who did not answer the first tier, but still selected a reason in the second tier, were deemed not to have answered the item. All of these categories were included in the percentage analysis is because not answering the whole or part of a question represented a choice made by the individual to indicate that they did not have the conceptual understanding being tested and may not hold alternative conceptions. This was indicated by remarks made in the comment space by some of these respondents such as “We haven’t done this yet” and “I don’t know about this.”

The percentage of responses by each year group to each item in the section of the instrument with items dealing with Level 4 curriculum objectives (Items 1 to 16) are shown in Table 5.1. The percentage responses for items dealing with Level 5 curriculum objectives (Items 17 to 36) are shown on Table 5.2. The percentage of responses for items dealing with Level 5 curriculum objectives (Items 37 to 52) are shown in Table 5.3.

The percentages that coincide with the scientifically correct answers are written in bold. For two of the items**,** 17 and 37, there were two scientifically correct answers. Item 17 was about whether *Euglena,* the photosynthetic microorganism, is an animal cell or a plant cell, which can be reasoned either way. Item 37 was about whether viruses are living or non-living which can also be reasoned either way. All other items were designed to have a single scientifically correct response. A full spreadsheet of all percentage responses by each year group is given in Appendix K.

The percentage of respondents who selected the scientifically correct answers increased from Year 9 students to Year 11 students in most questions. This trend is to be expected as students have received more teaching and learning and also with greater maturity their conceptual understanding should increase. There were some items where the younger students scored a higher percentage of ‘correct answers’ than older students. This occurred in to a greater extent in the Curriculum Level 4 section (Items 1 to 16). This could be due to factors such as bias within the samples and students ‘forgetting’ scientific concepts learned in earlier years and reverting to alternative conceptions.

Two items, 15 and 48, revealed alternative conceptions or misunderstandings with the majority of students at all levels. In Item 15, the largest group of respondents explained the apparent movements of the Sun and the Moon across the night sky during day-night cycle as being due to Earth orbiting the Sun and the Moon orbiting Earth rather than due to Earth’s rotation. In Item 48, the largest group of respondents did not understand the concept of sacrificial protection of iron by zinc in galvanized steel. In all other items the largest group of respondents, overall, selected the scientifically correct answer.

Table 5.1
Percentage of students showing alternative responses - Level 4

Item	[1]CO	Year	N	Choice A/B	Reason					
					1	2	3	4	NR	Total
1	LW 4-1	9	16	A	6.3			**87.5**		93.8
				B				6.3		6.3
		10	16	A		6.3		**81.3**		87.5
				B				12.5		12.5
		11	15	A	6.7			**80.0**		86.7
				B				13.3		13.3
2	LW 4-2	9	16	A		**93.8**				93.8
				B	6.3					6.3
		10	16	A		**87.5**	6.3			93.8
				B	6.3					6.3
		11	15	A		**93.3**		6.7		100.0
				B						
3	LW 4-3	9	16	A	**25.0**		43.8	6.3		75.0
				B		6.3	6.3	6.3		18.8
		10	16	A	**62.5**		12.5			75.0
				B			25.0			25.0
		11	15	A	**53.3**		26.7			80.0
				B			20.0			20.0
4	LW 4-4	9	16	A		6.3		6.3		12.5
				B	**68.8**		6.3	6.3		81.3
		10	16	A	12.5					12.5
				B	**81.3**			6.3		87.5
		11	15	A	6.7			20.0		26.7
				B	**66.7**		6.7			73.3
5	PW 4-1	9	16	A	31.3	6.3		12.5		50.0
				B	6.3		**37.5**			43.8
		10	16	A						
				B	12.5	12.5	**68.8**	6.3		100.0
		11	15	A	20.0		6.7			26.7
				B	6.7		**66.7**			73.3

Table 5.1 (continued)
Percentage of students showing alternative responses - Level 4

Item	CO	Year	N	Choice A/B	Reason 1	Reason 2	Reason 3	Reason 4	Reason NR	Total
6	PW 4-2	9	16	A	6.3	**81.3**	6.3			93.8
				B	6.3					6.3
		10	16	A		**93.8**				93.8
				B				6.3		6.3
		11	15	A		**66.7**	6.7	13.3		86.7
				B	6.7					6.7
7	PW 4-3	9	16	A	6.3	6.3		**81.3**		93.8
				B						
		10	16	A		6.3		**93.8**		100.0
				B						
		11	15	A	6.7			**86.7**		93.3
				B			6.7			6.7
8	PW 4-4	9	16	A		31.3	12.5		6.3	50.0
				B			6.3	**43.8**		50.0
		10	16	A		43.8				43.8
				B		6.3		**50.0**		56.3
		11	15	A						
				B				**100.0**		100.0
9	MW 4-1	9	16	A	**31.3**		6.3	6.3		43.8
				B		18.8	6.3	12.5	6.3	43.8
		10	16	A	**50.0**		18.8			68.8
				B		18.8		12.5		31.3
		11	15	A	**73.3**					73.3
				B		20.0		6.7		26.7
10	MW 4-2	9	16	A	6.3	**50.0**	6.3		6.3	68.8
				B	18.8			12.5		31.3
		10	16	A	18.8	**50.0**				68.8
				B	18.8			12.5		31.3
		11	15	A		**80.0**				80.0
				B	6.7			13.3		20.0
11	MW 4-3	9	16	A		**62.5**	6.3	6.3		75.0
				B		12.5	6.3	6.3		25.0
		10	16	A		**75.0**				75.0
				B		6.3	12.5			18.8
		11	15	A		**73.3**			6.7	80.0
				B	13.3			6.7		20.0
12	MW 4-4	9	16	A	**37.5**		18.8		6.3	62.5
				B	6.3	18.8		12.5		37.5
		10	16	A	**50.0**		12.5			62.5
				B		18.8		12.5		31.3
		11	15	A	**73.3**					73.3
				B		6.7		13.3		20.0

Table 5.1 (continued)
Percentage of students showing alternative responses - Level 4

Item	CO	Year	N	Choice A/B	Reason					
					1	2	3	4	NR	Total
13	PEB 4-1	9	16	A	**75.0**	12.5	6.3			93.8
				B					6.3	6.3
		10	16	A	**93.8**				6.3	100.0
				B						
		11	15	A	**100.0**					100.0
				B						
14	PEB 4-2	9	16	A	**37.5**		18.8	37.5		93.8
				B		6.3				6.3
		10	16	A	**81.3**			12.5		93.8
				B			6.3			6.3
		11	15	A	**66.7**		6.7	13.3		86.7
				B	6.7	6.7				13.3
15	PEB 4-3	9	16	A						
				B		6.3	68.8	**12.5**	6.3	93.8
		10	16	A			18.8	6.3		25.0
				B			56.3	**18.8**		75.0
		11	15	A						
				B	6.7		66.7	**26.7**		100.0
16	PEB 4-4	9	16	A						
				B		**93.8**		6.3		100.0
		10	16	A						
				B		**100.0**				100.0
		11	15	A	6.7					6.7
				B		**93.3**				93.3

Table 5.2
Percentage of students showing alternative responses - Level 5

Item	CO	Year	N	Choice A/B	Reason					
					1	2	3	4	NR	Total
17	LW 5-1	9	16	A	**50.0**	6.3			6.3	62.5
				B			**25.0**			25.0
		10	16	A	**81.3**					81.3
				B			**18.8**			18.8
		11	15	A	**60.0**					60.0
				B	6.7	6.7	**26.7**			40.0
18	LW 5-2	9	16	A	**75.0**		6.3			81.3
				B	6.3			12.5		18.8
		10	16	A	**68.8**					68.8
				B				31.3		31.3
		11	15	A	**66.7**					66.7
				B		6.7		26.7		33.3
19	LW 5-3	9	16	A	**31.3**	31.3		6.3		68.8
				B	6.3	6.3	12.5			25.0
		10	16	A	**43.8**	43.8		12.5		100.0
				B						
		11	15	A	**86.7**	6.7		6.7		100.0
				B						
20	LW 5-4	9	16	A	**62.5**	18.8	6.3	6.3		93.8
				B			6.3			6.3
		10	16	A	**87.5**		6.3	6.3		100.0
				B						
		11	15	A	**80.0**	20.0				100.0
				B						
21	PW 5-1	9	16	A		12.5		25.0		37.5
				B	**18.8**	6.3	37.5			62.5
		10	16	A	6.3	25.0		6.3		37.5
				B	**37.5**	6.3	12.5	6.3		62.5
		11	15	A	26.7	6.7				33.3
				B	**60.0**		6.7			66.7
22	PW 5-2	9	16	A		12.5	6.3	**31.3**		50.0
				B	18.8	6.3		12.5		37.5
		10	16	A		6.3		**50.0**		56.3
				B	12.5	12.5		12.5		37.5
		11	15	A		6.7		**93.3**		100.0
				B						
23	PW 5-1	9	16	A		*	6.3	6.3		12.5
				B	75.0		6.3			81.3
		10	16	A		**25.0**		18.8		43.8
				B	50.0	6.3				56.3
		11	15	A		**60.0**		13.3		73.3
				B	26.7					26.7

Table 5.2 (continued)
Percentage of students showing alternative responses - Level 5

Item	CO	Year	N	Choice A/B	Reason					
					1	2	3	4	NR	Total
24	PW 5-3	9	16	A	6.3	25.0	6.3			37.5
				B	**37.5**	6.3	6.3	12.5		62.5
		10	16	A	6.3	43.8				50.0
				B	**37.5**	6.3	6.3			50.0
		11	15	A	6.7	20.0				26.7
				B	**60.0**			6.7	6.7	73.3
25	PW 5-4	9	16	A	31.3	12.5		**56.3**		100.0
				B						
		10	16	A	31.3			**62.5**		93.8
				B		6.3				6.3
		11	15	A	13.3			**86.7**		100.0
				B						
26	MW 5-1a	9	16	A	6.3	**50.0**				56.3
				B	12.5	6.3	6.3			25.0
		10	16	A	12.5	**31.3**	6.3	6.3		56.3
				B		31.3	6.3			37.5
		11	15	A		**80.0**	6.7	6.7		93.3
				B		6.7				6.7
27	MW 5-1b	9	16	A	6.3	18.8	6.3	18.8		50.0
				B		**18.8**	25.0			43.8
		10	16	A	6.3	6.3		6.3		18.8
				B	12.5	**56.3**	12.5			81.3
		11	15	A	6.7	6.7		6.7		20.0
				B		**66.7**	6.7			73.3
28	MW 5-1b	9	16	A	12.5	6.3	**12.5**			31.3
				B	12.5	6.3	6.3	12.5		37.5
		10	16	A	18.8		**31.3**			50.0
				B	31.3	6.3	6.3			43.8
		11	15	A			**46.7**			46.7
				B	40.0		6.7	6.7		53.3
29	MW 5-2	9	16	A		12.5	6.3	**12.5**		31.3
				B	12.5	12.5		12.5		37.5
		10	16	A				**68.8**		68.8
				B	18.8					18.8
		11	15	A				**100.0**		100.0
				B						
30	MW 5-3	9	16	A	6.3		**12.5**			18.8
				B		18.8		31.3		50.0
		10	16	A	12.5		**31.3**			43.8
				B		12.5		37.5		50.0
		11	15	A	20.0		**60.0**			80.0
				B				13.3		13.3

Table 5.2 (continued)
Percentage of students showing alternative responses - Level 5

Item	CO	Year	N	Choice A/B	Reason					
					1	2	3	4	NR	Total
31	MW 5-4	9	16	A		50.0	6.3	**31.3**		87.5
				B	6.3					6.3
		10	16	A		43.8		**50.0**		93.8
				B	6.3					6.3
		11	15	A		6.7		**93.3**		100.0
				B						
32	PEB 5-1	9	16	A			**81.3**			81.3
				B				6.3		6.3
		10	16	A			**93.8**			93.8
				B				6.3		6.3
		11	15	A			**100.0**			100.0
				B						
33	PEB 5-2	9	16	A	12.5	6.3			6.3	25.0
				B		**37.5**		25.0		62.5
		10	16	A	6.3		6.3			12.5
				B		**75.0**	6.3	6.3		87.5
		11	15	A			6.7			6.7
				B		**80.0**	6.7	6.7		93.3
34	PEB 5-3a	9	16	A		12.5	12.5			25.0
				B		**68.8**				68.8
		10	16	A						
				B		**68.8**	31.3			100.0
		11	15	A						
				B		**100.0**				100.0
35	PEB 5-3b	9	16	A		**50.0**				50.0
				B	31.3	6.3	6.3			43.8
		10	16	A		**56.3**				56.3
				B	43.8					43.8
		11	15	A		**86.7**				86.7
				B	13.3					13.3
36	PEB 5-4	9	16	A	**87.5**	6.3				93.8
				B						
		10	16	A	**93.8**	6.3				100.0
				B						
		11	15	A	**100.0**					100.0
				B						

Table 5.3
Percentage of students showing alternative responses - Level 6

Item	CO	Year	N	Choice A/B	Reason					
					1	2	3	4	NR	Total
37	LW 6-1	9	16	A	**31.3**	31.3				62.5
				B	12.5		**6.3**	6.3		25.0
		10	16	A	**43.8**	18.8				62.5
				B			**37.5**			37.5
		11	15	A	**53.3**	13.3				66.7
				B	13.3		**20.0**			33.3
38	LW 6-2	9	16	A			12.5		6.3	18.8
				B		**25.0**	6.3			31.3
		10	16	A	6.3	12.5		6.3		25.0
				B	18.8	**37.5**	6.3			62.5
		11	15	A	6.7	6.7	6.7	6.7		26.7
				B	6.7	**60.0**	6.7			73.3
39	LW 6-3	9	16	A	6.3	6.3	12.5	**31.3**		56.3
				B		6.3	12.5		6.3	25.0
		10	16	A	6.3			**31.3**		37.5
				B	18.8	12.5	31.3			62.5
		11	15	A				**86.7**		86.7
				B	6.7			6.7		13.3
40	LW 6-4	9	16	A		18.8	**37.5**			56.3
				B	18.8					18.8
		10	16	A			**68.8**			68.8
				B	6.3	12.5	6.3			25.0
		11	15	A		6.7	**73.3**	6.7		86.7
				B	6.7		6.7			13.3
41	PW 6-1	9	16	A	31.3		6.3			37.5
				B		**18.8**		12.5		31.3
		10	16	A	18.8		6.3			25.0
				B		**68.8**				68.8
		11	15	A						
				B		**86.7**		13.3		100.0
42	PW 6-2	9	16	A	31.3		12.5			43.8
				B		**37.5**	6.3			43.8
		10	16	A	6.3		6.3			12.5
				B		**75.0**	12.5			87.5
		11	15	A	13.3		6.7			20.0
				B		**80.0**				80.0
43	PW 6-3	9	16	A	**37.5**				6.3	43.8
				B	6.3	6.3		6.3	6.3	25.0
		10	16	A	**50.0**			18.8		68.8
				B	18.8		6.3			25.0
		11	15	A	**66.7**		6.7	13.3		86.7
				B	6.7					6.7

Table 5.3
Percentage of students showing alternative responses - Level 6

Item	CO	Year	N	Choice A/B	Reason					
					1	2	3	4	NR	Total
44	PW 6-4	9	16	A	12.5	**50.0**	6.3	12.5		81.3
				B						
		10	16	A		**87.5**		6.3		93.8
				B						
		11	15	A	6.7	**93.3**				100.0
				B						
45	PW 6-1	9	16	A	18.8			6.3		25.0
				B	6.3	**43.8**				50.0
		10	16	A	31.3					31.3
				B		**50.0**	6.3	6.3		62.5
		11	15	A		6.7				6.7
				B		**93.3**				93.3
46	PW 6-2	9	16	A	6.3	12.5				18.8
				B		43.8		**18.8**		62.5
		10	16	A	6.3	6.3				12.5
				B		31.3		**50.0**		81.3
		11	15	A				20.0		20.0
				B		33.3		**46.7**		80.0
47	PW 6-3	9	16	A		12.5	6.3	**25.0**		43.8
				B	12.5	18.8				31.3
		10	16	A	6.3	6.3	12.5	**43.8**		68.8
				B		31.3				31.3
		11	15	A				**86.7**		86.7
				B		6.7	6.7			13.3
48	PW 6-4	9	16	A	6.3	**6.3**				12.5
				B	37.5	6.3	6.3	18.8		68.8
		10	16	A		*	12.5			12.5
				B	56.3	6.3	6.3	6.3		75.0
		11	15	A		**20.0**	6.7		6.7	33.3
				B	33.3	6.7	6.7	13.3		60.0
49	PEB 6-1	9	16	A	12.5	**56.3**				68.8
				B		6.3	6.3			12.5
		10	16	A	6.3	**87.5**				93.8
				B			6.3			6.3
		11	15	A		**93.3**				93.3
				B			6.7			6.7
50	PEB 6-2	9	16	A		12.5	6.3	**25.0**		43.8
				B	6.3	18.8			6.3	31.3
		10	16	A		12.5		**37.5**		50.0
				B	25.0	6.3	18.8			50.0
		11	15	A		6.7		**93.3**		100.0
				B						

Table 5.3
Percentage of students showing alternative responses - Level 6

Item	CO	Year	N	Choice A/B	Reason 1	Reason 2	Reason 3	Reason 4	Reason NR	Total
51	PEB 6-3	9	16	A	**18.8**			31.3		50.0
				B	6.3		6.3	6.3		18.8
		10	16	A	**37.5**			37.5		75.0
				B		18.8	6.3			25.0
		11	15	A	**60.0**			6.7		66.7
				B			6.7		20.0	26.7
52	PEB 6-4	9	16	A	**50.0**		6.3	6.3		62.5
				B		6.3	6.3	6.3		18.8
		10	16	A	**68.8**			25.0		93.8
				B			6.3			6.3
		11	15	A	**80.0**			20.0		100.0
				B						

Major alternative conceptions identified from the diagnostic instrument

A number of alternative conceptions were identified using the on-line diagnostic instrument. These alternative conceptions were categorized then summarized in Tables 5.4, 5.5 and 5.6. The alternative conceptions were essentially of a number of types described by the Center for Science, Mathematics and Engineering (1997). These are:

- Preconceived notions (PN) – These popular misconceptions rooted in everyday experiences. For example, water is an element because it is one of the elements earth, wind, fire and water. This is not students expressing a medieval notion, but probably stems from a popular TV cartoon series (Item 27).

- Nonscientific beliefs (NB) – These views are learned by students from sources other than scientific education such as religious or mythical teachings. For example, the notion that fossil shells on a hillside resulted from Noah’s flood (Item 14).

- Conceptual misunderstandings (CM) – These views arise when students are taught scientific information in a way that does not provoke them to confront paradoxes and conflicts resulting from their own preconceived notions and nonscientific beliefs. Most of the alternative conceptions identified were of this type e.g. the notion that zinc layer on galvanized steel only protects if coverage is complete. This shows an understanding of the need to exclude water and air from the iron, but a lack of conceptual understanding of sacrificial protection (Item 48).

- Vernacular misunderstandings (VM) – These views arise from words that mean one thing in everyday life and another in a scientific context. For example, the word 'salt' means sodium chloride as in table salt and not a family of chemical compounds derived from acids (Item 30).

- Factual misconceptions (FM) – These falsities are often learned at an early age and retained into adulthood. For example, the Sun is not a star, but a special, much larger heavenly object (Item 35).

In addition to the above mentioned alternative conceptions, some respondents showed misunderstandings of the information given in the stem of the item and an inability to process it. These misunderstandings related to the surface and deeper processes described in the asTTle V4 Manual, Chapter 1. (Brown, 2003; Ministry of Education, 2005a). These surface and deeper processes translate from the SOLO Taxonomy levels referred to in Chapter 4 (Biggs & Collis, 1982). Surface processes correspond with SOLO Pre-instructional and Unistructural levels and deeper processes correspond with SOLO Multistructural and Relational levels. Some students responded using their everyday experience rather than probing into the evidence provided in the item stem and so only used surface processes in the items that required interpretation and application of the information given. In some cases, the evidence may have challenged popular notions held by the respondent while in others the evidence was not understood by the respondent. Responses signifying use of surface rather than deeper processes were labeled as deeper process issues (DP). Items that identified this type of issue were Items 1, 4, 10, 11, 24, 31, 44 and 49 (Table 5.4).

There are also items where students show affective issues contrary to the intentions expressed in the particular objective. Items of this type tended to be in line 4 of the Planet Earth and Beyond strand where there was not so much ‘correct’ and ‘incorrect’ answers, but answers that reflected the desired attitude implied in the Planet Earth and Beyond curriculum objectives in this line. Questions of this type included Items 16, 37 and 52.

Many alternative conceptions identified are a combination of several types of alternative conceptions as described above, plus surface versus deeper levels of thinking, that contribute to an overall lack of understanding of the scientific idea or skill in question.

The alternative conceptions identified from the on-line diagnostic instrument are listed in Table 5.4. Alternative conceptions selected by less than 10% of respondents were excluded so that the more significant alternative conceptions were listed (Gilbert, 1977; Treagust & Mann, 2000; Tsai, Chen, Chou, Lain, 2007). Each alternative conception is labeled with the codes described below to signify the type of alternative conception each represents:

PN = Preconceived notions	NB = Non scientific beliefs
CM = Conceptual misunderstandings	VM = Vernacular misunderstandings
FM = Factual misconceptions	DP = Deeper processes issue

The propositional knowledge statements linking the scientific concepts that underlie each question are entered in Tables 5.4 – 5.6. In these tables the alternative conceptions identified from each item of the instrument are listed and categorized and linked to propositional knowledge statements (PKS). Each propositional knowledge statement was given a code for the objective line from the curriculum statement plus a number to denote its position in the sequence of conceptual understanding for that objective line. The codes used are based on the objective lines in each strand as explained in Chapter 3. The code LW line 1; 2, 3, 4 denotes Living World strand, objective line 1, PKS numbers 2, 3 and 4. These codes are used in Appendix E which lists the propositional statements derived from the concept maps in Appendix D. Each alternative conception identified in each item of the instrument is linked to the objective line and the proposition statements that make up the scientific conceptions for which the respondents hold alternative conceptions. Each alternative conception is classified into the types described above using the system derived from a combination of the categories of alternative conceptions used by the Center for Science, Mathematics and Engineering (1997) and the surface and deeper processes described in the asTTle V4 Manual, Chapter 1. (Brown, 2003; Ministry of Education, 2005a).

Comments added in Italics provide further explanation of the alternative conception or extra comments on the nature of the item and the way students responded to it. For example in Item 11 the question asked students to select whether salt dissolving in water is a temporary or permanent change. Some respondents selected statements from the second tier that in themselves were true, but were not the correct explanation for their notion that it is a permanent change.

- Dissolving salt cannot be reversed by passing through filter (DP).
- *True, but in itself, does not make change permanent.*
- Dissolving salt cannot be reversed by allowing salt to settle (CM).
- *True but in itself does not make change permanent.*

Item 15 identified alternative conceptions regarding the relative movements of the Sun and Earth in the majority of respondents and only a minority held the accepted scientific conception for explaining the day night cycle.

- Sun travels around Earth (PN).
- Earth is at the centre of the solar system (PN).
- Movements of sun and moon across sky during day-night cycle are due to Earth orbiting the Sun and the Moon orbiting Earth (PN).
- *A minority thought that Earth's rotation was the correct reason.*

Item 17 had two possible scientifically accepted responses which would have contributed to no significant alternative conceptions (over 10% of respondents) being identified.

No significant alternative conceptions.
This is the first item where two answers are possible, with opposite choices in the first tier supported with respective scientifically correct reasons. There were two correct responses, Euglena is plant and Euglena is animal.

Item 37 about viruses as living or non-living was the other item with two scientifically acceptable responses.

Table 5.4
Summary of alternative conceptions identified in the diagnostic instrument – Level 4

Item	PKS[1]	Alternative conceptions identified at Curriculum Level 4 (n=47)
1	LW line 1 1,2,3,4	• Insects and arachnids are not animals (VM). • Applying information (DP).
2	LW line 2 1,2	• Bright, scented flowers do not help plants to survive (CM). • Flowers are bright and scented so that they are attractive to people (PN).
3	LW line 1 3 LW line 3 1,2,3	• Left and right handedness is not inherited because right handedness is more common (CM). • Left and right handedness is inherited because right handedness is more common (PN). • Right handedness is not inherited because it is learned (PN). • Matter of choice (PN).
4	LW line 4 1,2,3	• Ladybirds do not benefit a rose bush (CM, DP). • Lady birds feed on a rose bush (CM, DP). • Ladybirds don't feed directly on the rosebush so cannot be of benefit (CM, DP). • Reducing ladybird number would reduce number of aphids and whitefly (CM, DP).
5	PW line 1 18,19,22,25	• Bulb will light up even when bulb not part of circuit (CM). • An electric current flows back and forth along a wire (CM). • Current will not flow even if there is a continuous conducting pathway (CM).
6	PW line 2 11	• Washing dries just by water dripping out of clothes (PN). • Washing dries by wind shaking the water out of the clothes (PN). • Washing dries by heat from sun boiling the water out of the clothes (CM).
7	PW line 3 1	• As speed increases, the driver's reaction time increases (DP). • Stopping distance always less than speed (wrong trend), (DP). • Type of car and the driver have an effect (PN).
8	PW line 4 4	• TV remote transmits electricity because it contains a battery (PN). • TV remote transmits electricity because a TV works by electricity (PN).
9	MW line 1 26	• Sodium is shiny so it is a metal (PN). • Sodium is a metal because it is soft (CM). • Sodium is a non-metal because it melts easily (PN). • Sodium is a non-metal because it is shiny (PN). • Sodium is a non-metal because it is soft (PN). • Sodium is a non-metal because it conducts electricity (CM).

Table 5.4 (continued)
Summary of alternative conceptions identified in the diagnostic instrument – Level 4

Item	PKS1	Alternative conceptions identified at Curriculum Level 4 (n=47)
10	MW line 2 1,2,3	• Metals corrode and plastics do not – true but not main issue in this question (DP). • Metals are stronger and can withstand heat – a reason why they are not suitable for packaging foods that need to be cooked in container (DP). • Metals conduct electricity (PN). *True, but not relevant to question* • Plastics are cheaper *True but not the reason that makes them suitable for packaging foods that need to be cooked in the container (DP).*
11	MW line 3 1,2,3	• Dissolving salt cannot be reversed by passing through filter (DP). *True, but in itself, does not make change permanent*. • Dissolving salt is a permanent change because it can be reversed by evaporation (CM) • Dissolving salt cannot be reversed by allowing salt to settle (CM). *True but in itself does not make change permanent*. • Salt changes to another substance when it dissolves (CM). *It changes form, but not to a new substance*.
12	MW line 4 5	• Fuels chemicals are too different become plastics (CM). • Plastics exist in fossil fuels and can be separated out (CM). • Fossils and plastics contain different elements (CM).
13	PEB line 1 1,2	• On a weather map the H on an anticyclone stands for hot zone (PN).
14	PEB line 2 1,2,3	• Fossil shells in rocks were put there by humans (PN). • Fossil shells formed from shells left after floods (PN). • Land was once covered by sea but the sea dried up leaving shells (PN).
15	PEB line 3 1,2,3	• Sun travels around Earth (PN). • Earth is at the centre of the solar system (PN). • Movements of sun and moon across sky during day-night cycle are due to Earth orbiting the Sun and the Moon orbiting Earth (PN). *A minority thought that Earth's rotation was the correct reason).*
16	PEB line 4 1,2	No significant alternative conceptions. *This question sought to diagnose attitudes rather than alternative conceptions.*

PKS[1] Propositional knowledge statement

Table 5.5 (continued)
Summary of alternative conceptions identified in the diagnostic instrument – Level 5

Item	PKS1	Alternative conceptions identified at Curriculum Level 5 (n=47)
17	LW line 1 5,6,7,8,9,10,11	No significant alternative conceptions. *This is the first item where two answers are possible, with opposite choices in the first tier supported with respective scientifically correct reasons. There were two correct responses, Euglena is plant and Euglena is animal.*
18	LW line 2 3,4	• Plants cannot think so do not have behavioural adaptations (PN).
19	LW line 3 11,12,13	• A higher proportion of individuals with a genetic trait indicate that the trait is dominant (PN). • Recessive characteristics would not reappear in subsequent crosses (CM). • Darker colours are dominant over lighter colours (PN).
20	LW line 4 7,8,9	• Decomposers recycle energy in communities (MC). • Life could continue without decomposers because there are plenty of minerals in the environment (PN).
21	PW line 1 31	• Light bulbs in series will be dimmer due to less resistance (CM). • Light bulbs in parallel will be dimmer because the current divides between them (CM). • Bulb brightness is dependent on number of bulbs in circuit no matter how connected (CM). • Bulbs in a series circuit are brighter because the current has less distance to travel (CM).
22	PW line 2 3,4,5	• An electric current does not lose energy to a lit bulb in the circuit (PN, CM). • Light energy from a lit bulb turns back to electrical energy so the current continues to flow (CM). • An electric light gives out light energy but this is not energy lost from the electric current in the circuit (PN, CM).
23	PW line 1 23,24,25	• Larger masses fall faster than smaller masses due to greater force of gravity (PN, CM). • Volume of a body significantly affects its rate of falling due to gravity (PN). • Air resistance causes objects to fall at the same rate (PN).
24	PW line 3 1,4	• Pendulum swing-time is affected by the mass of the bob as well as string length (PN, DP). • Pendulum swing-time is affected by the mass of the bob but not string length (PN, DP).
25	PW line 4 5,6	• Lack of realization that quantitative experiments need to be repeated several times and a mean taken before drawing conclusions (CM).
26	MW line 1 1,2,3,4,5,6,7, 8,9,10,11	• Change of state from liquid to gas involves increase in number of particles (CM). • Particle theory of matter does not make sense because the particle cannot be seen (PN). • Particle theory of matter and effect of giving particles heat energy (CM).
27	MW line 1 12,13,14,15,16,17	• Pure substance equates with an element (CM). • If a substance is made up of different elements, it is still an element (CM). • A compound is a mixture (CM). • Water is an element along with earth, wind and fire (PN).

Table 5.5 (continued)
Summary of alternative conceptions identified in the diagnostic instrument – Level 5

Item	PKS1	Alternative conceptions identified at Curriculum Level 5 (n=47)
28	MW line 1 18,19,20,21,22,23,24,25	• The number of protons and neutrons in an atom should be equal (CM). • There should be 8 electrons in an atom (CM).
29	MW line 2 6,7	• Acids are always hazardous (PN, VN). • Bases neutralize acids – lack of understanding (CM).
30	MW line 3 5	• Sodium hydroxide is a metal (CM). *It contains a metal but is not a metal.* • Dilute sulfuric acid does not react with sodium hydroxide (CM). *Lack of understanding at Year 9* • Salt means sodium chloride (VN).
31	MW line 4 1,2,3	• Burning fossil fuels is good for the environment because it increases plant growth (DP). • Carbon dioxide in the atmosphere enlarges the ozone hole (PN) *A large proportion held this view.*
32	PEB line 1 7,8 PEB line 2 4,5,6	• Earthquakes occur because the land is heated up by the sun causing it to expand (PN).
33	PEB line 2 8	• Protruding rock on a cliff face is the softer rock because it has been squeezed out (CM). • Thinner layers of rock indicate soft rock squashed under pressure (CM). • Cliff shape is determined only by the way the rock layers formed, not by weathering (CM).
34	PEB line 3 8	• Stars moving across the night sky is caused mainly by Earth's movement around the sun (CM). • Movement of stars in night sky is because the stars are actually moving (PN).
35	PEB line 3 9,10	• The Sun appears bigger than the stars because it is much larger (PN). *A significant minority in all age groups take this view.*
36	PEB line 4 3,4	• Ordinary people can't do anything to help the environment (PN). *All New Zealanders and ordinary people may not have been equated.*

PKS[1] Propositional knowledge statement

Table 5.6
Summary of alternative conceptions identified in the diagnostic instrument – Level 6

Item	PKS1	Alternative conceptions identified at Curriculum Level 5 (n=47)
37	LW line 1 12,13,18,19,20	• Viruses are made up of living cells (CM). • Viruses are not living because they can reproduce inside living cells (CM). *Meaning that because they reproduce **only** inside living cells. This is the second item where two answers are possible, with opposite choices in the first tier supported with respective scientifically correct reasons.*
38	LW line 2 6,8,9,11,12	• Meiosis leads to cells with the same number of chromosomes as the parent cell (CM). • Mitosis leads to cells with half the number of chromosomes as the parent cell (CM). • In meiosis the chromosomes replicate in both divisions (CM). • In mitosis the chromosomes replicate in both divisions (CM).
39	LW line 3 14,15,16,17	• Sexual reproduction is not necessary for the survival of the potato species over time because it is a complex process less likely to occur than asexual reproduction (CM). • Sexual reproduction is not necessary for the survival of the potato species over time because asexual reproduction occurs more quickly (PN, CM). • Sexual reproduction is not necessary for the survival of the potato species over time because asexual reproduction is more reliable in good conditions for growth (CM).
40	LW line 4 12,13,14,15	• Carrots grown in more crowded conditions are not competing because they all receive the same amount of light, minerals and water (CM). • Carrots grown in more crowded conditions are not competing as long as they are not in contact with each other underground (CM).
41	PW line 1 28,29	• Changing the number of bulbs in a circuit is the only variable affecting bulb brightness, irrespective of how bulbs connected and number of cells in the circuit (CM). • Valid conclusions can be drawn if more than one variable is changed at a time (CM).
42	PW line 2 2	• Water can be pumped back through a hydro-dam to make more energy since the water is not used up (PN). • Water can be pumped back through a hydro-dam to make more electricity because energy cannot be destroyed (CM). • Water cannot be pumped back through a hydro-dam to make more electricity because energy cannot be destroyed (CM).
43	PW line 3 2,3,4	• Extrapolation of a voltage versus current curve involves drawing a straight line from the top of the curve (CM). • Drawing a best fit line over a smooth voltage vs current curve is valid for extrapolation (CM). • Extrapolation of a voltage vs current curve can be done by taking the average of one of the variables (CM).
44	PW line 4 5,6	• Optical fibre has revolutionized telecommunications copper because it is cheaper than copper (SP). • Optical fibre has revolutionized telecommunications copper because it conducts electricity better than copper (DP).
45	MW line 1 27	• Ethane and ethanol belong to the same group because they both contain two carbon atoms (CM). • Ethane and ethanol do not belong to the same group because they both contain two carbon atoms (CM).

Table 5.6 (continued)
Summary of alternative conceptions identified in the diagnostic instrument – Level 6

Item	PKS1	Alternative conceptions identified at Curriculum Level 6 (n=47)
46	MW line 2 10	• Lime helps cabbages to grow because the absorb calcium carbonate as a food (PN). • Lime is not a plant food but it helps cabbage growth by lowering soil pH (PN). • Lime is a plant food that helps cabbage growth by lowering soil pH (PN). • Lime is a plant food that helps cabbage growth by raising soil pH (PN).
47	MW line 3 7	• Marble lumps fizz faster powder because lumps have a larger surface area (PN). • Powdered marble only seems to react faster than lumps because it gives off a larger number of smaller bubbles (PN). *A difference in perception here between real and apparent reaction.* • Marble lumps fizz faster powder because hydrogen ions would collide with the lumps more often (PN).
48	MW line 4 7,8,9,10,11	• Zinc prevents iron from rusting by sealing out oxygen so would not stop rusting if coverage incomplete (CM). • Zinc does not prevent iron from rusting because it passes electrons on to the iron atoms (CM). • Zinc does not prevent iron from rusting because it removes electrons from the iron atoms (CM). • Zinc does prevent iron from rusting because it removes electrons from the iron atoms (CM). • Zinc prevents iron from rusting by sealing out water so would not stop rusting if coverage incomplete (CM). *The majority of respondents did not understand sacrificial protection*
49	PEB line 1 11	• A mineral that is white could be any of the white minerals listed (despite its reaction with acid), (DP).
50	PEB line 2 9,10	• Igneous rocks cannot become sedimentary rocks because they form in different places (CM). • Igneous rocks that flow into the sea form sedimentary rocks (CM). • Igneous rocks cannot become sedimentary rocks because they are quite different (CM).
51	PEB line 3 15,16	• Galaxies moving apart do not support the big bang theory for the origin of the universe because they are not really moving away from each other, they just appear to be (NB). • Galaxies moving apart do not support the big bang theory for the origin of the universe because the universe did not have a beginning or end, it has always been there (NB). • Galaxies moving apart proves the big bang theory (NB).
52	PEB line 4 7,8	• Fossil fuels don't need to be conserved because new reserves will be discovered (PN). • Fossil fuels don't need to be conserved because new energy sources will be developed (PN) • If fossil fuels are used efficiently because they are being replaced by natural processes (PN, NB).

PKS[1] Propositional knowledge statement

Discussion on the major alternative conceptions identified by the instrument

Completion of the analysis of student responses from the on-line instrument identified the full range of types of alternative conceptions described by the Center for Science, Mathematics and Engineering. The majority of the alternative conceptions identified were in the category of Conceptual misunderstandings (CM).

The range of alternative conceptions was lower than the number identified from the open ended surveys described in Chapter 4. The on-line instrument identified 133 alternative conceptions whereas the open ended surveys identified 164. There may be a number of reasons for this including the nature and in-built constraints of the instrument and the student samples.

1. The nature and in-built constraints of the instrument.

- The range is limited to three alternative conceptions in the second tier of the two-tier instrument, although there are eight possible choice combinations (See Tables 5.4 to 5.6)
- The nature of the items may have led students to make particular choices that they may not have made in an open ended situation. Because alternative conceptions are more visible, students will make a choice between possibilities that would have the effect of narrowing the range of alternative conceptions.
- The two-tier instrument did not include alternative conceptions at the pre-instructional and unistructural levels of the SOLO Taxonomy.
- Alternative conceptions identified in less than 10% of respondents were not included.

2. The student samples.

- The students selected for the on-line survey were full time students at The Correspondence School. Although full time students at The Correspondence School are from a wide range of ethnic and socioeconomic status, the students who had the on-line capability would be biased against most of the at-risk students who did not have internet access. Overall the decile rating of TCS full time students (Ministry of Education, 2006c) and the students from the survey sample schools was similar; however, the on-line factor may have biased the sample towards students who are more educationally motivated. The classroom samples of students who completed the surveys would have been more diverse in terms of educational motivation and engagement.

- The Correspondence School cohort consisted of students in Years 9, 10 and 11. The survey was given to students in Years 8, 10 and 11. The Year 8 students would have less maturity and a year less of being taught science so their range of alternative conceptions may be greater.
- The Correspondence School cohort was a smaller overall sample than the survey sample. This would lead to a smaller range of alternative conceptions.

The range of alternative conceptions varied from question to question. The average number of types of alternative conceptions per student at each of the three year levels is shown in Table 5.7. This number was calculated by counting up the number of alternative conceptions selected by respondents and dividing by the number of active respondents. The active respondents are the total number of answered questions by respondents in the year group divided 52, the number of questions. This eliminated the unanswered questions so that they did not affect the final calculations.

The number of **types** of alternative conceptions per student equals the total number of **types** of incorrect alternatives divided by the active respondent number (N). Types of alternative conceptions per student for each year group are shown in Table 5.7.

Table 5.7
Mean number of active respondents and types of alternative conceptions per student

Year level	Active respondent number[1]	Mean No of types of alternative conception per student	Mean No of alternative conceptions per student
9	13.7	13.6	25.6
10	15.6	8.5	13.7
11	14.7	7.0	11.0

[1]Number of questions answered by cohort divided by 52

As shown in Table 5.7 there is a decrease in the number of types of alternative conceptions from Year 9 to Year 11 students, although the most significant change is from Year 9 to Year 10.

The mean number of alternative conceptions per student was calculated for each year level. Mean number of alternative conceptions per student equals total number of incorrect alternatives divided by the active respondent number (N). The mean numbers of alternative conceptions per student for each year group are shown in Table 5.7. The number and range of alternative conceptions decreased from Year 9 to Year 11 students. The general decrease in number of alternative conceptions from Year 9 to Year 11 would be for a number of reasons such as variations in:

- Content and concepts coverage and opportunities for revisiting of basic concepts.
- The maturity factor resulting from a longer time in science learning programmes.
- Curriculum coverage and level of understanding by students will have differed according to age and stage.
- Literacy and numeracy levels required to interpret the questions.
- Degree of difficulty of questions, even within a level, due to varying levels of conceptual development required to understand them.

Individual Responses in the comment Space

The comment space provided useful feedback about alternative conceptions that the respondents may hold which differed from the alternatives provided in the second tier of the item. Respondents could also write about their belief systems that precluded acceptance of the scientific idea. Examples of this arose in Item 51 on whether the observed expanding universe supported the big bang theory for the origin of the universe. The item was more to do with evidence to support a scientific theory but the belief systems of several respondents over-rode the point of the item and several respondents went into some detail on these issues. One Year 11 respondent wrote:

> Unlike (4) a nonliving thing or space (as in the universe) cannot expand of itself, for example, a mountain cannot increase in size without external forces such as an earthquake or plate movement. Of course, living things grow, but i don' t agree with the theory that the universe is an intelligient being with growth and a will. I also don't believe in the Big Bang theory so (1) doesn't apply for me. I believe that at the beginning of time in the universe, God created the heavens, the stars, the milky way, planets, moons and our own earth, God has a brain with wisdom and knowledge beyond our imagination, far beyond that of the mind of what scientists say the universe has. (2) says that the galaxies only appear to be moving, well if measurements say it's moving it probably is, although really, humans haven't been measuring the movements of stars for long enough (in comparison with what scientists say is the age of the earth etc) to know if the galaxies movements are real or not. (3) i don't agree with either, because of Genesis 1:1.. "in the beginning, God created the heavens and the earth", there WAS a beginning of the universe, but there is no beginning of God, He is the only infinite being , the universe is finite, for an example just look at a star that blows up, it's not infinite, it just has a very long "life" ! (Respondent 35)

Other remarks of this type for this item included:

> I believe that God created the world … not that it exploded from some point in space! (Respondent 39)
>
> There was no “Big bang” and the galaxies were put there on purpose so they can’t be moving apart. (Respondent 42)

The notion that the universe is infinite was expressed by a Year 9 respondent:

> The universe has no end (if it did what’s beyond that?). (Respondent 2)

New alternative conceptions held by some students were written in the comment space. An example of this arose in Item 6 on the main process by which washing dries on a washing line. One Year 11 respondent wrote:

> The washing dries because of a combination of gravity drawing water out of the clothes and the sun's heat energy evaporating the water. Another possibility is diffusion of water from an area of high concentration (in the wet clothes) to an area of low concentration (the air). (Respondent 35)

This student obviously had a good understanding of two processes involved in the drying of washing, and introduced the idea of diffusion, but may indicate a misunderstanding relating to the physical state of the water during diffusion that could be investigated by further teacher-student dialogue.

Some respondents gave additional reasons for their selected alternative based on personal knowledge. Item 3 gave evidence in the stem indicating that left or right handedness is inherited rather than non-inherited. One Year 11 respondent selected the non-inherited option and wrote:

> It’s usually said that the hand being sucked on before birth is the preferred hand. (Respondent 38)

This respondent obviously had an interpretation of an observed phenomenon and inferred that this indicated that left or right handedness is non-inherited. This belief or prior knowledge over-rode the evidence given in the stem of the question. Another example of a Year 9 respondent using personal experience to highlight another factor not mentioned in Item 10 on the relative advantages of tin cans or plastic for food packaging:

> Plastics go into food. (Respondent 2)

Plastics can taint the flavour of foods, a factor that needs to be considered in a review of this item.

In some items, respondents made additional comments to support the selection of the scientifically correct answer they had made. In Item 8 a Year 11 respondent made explicit an understanding of the involvement of infrared radiation in a TV remote device:

> Usually infrared is used in those sorts of things. (Respondent 38)

Similarly in Item 29 the same respondent showed an understanding of acid-base chemistry:

> Soda is a base, citric acid is an acid. (Respondent 38)

In Item 32 on why earthquakes occur more often in New Zealand than in Australia a Year 9 respondent supported the scientifically correct answer that New Zealand has more earthquakes because it is near the tectonic plate boundaries of the Pacific and Indo-Australian plates by mentioning a family visit to Taupo Volcanic Activity Activity Centre where this concept was learned from an interactive display.

> Our family visited a geology centre in Taupo where a display showed this. (Respondent 10)

There were a few examples of respondents supporting the scientifically correct choice of answer with a remark indicating an understanding of general principles but erroneous specific knowledge. In Item 8 a Year 9 respondent understood that a TV remote used some form of light but assumed that it was a laser beam:

> It uses a laser beam which is a form of light. (Respondent 10)

Some remarks indicated a lack of conceptual understanding at the level required. In Item 8, one Year 9 respondent understood that there are different types of atoms but did not understand the numerical relationship between protons and electrons

> There are different types of atoms (shapes). (Respondent 2)

Remarks in the comment spaces enabled respondents to explain their thinking and reveal issues relating to question difficulty. Some of these comments also gave indications of possible lack of clarity or ambiguity with the question that could lead to further refinement of the items. With Item 23 a year 9 respondent was confused with the second tier alternatives:

> I don't know this could be all the answers. (Respondent 2)

A number of comments in the comment space were indicators of degree of difficulty which could have been due to issues such as depth of understanding, literacy or numeracy and interpretation or coverage. Comments of this kind included:

> I don't know how to read a weather map.
> I do not understand the picture.
> I don't understand this.
> I haven't covered this.
> I don't know, I haven't read about this.
> I have no idea.

Identification of the curriculum level at which the students are working

Analysis of the total scientifically correct responses by each student is recorded on the spreadsheet in Appendix N. The totals are recorded by section of the instrument, year level, by question and the grand total for each respondent.

The average percentages of scientifically correct responses provided by students in each section are shown in Table 5.8. A full list of percentage correct responses by student in each section is presented in Appendix N. The general trends were:

- Increases in the percentage of correct responses from Year 9 to Year 11 in each curriculum level sections of the instrument. These increases match the trend in decrease in the type and number of alternative conceptions from Year 9 to Year 11 overall.
- Decreases in the percentage of correct responses in the Curriculum Level 4 section to the Curriculum Level 6 section for Years 9 and 10 indicated that the concepts got more difficult at higher curriculum levels.
- The Year 11 group did not follow this trend in the Curriculum Level 4 section where the mean score was lower than for the Curriculum Level 5 and 6

sections. This was due, in part, to two items, 9 and 15, with alternative conceptions predominating in all three year groups.

Table 5.8
Mean percentages scientifically correct responses by year group in each section

	Section of Instrument/Curriculum Level		
Year Level	**4**	**5**	**6**
9	58.3	41.9	32.6
10	72.1	60.6	54.5
11	75.1	81	77.1

The curriculum level at which the student is working was ascertained as follows. When a respondent scored over 50% for the items set for a given level on the on-line instrument, that respondent was deemed to be working at that level. For example, if a respondent scored over 50% for the Level 4 items in the instrument, but 50% or below for the Level 5 and Level 6 items, then that respondent was working at Curriculum Level 4. On this basis, the curriculum level at which each respondent was working was determined for all respondents. The results are shown on Table 5.9.

There is clearly a high correlation between the curriculum level the student is working at as determined by the instrument and the curriculum level of the actual programme in which the student had been enrolled. Since the allocation of appropriate programmes was based on diagnostic data and ongoing monitoring of performance, this result indicated that the instrument had the potential as a diagnostic indicator in the discernment process for appropriate science programme allocation and personalization.

Table 5.9
Curriculum level ascertained from the instrument compared with of curriculum level of the student's programme

Year Level	Curriculum Level Range	Mean Curriculum Level	Curriculum Level of programme
Year 9	3 to 6	4.3	4-5
Year 10	4 to 6	5.3	5-6
Year 11	5 to 6	5.9	6

Marking of the student responses was done automatically and the scientifically correct responses were recorded on a spreadsheet table and second spreadsheet was set up to record the number of correct responses in each strand. This procedure led to the generation of a table like the example for a student shown in Table 5.10. **The student selected was a Year 10 student with an overall score (57.7%) close to the mean for this age group.** From these data it was possible to ascertain quickly if the student showed an academic weakness in particular strands of the curriculum.

Table 5.10
Number of scientifically correct answers by curriculum strand and level

	LW[1]			MW[2]			PEB[3]			PW[4]			Total
CL[5]	4	5	6	4	5	6	4	5	6	4	5	6	
Number correct	4	3	2	2	1	1	4	3	3	4	2	1	30
Number attempted	4	4	5	4	6	4	4	4	4	4	5	4	52
Total items in strand	4	4	5	4	6	4	4	4	4	4	5	4	52

[1] Living World strand
[2] Material World strand
[3] Planet Earth and Beyond strand
[4] Physical World strand
[5] Curriculum Level (4, 5 or 6)

In the example shown it can be seen that this student was stronger in the Living World and Planet Earth and Beyond strands, working at Curriculum Level 4 to 5, but in the Physical World and Material World strands at the lower, Curriculum Level 3 to 4. Data like those in Table 5.11 therefore gave an indication of the curriculum level at which a student is working within each strand of the curriculum.

Level of difficulty of the items

The percentage of correct answers for each of the 52 items (Appendix O) varied within curriculum level sections. The mean percentages, and range of percentages, of correct answers for the items of the instrument by curriculum level section are shown in Table 5.11. The mean percentages of correct answers in each section decreased from the curriculum level 4 section to the curriculum 6 section, indicating an increase in difficulty with increasing curriculum level.

The hardest item in the curriculum level 4 section was Item 15 with only 17% of respondents selecting the scientifically correct answer. Most respondents, as discussed earlier in this chapter, related the apparent movements of the Sun and the Moon across the sky during the day-night cycle as being due to Earth's orbiting the Sun and the Moon orbiting Earth rather than due to Earth's rotation. This item was an outlier for this section being the next most difficult item at 51 percent correct. The wording of the item may have confused the students. Research by Dunlop (2000) and Crooks (2003) has shown that students do much better with the concept of Earth's rotation if provided with a globe and a torch than if presented with a question in written form.

The curriculum level 5 section had the lowest range of percentages of correct answers even with more items (20 as opposed to 16 in each of the other two sections). The hardest item in this section, Item 23, dealt with alternative conceptions relating to falling objects with 30 percent of respondents returning correct answers. The concept of constant acceleration due to gravity is so counter-intuitive to most students and even when demonstrated clearly it is confused by the effect of air resistance on the rate of falling of light objects.

The hardest item in the instrument overall was Item 48 in the curriculum level 6 section on sacrificial protection of iron by zinc in galvanized steel. Only 9 percent of students selected the correct answer with this item. The difficulty with this item is probably due to the sequence of Curriculum Level 6 concepts and propositions that need to be understood in order to understand the sacrificial protection at the level of electron movements. This item was also an outlier with the next most difficult item in this section in which 40 percent of respondents selected the scientifically correct answer.

Table 5.11
Mean percentages and range of percentages of correct answers for the items of the instrument by curriculum level section

Curriculum level section of instrument	Range of percentages	Mean percentage from 52 respondents
Level 4	17 to 96	68.3
Level 5	30 to 91	60.7
Level 6	9 to 79	54.2

The level of difficulty of items is the result of a complex set of variables including the variation of the difficulty of concepts and propositions that underpin the relevant curriculum objectives, the effectiveness of science teaching programmes, the wording and design of the items and the conceptual level of the students undergoing the assessment.

Indices of difficulty and discrimination

The index of difficulty is the proportion of the total group who gave a scientifically incorrect answer for an item. The index of difficulty was calculated for each item of the instrument as the percentage of the total group who gave incorrect answers. Thus a high index indicates a difficult item and a low index an easy item. The indices of difficulty were recorded on Tables 5.12-5.14.

The index of discrimination is the degree to which an item discriminates between high achieving students and low achieving students. The instrument was not intended to have a normative function although an intended function of this instrument was to ascertain the conceptual level at which students are working. The index of discrimination has validity in relation to this function. The index of discrimination for each item was calculated using the system used by Scoring office, Michigan State University (2007). The scores of the respondents were listed in in order from high to low. The group of students who completed the instrument was divided into upper, middle and lower groups on the basis of their scores in the instrument. Optimal item discrimination is obtained when the upper and lower groups each contain 27% of the total group. The upper 27% was the top 13 respondents and the lower 27% was the bottom 13 respondents. The middle group consisted of 21 respondents. The index of discrimination is the difference between the proportion of the upper group and proportion of the lower group who gave scientifically correct answers. For each item of the instrument the percentage of scientifically correct answers was calculated for the upper group and lower groups. The index of discrimination for each item was calculated by subtracting the percentage of correct answers in the lower group from the percentage of correct answers in the upper group. The index of discrimination is dependent on the difficulty of an item and may reach a maximum of 100 for an item with an index of difficulty of 50, i.e. when 100% of the upper group and none of the lower group answer an item correctly.

The maximum discrimination value is the highest possible index of discrimination for an item of a given level of difficulty. Maximum discrimination for each item was determined by adding the percentage of correct answers of the upper and lower groups together. If this figure came to more than 100% the total was subtracted from 200 to obtain the maximum discrimination.

Discriminating efficiency is the ratio of the actual discrimination (discrimination index) to the possible discrimination (maximum discrimination). Discrimination efficiency is obtained by dividing the index of discrimination by the maximum discrimination. Discriminating efficiency was calculated for each item of the instrument.

The index of discrimination, maximum discrimination and discriminating efficiency were recorded for each item of the instrument on Tables 5.12-5.14. The means for index of difficulty, index of discrimination, maximum discrimination and discriminating efficiency were calculated for each of the curriculum level section of the instrument and recorded on table 5.15.

Table 5.12
Indices of difficulty and discrimination for items in instrument Level 4 section

Item	[1]PR - upper	[1]PR - lower	[2]IDif	[3]IDisc	[4]MDisc	[5]DiscE
1	92	85	15	7	53	13
2	100	85	9	15	15	100
3	77	8	49	69	85	81
4	77	54	30	23	69	33
5	77	38	40	39	85	46
6	92	69	21	23	39	59
7	77	85	13	-8	38	21
8	100	38	36	62	62	100
9	77	31	47	46	92	50
10	85	38	38	47	77	61
11	77	46	30	31	77	40
12	77	23	49	44	100	44
13	100	77	6	23	23	100
14	77	38	38	39	85	46
15	15	23	83	-8	38	21
16	100	92	4	8	8	100

[1]PR = Proportion right [2]IDif = Index of difficulty
[3]IDisc = Index of discrimination [4]MDisc = Maximum discrimination
[5]DiscE = Discrimination efficiency

Table 5.13
Indices of difficulty and discrimination for items in instrument Level 5 section

Item	[1]PR- upper	[1]PR - lower	[2]IDif	[3]IDisc	[4]MDisc	[5]DiscE
17	100	62	7	38	38	100
18	62	77	30	-15	61	25
19	85	46	49	39	69	57
20	92	46	26	46	62	74
21	85	15	55	70	100	70
22	85	38	43	47	77	61
23	62	15	70	47	77	61
24	77	23	49	54	100	54
25	85	38	30	47	77	61
26	85	31	45	54	84	64
27	77	15	51	62	92	67
28	62	8	68	54	70	77
29	100	31	38	69	69	100
30	77	8	66	69	85	81
31	85	31	43	54	84	64
32	100	69	9	31	31	100
33	100	38	32	62	62	100
34	100	62	21	38	38	100
35	92	38	36	54	70	77
36	92	85	9	7	23	30

[1]PR = Proportion right [2]IDif = Index of difficulty
[3]IDisc = Index of discrimination [4]MDisc = Maximum discrimination
[5]DiscE = Discrimination efficiency

Table 5.14
Indices of difficulty and discrimination for items in instrument Level 6 section

Item	[1]PR - upper	[1]PR - lower	[2]IDif	[3]IDisc	[4]MDisc	[5]DiscE
37	85	38	32	47	77	61
38	77	8	60	69	85	81
39	85	15	51	70	100	70
40	92	31	38	61	77	79
41	100	8	45	92	92	100
42	77	46	40	31	77	40
43	77	23	7	54	100	54
44	100	38	23	62	62	100
45	92	23	40	69	85	81
46	77	23	57	54	100	54
47	85	15	49	70	100	70
48	8	8	91	0	16	0
49	100	69	21	31	31	100
50	69	23	47	46	92	50
51	62	15	60	47	77	61
52	85	46	32	39	69	57

[1]PR = Proportion right [2]IDif = Index of difficulty
[3]IDisc = Index of discrimination [4]MDisc = Maximum discrimination
[5]DiscE = Discrimination efficiency

The index of discrimination was negative for three items, 7, 15 and 18. This indicates that a greater proportion of upper group than of the lower group selected an incorrect option. Item 48 had a discrimination index of zero indicating that an equal number of the upper and lower groups selected an incorrect option. This suggests ambiguity in these items which is undesirable and indicates that they need to be reviewed. Item 48 had the highest index of difficulty. The low index of discrimination for this item may have been due to the small number of students in the upper and lower groups obtaining the correct answer by chance. The higher the index of discrimination the more effective the item is for discrimination between high and low achieving students. The mean index of discrimination increased from the curriculum level 4 section of the instrument to the curriculum level 6 section indicating that discrimination increased as the items required higher levels of conceptual understanding (Table 5.15).

The discriminating efficiency was 100 for 11 items. This occurs when the index of discrimination is the same as the maximum discrimination and the item discriminates at full potential for an item of its difficulty. Most items in the instrument had a discriminating efficiency of 50 or more. The mean discriminating efficiency was highest for the items in the curriculum level 5 section of the instrument (Table 5.15).

Table 5.15
Means for Index of Difficulty, Index of Discrimination, Maximum Discrimination and Discrimination Efficiency for Each Curriculum Section of the Instrument

Curriculum level of section	Mean ²IDif	Mean ³IDisc	Mean ⁴MDisc	Mean ⁵DiscE
4	31.8	28.8	59.1	51.9
5	38.9	46.4	68.5	68.7
6	39.9	52.6	77.5	66.1

[2]IDif = Index of difficulty
[3]IDisc = Index of discrimination
[4]MDisc = Maximum discrimination
[5]DiscE = Discrimination efficiency

The items of this on-line diagnostic instrument were designed to ascertain the curriculum level at which students are functioning and to diagnose alternative science conceptions to inform the next steps in the teaching-learning process.

Item analysis that provides a record of student response is useful for indicating possible ambiguity in some items in this type of diagnostic instrument. It provides little information about the appropriateness of an item for a programme of learning. The appropriateness or content validity of an item must be determined by comparing the content of the item with the course objectives.

Chapter summary

Analysis of student responses to the on-line instrument was carried out as follows:

- The student responses were recorded on a spreadsheet and the percentage of each type of response was calculated. There was a general trend of increase in the percentage of students who selected scientifically correct answer from year level nine to eleven.
- The significant alternative conceptions that were identified by the on-line instrument were recorded on a table and classified according to type. The on-line diagnostic instrument identified was 81% of the number of alternative conceptions identified by the open ended surveys.

- Analysis was done on the range of type and number of alternative conceptions by respondent year level and the number of alternative conceptions decreased from Year level 9 to 11.
- Analysis of the comments in the answer spaces showed that respondents used this to explain their thinking and reveal issues relating to question difficulty and possible lack of clarity or ambiguity with the questions.
- Analysis of students' percentage of correct answers showed close correlation between the curriculum level at which students were working as determined by the on-line instrument and the curriculum level of the student programme determined by internal programme discernment processes.
- Analysis of the percentage of scientifically correct answers given by the cohort of students was used to ascertain the degree of difficulty of the questions. The mean percentage of correct answers in each section showed that, generally, the questions got harder from the curriculum level 4 section to the curriculum level 6 section.
- Indices of difficulty and discrimination for each item of the instrument. Both of these indices increased from the curriculum level 4 section of the instrument to the curriculum level 6 section. The mean discriminating efficiency was highest for the curriculum level 5 section.

Chapter 6 discusses the main findings of the various studies carried out by the author and addresses a number of recommendations and implications for flexible use of two-tier on-line items for formative assessment and improving science conceptual understanding in the 21st century learning environment.

Chapter 6

Summary, Conclusions and Recommendations

Overview of chapter

The first part of Chapter 6 summarises findings in relation to the efficacy of the on-line two-tier diagnostic instrument as an effective and economical rapid response tool for diagnosis of student alternative conceptions in science and for ascertaining where students are academically relative to the targets of the science curriculum levels. The second part of the chapter discusses the limitations, recommendations and future developments of the instrument for student formative assessment to enhance learning in science. The final part of the chapter discusses the potential of the on-line instrument to provide the 21st century learner with formative self-assessment opportunities to enhance personalized self-directed science programmes.

Introduction

The constructivist theory of learning views learners as actively engaged in making meaning. The teacher needs to provide a learning environment in which students can analyse, investigate, collaborate, share, construct their understanding by reflecting on what they already know. Students come to class with an established world-view that has been formed by years of prior experience and learning. This word-view filters all experiences and affects their interpretation of observations. For students to change their world-view work is required by both the teacher and the student (Cobern, 1996). The teacher needs to be a learner and a researcher who strives for greater awareness of the perspectives of the learners and their world-views. The teachers, as facilitators, need to continually adjust their actions in order to engage students in meaningful learning. Part of the process of facilitating student learning, using constructivism as a referent (Tobin & Tippins, 1993) involves ascertaining students' alternative conceptions. In this thesis, the author has shown that a two-tier diagnostic instrument can be developed in an on-line environment and used as an economical and effective tool for identification of student alternative conceptions in science. The instrument can be used at the macro level of discernment to inform programme design and development. It can also be used at the micro level of formative diagnosis whereby identified alternative conceptions can be used to inform the next steps in teaching for scientific conceptual growth and change.

Efficacy of instrument for diagnosing learning needs

The author researched many diagnostic science assessment instruments. Most focused on specific science topics. Many were in a multi-choice format and a small proportion of these used the two-tier multi-choice format. The only on-line instrument for assessing a broad range of science conceptions using a two-tier format was a 47 item Science Belief Test developed by Larrabee et al. (2006). This instrument did not use a multi-choice format in the second tier, but students made written responses to support their true/false response to the first tier.

The instrument developed by the author assessed a broad range of science conceptions using a two-tier multi-choice format in an on-line environment. Students who had alternative conceptions, not included in the distracters, were able to express these in the comment box at the end of each question. The instrument identified alternative conceptions held by students at all levels and against concepts that underpin all objectives in *Science in the New Zealand Curriculum* from Levels 4 to 6.

The responses of the students in the cohort who completed the questions of the instrument could be marked and processed quickly and recorded on a master spreadsheet. The curriculum levels identified from this spreadsheet were analysed by comparing them with the curriculum levels identified on the basis of diagnostic and formative processes that occurred in the learning DnA pedagogy described in Chapter 1. There was close agreement between the curriculum levels ascertained by the on-line instrument and the curriculum level for which the student programmes were designed. This high degree of correlation indicated that the two-tier diagnostic instrument was reliable for discerning the science curriculum level at which the student was working and achieving. Use of associated spreadsheet summary charts enabled the curriculum level within each contextual strand to be ascertained also. Thus, weaknesses could be identified rapidly so that appropriate reusable learning objects or synchronous interaction could be incorporated into the personalized learning programme for the student. Such information is of value to the teacher for programme design and development (Treagust, 2006).

The instrument also identified a large number and range of alternative conceptions held by the cohort of students investigated. Because the distracters in each question were grounded in evidence based on alternative conceptions held by students in the age ranges investigated, the items pin-pointed alternative conceptions that have the potential to act as barriers to further science learning. The two-tier approach probes deeper levels of student thinking and provides a mechanism for determining students' underlying ideas. A summary of alternative conceptions diagnosed through the instrument is given in Table 5.4 in Chapter 5.

The research showed that an on-line instrument of this kind provides reliable evidence to inform the design and development of personalized student science programmes, and to inform the next steps in the learning process for correcting alternative conceptions. This was demonstrated by the identification of 81% of number of alternative conceptions identified with open ended surveys and the high correlation of the determination of science conceptual development level with the level of personalized science programme the student was enrolled in.

The on-line functionality made the instrument a powerful tool for rapid response by students and rapid processing by the teacher. The two-tier format lent itself well to the on-line version of the instrument and the items within it. The electronic processing of student responses enabled rapid feedback to the students. The economy in time and energy to provide formative feedback, feed-forward and next steps in the teaching–learning process was of obvious benefit to both students and teachers, particularly in the distance education environment. Research on formative assessment (Black & Wiliam, 1998) has shown that it has one of the highest effect sizes, of any learning intervention, on improving student achievement. However formative assessment can be time consuming for teachers.

> Teachers at all levels often face heavy workloads and large class sizes, under such circumstances it may be a challenge to expect them to enter into learning-centred dialogues

> with individual students. When teachers are overloaded with a number of duties and responsibilities, they may perceive formative assessment as something of a luxury ………formative assessment and good teaching are inextricable, so for teachers/lecturers to say they have no time for it would be tantamount to saying that they don't have time to teach effectively. (Carless, 2003 p. 6)

The instrument thus provides an effective formative tool for the busy teacher to enhance the student learning process and resulting understanding of science.

Conclusions

The on-line instrument offers a flexible and economical way of ascertaining student alternative conceptions for a wide range of scientific concepts. The instrument can be accessed from the website from any computer, with internet access, so that respondents may complete it from any time or place that is convenient for them without having to travel to a specific location at a particular time. Students receive immediate feedback on their results at the conclusion of the survey. Students who have grown up with computers, 'digital natives' (Prensky, 2001a, 2001b, 2005), may feel more comfortable with selecting responses in an on-line format than working with pencil and paper. The collected data can be more easily analyzed because it is returned in a form that allows easy transfer on to spreadsheets for processing. Savings are also made in the processes of having to print off surveys and, in the distance learning environment, there are savings in packaging, distribution and collection. Students are also freed up from having to put the survey in an envelope and post it back to the organization.

The instrument has recently been reformatted into more economical units – the three levels, so that students may elect to respond to the instrument at one, two or all three levels. Items also have been used in diagnostics compiled by other teachers and in student self-assessed reusable learning objects. Items from the instrument have been incorporated into on-line diagnostic instruments compiled by other teachers for the purposes of course specific on-line discernment instruments that provide instant feedback to students with explanations about why particular alternative conceptions conflict with accepted scientific understanding. This information provides opportunities for the distance learner to be confronted with conceptual conflict and paves the way for the next steps in the process for the learner and the teacher to facilitate conceptual change so that deeper learning can proceed.

The on-line science diagnostic instrument has the potential for the following actions:

- Ascertain the science curriculum level at which students are working, that is identify where students are academically relative to the targets of curriculum levels.
- Design and develop individual science learning pathways by identifying strengths and weaknesses of a student's individual performances.
- Design and develop group learning pathways by identifying the strengths and weaknesses of students' group performances.
- Implement the next teaching step in the science learning programme.
- Measure value-added in terms of how students are performing academically compared to earlier reports.

Limitations of study and recommendations

In considering the limitations of this research teaching context needs to be taken into account. There is a need, as with any diagnostic assessment instrument, to consider contextual error when considering the accuracy and efficacy of the instrument. Also in considering further development of the instrument multiple contexts need to be taken into account. Student background has a significant bearing on the validity of the responses they provide therefore cultural and linguistic factors need to be considered when diagnostic assessment instruments are used with multicultural cohorts of students. These issues are discussed in this section.

In most instances this instrument used one question to identify alternative conceptions underpinning each curriculum objective. The instrument was designed for Year 9 to 11 students on distance learning programmes at The Correspondence School. Other New Zealand Schools would require modifications to this instrument because of variations in specific content and context for teaching to the science curriculum objectives in their science learning programmes.

Contextual error can play a significant role in the accuracy of the diagnosis of specific alternative conceptions. Research has shown that students' responses to diagnostic questions are often context specific and that inconsistencies are shown in the way that students apply their personal understandings to the same concept expressed in different contexts. Thus, one particular context-specific question may not give a reliable indication of a student's conceptions of the topic in a broader sense (Dunlop, 2000; Millar & Hames, 2001b; Palmer, 1998). Rephrasing of a question, or the use of graphics in an on-line context, may result in a different response by students in relation to their understanding of a particular concept (Dancy & Beicher, 2006; Tasker & Dalton, 2006). A student could answer one particular question regarding motion in such a way as to indicate the presence of alternative conceptions but if the question was rephrased into a different context, the student could respond completely differently. As a result, the response of a student to one particular question may be very context-specific and may not give a reliable indication of that student's conceptions of the topic in a broader sense.

Consequently, multiple contexts need to be developed in item range in order to pin-point alternative conceptions with greater accuracy. Use of simulations and animations in items in the on-line environment would help with this (Crooks, 2006; Dunlop, 2000). For this reason, it is necessary for a bank of questions to be built up by an iterative process so that each concept can be tested by several questions. Such questions can then be used in pairs or groups so that student responses can be subjected to accuracy analysis by correlation. This procedure would lead to the development of a bank of science diagnostic items that have been rigorously tested to ensure internal reliability and validity of any instrument developed from them.

Ethnic, cultural, home language factors can have a significant effect on students' world-views and as a consequence have an influence on how students respond to science assessment items (Gonzáles-Espada, 2004; Nuthall, 2005; Tobin, 2007).

> Academic assessments are themselves cultural products associated with a particular cultural tradition, though the cultural basis of assessment practices often goes unrecognised. (Luyke et al, 2007 p. 5)

This issue is an important consideration with New Zealand's increasingly multicultural student population especially for Maori and Pasifika students (Waiti & Hipkins, 2002). Cultural validity needs to be addressed through processes to eliminate cultural bias in questions. Designing culturally neutral instruments and items within it is a complex issue with regard to formatting, wording, context, visual cues and textual organisation.

The National Education monitoring project (NEMP) uses strategies for assessing science in everyday contexts as an organising theme (University of Otago, 2003). Unlike the pencil and paper focus of the Third International Mathematics and Science study (TIMSS) testing (Ministry of Education 2001), NEMP consists of many oral and practical tasks. Within this different framework, NEMP results have shown an improvement in the performance of Maori students across two testing cycles (Flockton & Crooks, 2000). With an on-line assessment instrument simulations of practical activities from real-world contexts can be designed. Also a multimedia facility for use of sound, colour, animation may help overcome issues of decoding that students who are not from the mainstream culture have with diagrams, graphs and tables (Luyke et al, 2007).

For students from non-English-language backgrounds, home language influences, combined with limited English proficiency, may interfere with their ability to interpret test items correctly. With a multi-choice instrument, where students select the most appropriate answer to reflect their thinking, phonographic and orthographic issues are less significant since the students are only using language to write their own responses if they choose to make a remark in the comments space. Semantic differences can be significant particularly with the polysemic nature of many science terms used. Words that have a specialised and precise scientific meaning, different from the everyday meanings of the word as used in causal or informal language (Clarkson, 2007; Klein, 2006) lead to misunderstandings with many students. Examples of such words are work, power, gas, animal, fish, bug fruit, chemical, state, element, salt and theory. One further example identified in this research was the word 'environmental' in the context of non-inherited rather than the ecological context. This led to this word being changed to 'non-inherited' in Item 3 of the on-line instrument. These linguistic issues related to the polysemic nature of science occur with native English speakers as well as second language English speakers. The translation of the scientific terms into the student's home language can also cause misunderstandings (Yen, Yao & Mintzes. 2007). An example of this was provided by a speaker at the The Second International Conference on Science Education 2007. When the speaker was teaching the rules of magnetic attraction and repulsion he used the expression 'like poles repel' to a multicultural class in which there were 13 home languages. Some students, whose home language was French, translated the word 'like' to the French 'aimer', meaning 'to like', as in 'to be fond of' rather than meaning 'similar'. These students had difficulty making sense of poles liking each other yet repelling! The teacher resolved the issue by stating that similar poles repel (Essien, 2007).

Designing culturally neutral test items is bound up with the science learning environment and pedagogical approach. Three main approaches are advocated by different researchers. The cross-cultural perspective (Snively & Corsiglia, 2001) is where science in the school curriculum is broadened to include traditional ecological knowledge. The multicultural perspective (Stanley & Brickhouse, 2001) is where students learn about different ways to think what science is and how it works. The pluralist perspective (Cobern & Loving, 2001) is where science is taught separately but alongside other world views. The debate about these three models continues in New Zealand in an effort to increase the participation and achievement of Maori and Pasifika students in science (Waiti & Hipkins, 2002).

Future developments

Two-tier diagnostic instruments are a valid way of ascertaining student alternative conceptions in science. They can also give a reliable indication of the conceptual level at which students are operating academically in relation to curriculum levels in the New Zealand Science curriculum statement. The items developed in this research provide the beginning of a resource bank of items that could be used in a similar way to the items in the asTTle tests for reading, writing and mathematics (Ministry of Education, 2003b). A much larger bank of two-tier multi-choice items designated by level, strand and objective would allow for surveys to be created according to the curriculum coverage of individual students or cohorts of students.

However, the building of such a bank would take time to do because of the processes that need to be performed in order to produce items that contain valid distracters that represent the common alternative conceptions held by students at a particular stage and level. Once created and put into an electronic format to enable a teacher to select for level, strand and content, the survey can be implemented and analysed quickly to provide quality formative feedback to the teacher to enable him/her to adapt the student learning programme to address identified alternative conceptions. It would also be possible for teachers to implement pre- and post teaching surveys in order to measure the value added by their teaching (Millar & Hames, 2002, 2003). This survey could be done pre and post topic or from year to year with a cohort of students in order to measure progress over set periods of time. The two-tier diagnostic items also can be used individually for students in order to ascertain alternative conceptions in relation to a particular curriculum objective and also to get an indication of their level of thinking in terms of the SOLO taxonomy (Biggs, 1999, Biggs & Collis, 1982). The set up of a resource bank of this kind using single tier multi-choice items for mathematics and science was described by Ciofalo and Wylie in 2006.

> We are working with a group of teachers to construct a bank of 50 to 100 multiple-choice items for 4th and 8th grade mathematics and science. Each item is connected to a particular content standard or objective, and at least one or more of the incorrect answers are related to alternative conceptions that students often have regarding that particular learning goal….
> The expectation is that teachers will use one item at a time, within the flow of day-to-day lessons. Teachers will be able to search through the database of items to identify one or two that are relevant to a particular instructional topic they will be focusing on in an upcoming lesson. (Ciofalo & Wylie, 2006 p. 2)

Two-tier items in this on-line diagnostic instrument have the potential to be used individually or in content and contextually related groups so that they can be used as part of a formative process for identification of science alternative conceptions in a quick and economical way. This process would enable rapid intervention to take place so that the alternative conceptions can be challenged while the student is still engaged in the learning process of a particular topic (Millar & Hames, 2003). In the distance education environment, this procedure informs the selection of suitable reusable learning objects to bring about conceptual change where required during the course, thus addressing alternative conceptions at the time they may inhibit a learning process that builds on correct scientific understanding of basic propositions. There is also the potential for students to have access to on-line items at appropriate check points of their programme so that they can self-assess and self-diagnose. With students working in on-line learning communities in the distance education context, formative self-evaluation, together with discussion in a dynamic synchronous learning environment, would be a powerful tool to enable students to deal with potential stumbling blocks in a timely manner to enhance the learning process. The flexibility and efficiency of these items makes them valuable for the classroom teacher in the face-to-face teaching environment, and in the distance education environment, as discernment indicators from which the ongoing teaching-learning programme can be designed and developed, as in the learning DnA described in Chapter 1.

Formative assessment of this kind could be used by students to discern their own alternative conceptions and lead them to access appropriate reusable learning objects to progress their learning and understanding. Students learning in a digital learning environment in which they pursue learner-centred programmes at their own pace would benefit from such a facility and the extension of their locus of control with respect to their personalised learning programme. Extending the capabilities of the on-line environment would enable a multi-sensory approach using simulations that would make the questions more meaningful to many students for whom there have been issues with written formats (Flockton & Crooks, 2000; Schwartz & Heiser, 2006). Careful research and evidence-based design would be essential for development of such items. Once established, the item bank could be a powerful tool for providing diagnostic and formative evaluation for student learning. The Taiwan National Science Concept Learning Study is a large scale project in which two-tier tests were designed to identify science conceptions of students from large national samples. In this project pencil and paper tests were designed in a range of science topics resulting in a substantial bank of science two-tier diagnostic items (Treagust & Chandrasegran, 2007; Lee, 2007; Tsai, Chen, Chou & Lain, 2007; Yen, Yao & Mintzes, 2007).

Formative assessment with targeted feedback has been shown to make a significant difference to students' motivation to learn and to their deeper learning processes (Black & Wiliam, 1998; Sadler, 1988). On-line two-tier diagnostic survey items can serve both functions. Development of banks of these items would provide a resource from which age and stage appropriate surveys can be constructed to be used for science in much the same way the asTTle resource banks are currently used for reading, writing and numeracy. Items could be developed that use more sophisticated digital formats including animations, interactive reusable learning objects. This would improve the number and range of items that cover particular curriculum objectives, thus improving the internal validity of surveys compiled from them. Inclusion of items that cover a range of cultural perspectives would help to eliminate cultural bias. The range of items could also be extended to cover levels 4 to 8 in the science curriculum and the curricula of specialised science disciplines of physics, chemistry, biology at levels 6 to 8.

Diagnostic items are not only a teaching resource but could also be used for professional development purposes by contributing to teachers' pedagogical content knowledge. This knowledge connects content with teaching strategies, including multiple ways to present knowledge, and understanding of how novice learners might address a topic differently from experts (Settlage & Goldston, 2007). Items in a resource bank of two-tier diagnostic items for science learning would be a source of such information.

The 21st Century Learner

The pervasiveness of the internet and communications technology has resulted in the development of the knowledge society. The existence of this technology has led educators, politicians and industrialists to predict radical changes in the way that society functions at local, national and global levels. For education, the whole concept of what constitutes knowledge and how it functions is under discussion. Educational futurologists are grappling with how the education system must prepare students for life in the 21st century (Organisation for Economic Cooperation and Development, 2000). In New Zealand a group called Secondary Futures has been set up to look into this issue and, through a consultative process with the wider community, has come up with a vision of what education and learning will look like in 2026 (Secondary Futures, 2004).

Learning and curriculum development in the 21st century show a number of trends. A greater emphasis on generic skills, with a move away from separate disciplines within siloed departments, towards a team approach and connected communities of learners (Brown, 1999; Ellyard, 2005; Harpaz & Lefstein 2000; Harpaz 2005; Seaton, 2002). There is also a need to change the emphasis in secondary education away from discipline-based content towards systems level thinking and an integration of academic knowledge with applied knowledge (Hipkins, 2004; Gilbert, 2005). For example, Jane Gilbert in her book *Catching the Knowledge Wave* (2005) states:

> A school curriculum designed to prepare people for life in the knowledge society needs to help students see knowledge as a series of connected systems rather than a series of separate fields. Instead of understanding the detailed facts of science or history, students need to understand how science and history work as systems……..The facts of history or science still matter, as will knowing how scientists and historians work. Knowing these things will be important as an end goal, but because it develops understanding of science or history as systems. (p.156)

The New Zealand Schooling Strategy (Ministry of Education, 2004a) states the need for learners to develop generic competencies to foster life-long learning:

> Effective teaching supports students to take charge of their learning and become independent learners. It fosters student "learning to learn" and "thinking about thinking" (metacognitive) skills, as well as supporting student self-monitoring of their behaviour and progress. (p. 22)

The New Zealand Curriculum Stocktake consultative processes (2002b;) considered the current *New Zealand Curriculum Statement* and considered what changes needed to be made to enable it to prepare students for 2020. The result of these processes was the *Draft New Zealand Curriculum 2006*. This document showed an emphasis on a more generic approach expressed in a vision, key competencies and principles. The key competencies included statements on managing self, relating to others, participating and contributing, thinking and using language, symbols, and texts. The emphasis on higher thinking skills, ICT and community is significant:

> Thinking is about using creative, critical, metacognitive and reflective process to make sense of and question information, experiences, and ideas (p.11).
>
> They [students] use ICT confidently to overcome barriers to communication, access information and interact with others. (p.12)

The notion of lifelong learners in a connected world is expressed in the draft curriculum vision:

> Confident, connected (Able to relate to others. Effective users of communication tools), lifelong learners, actively involved. (p. 8)

The desirability for some cross-curricular focus is suggested in the section on designing the school curriculum:

> The knowledge skills and attitudes that students need for addressing real-life issues and in real-life contexts are seldom found within a single learning area. (p. 26)

The trend towards students becoming life long learners, the real-life relevance of education, student voice, community support and connectedness has led to the concept of personalised learning. Learner centredness has been extended beyond individual courses to encompass negotiated learning pathways through multiple providers and in all levels education, from early childhood to the end of secondary, with family and community support (Department for Education and Skills, 2004; Kedian, 2006; Ministry of Education, 2006b). The components of personalised learning have resulted from evidence of 'what works' from a large body of research in education both in New Zealand and overseas. Much of this research has been compiled by the New Zealand Ministry of Education in *Quality teaching for diverse students: Best evidence synthesis* (Ministry of Education, 2003a).

Where is science education in all of this? Barker, Hipkins and Bartholomew (2004) expressed the need for the New Zealand science education to resonate with the key competencies.

> We need, therefore, to create a space for competencies that students find meaningful and motivational while they are at school, and which reflect a view of science education that is appropriately expansive, socially integrated and future focussed. (p. 10)

Much of the science taught in schools has had two perspectives.

- A body of knowledge which reflects an objective reality that the student must seek to understand.
- A process of investigation and discovery that centres on the scientific method.

The changes in the educational needs for learners in the 21st century highlighted above change the emphasis from science as a body of knowledge to the way science works as a discipline (Gilbert, 2005). There needs to be a greater balance between science as a body of knowledge, science methodologies and the nature of science (McComas, 1996; Lederman & Abd-El-Khalick, 1998; Lederman, 1998). This should happen by placing a greater emphasis on the nature of science and scientific inquiry. Aspects of the nature of science that need to be explicit in the teaching of science according to Lederman et al. are:

- Tentativeness - Scientific ideas undergo change as new evidence comes to light.
- Creativity - Science involves creative processes such as forming theories.
- Subjectivity - There is a subjective element in all scientific thought.
- Observation versus Inference - Students must understand the difference between these processes.
- Functions and relationships of theory and law - Much science consists of models or theories which we use to help us to explain observations. Laws are observed relationships. Laws are often explained by theories, but theories do not become laws. Theories cannot be proved, they are simply supported by evidence.
- Social and Cultural Context - Scientific ideas are socially and culturally embedded.
- Empirically based - scientific knowledge is based on empirical observation and experiment.

Rudolph (2007) in an article *An inconvenient truth about science education*, discusses this issue with respect to the debate over global warming in the United

States whereby the public's oversimplified view of science, as an activity that is capable of producing verifiable knowledge by means of a prescribed experimental method. Those who seek to undermine public faith in much scientific work for political or economic gain often do so by highlighting the inherent uncertainties in this work.

> We need to help students understand the variety of methods and techniques that scientists use to explore the diverse phenomena in the world – that is, the process of knowledge construction as it's actually practiced (in all its localised instances) rather than the facile stereotype of some non-existent, singular scientific method. (Rudolph 2007, p. 2)

The focus centres around authentic inquiry experiences involving rich questions constructed by students (Edwards, 1997; Lederman, 1998; National Science Teachers Association, 2004). Students need to learn how to frame scientific questions and use evidence, scientific reasoning and critical thinking to answer them. In short, students need to learn how scientists study the natural world and develop a deeper understanding of scientific ideas. Expression of the need for a greater emphasis on scientific inquiry has led to some debate about the time such an approach takes away from learning content and the need for a balance between the two (Robinson, 2006/7). Some items in the on-line instrument contained elements of the nature of science and scientific inquiry (see for example items 41 and 51).

With this change in approach, care must be taken to ensure that students do gain a deeper understanding of scientific concepts in order to construct their understanding for scientific literacy in an ever more complex world. Essential to this is the process of constructing sound scientific understandings and the recognition that there is a logical, sequential process that needs to be scaffolded in the learning environment. This understanding will empower students to use science appropriately in their sense-making processes and hence in their decision-making processes, whether this is voting on a political issue, choosing the correct diet, making health-related decisions, or leading more environmentally friendly lifestyles. Part of the process for enabling students to achieve scientific literacy, and what we might term a functional level of understanding in a modern world, is to provide learning environments in which students' alternatives are challenged in a timely manner by diagnostic and formative processes built into the programme. These can be through teacher-based formative processes or student self-assessment and lead to appropriate next steps to challenge and change the alternative conception towards alignment with the scientific viewpoint. On-line two-tier diagnostic instruments can have an important role in this process. Because these instruments are evidence-based by their use of commonly held alternative conceptions in the distracters, they are able to pin-point and challenge a ranges of alternative conceptions held by students in all age groups or cover a variety of science concepts crossing a range of science disciplines that may be pertinent to a cross curricular project on a real world system. The two-tier structure allows the instrument to probe to deeper levels of student mental constructions of scientific concepts and processes than the conventional single tier multi-choice format. A bank of two-tier science diagnostic items would provide the flexibility for selection of items for timely formative use in a science learning programme or to measure value added when the student has completed a unit of work.

The changes to knowledge and learning in the 21st century outlined above will have implications for the way in which students effectively construct their understanding of scientific ideas. Science will need to be presented as part of students' real world experiences if they are to embrace it as a useful and relevant form of knowledge for transfer to diverse settings (Perkins, 1993).

> Science in conflict with student worldviews and common sense ideas should not be suppressed or declared wrong but reconnected and re-constructed. Science through science education needs to be joined with other school disciplines in the common goal of helping students develop a coherent view of knowledge which is more consistent with how knowledge is organised and used within one's worldview. (Cobern, 1996 p. 21)

Efforts to humanise science are to be applauded whether science is taught as part of an integrated programme or embedded in cross-curricular approaches or whether a greater emphasis is placed on the nature of science and the way science represents a valid view of real-life issues. It is important that understanding the main ideas of science is achieved without a loss of sequential construction as a result of excessive fragmentation. As shown in the concept maps and propositional knowledge statements in Appendices D and E respectively, there is a sequential nature to the construction of scientific understanding (see Chapter 3). If steps are missed in these sequential constructive processes, major misunderstandings can result. The notion that the 21st century digital native learns in a non-sequential way, 'just in time' rather than 'just in case', is also an issue with regard to construction of scientific understanding (Mitra, 2003; Prensky, 2001a, 2001b).

I remember one case when I was teaching a 6th Form biology class about how fish breathe. Just when it seemed that all students had understood that fish removed dissolved oxygen from the water passing through their gills, one very able student then said, "So fish must give off hydrogen?" When I enquired why she thought that, she said, "You said fish take oxygen out of the water." "Water is H_2O, so if the oxygen is taken out, that leaves hydrogen." The student had alternative conceptions about the difference between combined oxygen which was part of the water molecule, and dissolved oxygen molecules mixed in with water molecules. This alternative conception was the result of misunderstandings from science taught three years earlier, so that this student really had little understanding of what was happening at the molecular level of respiration in fish (or any other living thing). This alternative conception could have gone unnoticed unless an end of topic test on respiration contained an item specifically addressing this issue. In holistic, integrated or cross-curricular programmes, science learning outcomes will need to be mapped to objectives, and the concepts that underpin them, otherwise there is a risk that misunderstandings of this type could become more prevalent. A simple two-tier item designed around the concept of dissolved oxygen would identify misconceptions of this kind and the appropriate next steps could be implemented.

It is important that students gain an understanding of important science concepts to enable construction of scientific understanding to help them make sense of, and contribute to, their world in the 21st century. Effective, evidence based on-line diagnostic indicators, of the type developed for this research, provide tools to help with this goal.

Summary

- The on-line instrument provided a rapid response and economical diagnostic instrument for ascertaining the level of student conceptual development against New Zealand Science Curriculum Levels.
- The on-line two-tier diagnostic instrument can be used for ascertaining student alternative conceptions in relation to objectives in The New Zealand Science Curriculum as part of a formative evaluation process to inform the next steps in the teaching process.
- The instrument provided data that was useful as part of the discernment process for designing and developing personalised science learning programmes.
- The instrument has the potential to be used to ascertain 'value added' in terms of learning achievement resulting from engagement in personalised science programmes.
- The instrument provided evidence-based formative data enabling action to be taken to modify misunderstandings of scientific concepts essential for further learning in science.
- The items have the potential to be used singly or in groups by teachers. The instrument can be used as for formative assessment to provide data to inform the next steps to be taken to bring about conceptual change to deal with misunderstandings of scientific concepts that would act as a barrier for further learning in science.
- Students in self-assessment are provided with formative data to inform the next steps in their learning process.
- The instrument had limitations with internal reliability due to there being only one question per curriculum objective. This could be addressed by designing more items and by use of on-line simulations and animations.
- Further development would entail increasing the number of items for each curriculum objective and using items that are a-cultural or cover a range of cultural perspectives.
- An item bank developed from on-line two-tier items of the type used in the instrument has the potential to help students in the 21st century learning environment to understand scientific concepts.

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APPENDICES

Appendix A

Objective of study

The objective of this study was to produce and test an on-line two-tier diagnostic instrument that:

- can be used to ascertain student alternative conceptions of scientific concepts that underlie the objectives in the New Zealand Science Curriculum at Levels 4, 5 and 6.
- can be used to ascertain the science curriculum level at which a student is functioning in order to inform the design of a student's individual learning programme.
- can be used as a formative assessment instrument to inform teaching and learning.
- is in an on-line format and can be answered and transmitted electronically.
- is a useful and economical method of discerning student science learning needs in a distance education setting.
- forms the basis for a bank of items that can be used to generate diagnostic instruments to ascertain alternative conceptions in individual students or with cohorts of students.
- can be used by students for formative self-assessment.

Appendix B

New Zealand Science Curriculum aims and Level 4, 5 and 6 objectives

The New Zealand Science Curriculum – Aims for each strand with objectives for Level 4, 5 and 6 grouped by number within strands.

Making Sense of the Living World

Aims

In their study of the living world, students will use their developing scientific knowledge, skills, and attitudes to:

1. Gain an understanding of order and pattern in the diversity of living organisms, including the special characteristics of New Zealand plants and animals.
2. Investigate and understand relationships between structure and function in living organisms.
3. Investigate and understand how organisms grow, reproduce, and change over generations.
4. Investigate local ecosystems and understand the interdependence of living organisms, including humans, and their relationship with their physical environment.

Objectives for Levels 4, 5 and 6

4-1 Investigate and classify closely related living things on the basis of easily observable features.

5-1 Investigate, and classify in broad terms, the living world at a microscopic level.

6-1 Investigate and describe examples of different types of helpful and harmful micro-organisms.

4-2 Investigate and describe special features of animals or plants which help survival into the next generation.

5-2 Investigate and describe structural, physiological, and behavioural adaptations which ensure the survival of animals and flowering plants in their environment.

6-2 (a) Describe cell division and explain how genetic information is passed from one generation to the next.

(b) Investigate examples of the contemporary application of genetics.

4-3 Investigate and describe patterns in the variability of a visible physical feature found within a species.

5-3 Investigate patterns in the inheritance of genetically controlled characteristics and explain the importance of variation within a changing environment.

6-3 (a) Describe cell division and explain how genetic information is passed from one generation to the next.

(b) Investigate examples of the contemporary application of genetics.

4-4 Use simple food chains to explain the feeding relationships of familiar animals and plants, and investigate effects of human intervention on these relationships.

5-4 Investigate and understand trophic and nutrient relationships between producers, consumers, and decomposers.

6-4 Investigate a New Zealand example of how people apply biological principles to plant and animal management.

Making Sense of the Physical World

Aims

In their study of the physical world, students will use their developing scientific knowledge, skills, and attitudes to:

1. Gain an understanding of the nature of physical phenomena from practical investigation and the consideration of scientific models.
2. Establish scientific concepts of energy and investigate ways in which energy changes can be put to use.
3. Explore and establish trends, relationships, and patterns involving physical phenomena.
4. Explain how physical phenomena are used in everyday technology and how such technology affects people and their environment.

Objectives for Levels 4, 5 and 6

4-1 Investigate and offer explanations for commonly experienced physical phenomena and compare their ideas with scientific ideas.

5-1 Carry out simple practical investigations, with control of variables, into common physical phenomena, and relate their findings to scientific ideas.
6-1 Carry out practical investigations, with effective control of variables, into common physical phenomena, and relate their findings to scientific theories.
4-2 Investigate and offer explanations for commonly experienced physical phenomena and compare their ideas with scientific ideas.
5-2 Describe various ways in which energy can be transformed and transferred in our everyday world.
6-2 Demonstrate an understanding of the applications of energy and its transfer and transformation.
4-3 Process and interpret information to describe or confirm trends and relationships in observable physical phenomena.
5-3 investigate and describe the patterns associated with physical phenomena ' some patterns may be expressed in graphical terms.
6-3 Investigate and establish patterns in physical phenomena and make useful predictions.
4-4 Investigate and offer explanations of how selected items of technology function and enhance everyday activities of people.
5-4 Investigate how physical devices or systems can be used to perform specified functions.
6-4 Investigate and report on how physical principles are used in some common household appliances.

Making Sense of the Material World

Aims

In their study of the material world, students will use their developing scientific knowledge, skills, and attitudes to:

1. Investigate the nature and properties of substances, identify patterns in these properties, and understand why chemists group substances in the ways they do.
2. Apply their knowledge of the properties of substances to the safe and appropriate use of these in the home, in industry, and in the environment.
3. Investigate reactions, and applications of these, in chemical processes.

4. Make informed decisions about the interrelationship of chemical substances and processes, with technology, people, and the environment.

Objectives for Levels 4, 5 and 6

4-1 Investigate and group common materials in terms of properties.

5-1 (a) Investigate familiar substances and describe, using the concept of the particle nature of matter, how they may exist as solids, liquids, and gases,

(b) distinguish between elements, compounds, and mixtures, using simple chemical and physical properties, and describe a simple model of the atom.

6-1 Investigate and understand how familiar chemical substances can be grouped into families which have characteristic chemical properties;

(Metals and common metal compounds such as oxides, hydroxides, and carbonates; non-metallic oxides; hydrocarbons and simple alcohols should be studied).

4-2 Investigate and explain how uses of everyday materials are related to their physical and simple chemical properties.

5-2 Apply their knowledge of chemical and physical properties of substances to investigate their safe and appropriate use in the home and the community.

6-2 Investigate and relate the physical and chemical properties of a family of substances to their use in the home and the community.

4-3 Investigate and describe ways of producing permanent or temporary changes in some familiar materials,

5-3 Investigate some important types of substances and the way they change chemically in everyday situations.

6-3 Investigate and understand factors that affect chemical processes, e.g., factors affecting changing rates of reactions.

4-4 Investigate the positive and negative effects of substances on people and on the environment.

5-4 Research and describe how selected materials are manufactured and used in everyday goods and technology.

6-4 Investigate and describe the applications and effects of chemical processes in everyday situations.

Making Sense of Planet Earth and Beyond

Aims

In their study of planet Earth and beyond, students will use their developing scientific knowledge, skills, and attitudes to:

1. Investigate the composition of planet Earth and gain an understanding of the processes which shape it.
2. Investigate the geological history of planet Earth and understand that our planet has a long past and has undergone many changes.
3. Investigate and understand relationships between planet Earth and its solar system, galaxy, and the universe.
4. Investigate how people's decisions and activities change planet Earth's physical environment, and develop a responsibility for the guardianship of planet Earth and its resources.

Objectives for Levels 4, 5 and 6

4-1 Investigate major factors and patterns associated with weather, and use given data to predict weather.

5-1 Investigate and describe processes which change the Earth's surface over time at local and global levels

6-1 (a) Investigate and classify some common minerals and rocks according to their easily observed properties and relate to their common use.

(b) Investigate how the three major types of rocks are formed (igneous, metamorphic, and sedimentary) and describe how rock sequences provide evidence for past events through geological time.

4-2 Collect and use evidence from landforms, rocks, fossils, and library research to describe the geological history of the local area.

5-2 Investigate and describe processes which change the Earth's surface over time at local and global levels.

6-2 (a) Investigate and classify some common minerals and rocks according to their easily observed properties and relate to their common use,

(b) Investigate how the three major types of rocks are formed (igneous, metamorphic, and sedimentary) and describe how rock sequences provide evidence for past events through geological time.

4-3 (a) Use simple technological devices to observe and describe our night sky, *e.g., binoculars, simple star maps.*

(b) Investigate and use models which explain the changing spatial relationships of the Earth, its moon, and the Sun, and the way different cultures have used these patterns to describe and measure time, and position.

5-3 (a) Use simple technological devices, such as telescopes and simple star maps, to observe and describe changing patterns in our night sky,

(b) Use information obtained from technological devices, such as radio telescopes and satellites, to clarify, challenge, and extend their ideas about the general characteristics of some near and far space objects.

6-3 Use information from a range of sources, including their own observation, to explain spatial relationships of objects in the night sky and the challenge such spatial relationships present to space exploration.

4-4 Investigate a local environmental issue and explain the reasons for the community's involvement.

5-4 Research a national environmental issue and explain the need for responsible and co-operative guardianship of New Zealand's environment.

6-4 Report on an important natural resource in New Zealand, including its method of formation, location, and extraction, as appropriate, and any issues associated with its use.

Appendix C NZ science curriculum objectives matched with Bloom's Taxonomy cognitive outcomes

Curriculum level and objective number	**NZ Science Curriculum Objective (key verbs in Italics)**	**Bloom's taxonomy highest level cognitive outcome (Revised Anderson, et al. 2001)**
LW4-1	*Investigate* and *classify* closely related living things on the basis of easily observable features	understanding
LW5-1	*Investigate* and *classify* in broad terms, the living world at a microscopic level.	understanding
LW6-1	*Investigate* and *describe* examples of different types of helpful and harmful micro-organisms.	applying
LW4-2	*Investigate* and *describe* special features of animals or plants which help survival into the next generation.	understanding
LW5-2	*Investigate* and *describe* structural, physiological, and behavioural adaptations which ensure the survival of animals and flowering plants in their environment.	analysing
LW6-2	(a) *Describe* cell division and *explain* how genetic information is passed from one generation to the next. (b) *Investigate* examples of the contemporary *application* of genetics.	understanding applying
LW4-3	*Investigate* and *describe* patterns in the variability of a visible physical feature found within a species.	understanding
LW5-3	*Investigate* patterns in the inheritance of genetically controlled characteristics and *explain* the importance of variation within a changing environment.	analysing
LW6-3	(a) *Describe* cell division and *explain* how genetic information is passed from one generation to the next. (b*) Investigate* examples of the contemporary *application* of genetics.	analysing analysing
LW4-4	*Use* simple food chains to *explain* the feeding relationships of familiar animals and plants, and *investigate* effects of human intervention on these relationships.	understanding
LW5-4	*Investigate* and *understand* trophic and nutrient relationships between producers, consumers and decomposers.	understanding
LW6-4	*Investigate* a New Zealand example of how people *apply* biological principles to plant and animal management.	applying

Appendix C (continued)

Curriculum level and objective number	**NZ Science Curriculum Objective (key verbs in Italics)**	**Bloom's taxonomy highest level cognitive outcome (Revised Anderson, et al. 2001)**
PW4-1	*Investigate* and *offer explanations* for commonly experienced physical phenomena and *compare* their ideas with scientific ideas.	understanding
PW5-1	*Carry out* simple practical investigations, with control of variables, into common physical phenomena, and *relate* their findings to scientific ideas.	analysing
PW6-1	*Carry out* practical investigations, with effective control of variables, into common physical phenomena, and *relate* their findings to scientific theories.	evaluating
PW4-2	*Investigate* and *offer explanations* for commonly experienced physical phenomena and *compare* their ideas with scientific ideas.	understanding
PW5-2	*Describe* various ways in which energy can be transformed and transferred in our everyday world.	understanding
PW6-2	*Demonstrate an understanding* of the *applications of energy* and its transfer and transformation.	applying
PW4-3	*Process* and *interpret* information to *describe* or *confirm trends* and relationships in observable physical phenomena.	understanding
PW5-3	*Investigate* and *describe* the patterns associated with physical phenomena. Some patterns may be *expressed in graphical terms.*	analysing
PW6-3	*Investigate* and *establish patterns* in physical phenomena and *make useful predictions.*	evaluating
PW4-4	*Investigate* and *offer explanations* of how selected items of technology function and enhance everyday activities of people.	understanding
PW5-4	*Investigate* how physical devices or systems can be *used* to perform specified functions,	applying
PW6-4	*Investigate* and *report* on how physical principles are used in some common household appliances.	analysing

Appendix C (continued)

Curriculum level and objective number	**NZ Science Curriculum Objective (key verbs in Italics)**	**Bloom's taxonomy highest level cognitive outcome (Revised Anderson, et al. 2001)**
MW4-1	*Investigate* and *group* common materials in terms of properties.	understanding
MW5-1	(a*) Investigate* familiar substances and *describe*, using the concept of the particle nature of matter, how they may exist as solids, liquids, and gases. (b) *Distinguish* between elements, compounds, and mixtures, using simple chemical and physical properties, and *describe* a simple model of the atom.	analysing applying
MW6-1	*Investigate* and *understand* how familiar chemical substances can be *grouped* into families which have characteristic chemical properties. (Metals and common metal compounds such as oxides, hydroxides, and carbonates; non-metallic oxides; hydrocarbons and simple alcohols should be studied.)	analysing
MW4-2	*Investigate* and *explain* how uses of everyday materials are related to their physical and simple chemical properties.	applying
MW5-2	*Apply* their knowledge of chemical and physical properties of substances to *investigate* their safe and appropriate use in the home and the community.	applying
MW6-2	*Investigate* and *relate* the physical and chemical properties of a family of substances to their use in the home and the community.	analysing
MW4-3	*Investigate* and *describe* ways of producing permanent or temporary changes in some familiar materials.	applying
MW5-3	*Investigate* some important types of substances and the way they change chemically in everyday situations.	applying

Appendix C (continued)

Curriculum level and objective number	**NZ Science Curriculum Objective (key verbs in Italics)**	**Bloom's taxonomy highest level cognitive outcome (Revised Anderson, et al. 2001)**
MW6-3	*Investigate* and *understand* factors that affect chemical processes, e.g., factors affecting changing rates of reactions.	analysing
MW4-4	*Investigate* the positive and negative *effects* of substances on people and on the environment.	analysing
MW5-4	*Research* and *describe* how selected materials are manufactured and used in everyday goods and technology.	analysing
MW6-4	*Investigate* and *describe* the *applications* and *effects* of chemical processes in everyday situations.	analysing

Appendix C (continued)

Curriculum level and objective number	**NZ Science Curriculum Objective (key verbs in Italics)**	**Bloom's taxonomy highest level cognitive outcome (Revised Anderson, et al. 2001)**
PEB4-1	*Investigate* major factors and patterns associated with weather, and use given data to *predict* weather.	understanding
PEB5-1	*Investigate* and *describe* processes which change the Earth's surface over time at local and global levels.	understanding
PEB6-1	(a) *Investigate* and *classify* some common minerals and rocks according to their easily observed properties and *relate* to their common use. (b) *Investigate* how the three major types of rocks are formed (igneous, metamorphic, and sedimentary) and *describe* how rock sequences provide evidence for past events through geological time.	analysing analysing
PEB4-2	*Collect and use* evidence from landforms, rocks, fossils, and library research to *describe* the geological history of the local area.	applying
PEB5-2	*Investigate* and *describe* processes which change the Earth's surface over time at local and global levels.	analysing
PEB6-2	(a)*Investigate* and *classify* some common minerals and rocks according to their easily observed properties and *relate* to their common use. (b) *Investigate* how the three major types of rocks are formed (igneous, metamorphic, and sedimentary) and *describe* how rock sequences provide evidence for past events through geological time.	analysing analysing
PEB4-3	a)*Use* simple technological devices to *observe* and *describe* our night sky. b)*Investigate* and *use models* which explain the changing spatial relationships of the Earth, its Moon, and the Sun, and the way different cultures have used these patterns to describe and measure time, and position.	appying analysing

Appendix C (continued)

Curriculum level and objective number	**NZ Science Curriculum Objective (key verbs in Italics)**	**Bloom's taxonomy highest level cognitive outcome (Revised Anderson, et al. 2001)**
PEB5-3	(a*) Use* simple technological devices, such as telescopes and simple star maps, to *observe and describe* changing patterns in our night sky. (b) *Use* information obtained from technological devices, such as radio telescopes and satellites, to *clarify*, *challenge*, and *extend* their ideas about the general characteristics of some near and far space objects.	applying creating
PEB6-3	*Use information* from a range of sources, including their own observation, to *explain* spatial relationships of objects in the night sky and the *challenge* such spatial relationships present to space exploration.	evaluating
PEB4-4	*Investigate* a local environmental issue and *explain* the reasons for the community's involvement.	understanding
PEB5-4	*Research* a national environmental issue and *explain* the need for responsible and co-operative guardianship of New Zealand's environment.	analysing
PEB6-4	*Report* on an important natural resource in New Zealand, including its method of formation, location, and extraction, as appropriate, and any issues associated with its use.	analysing

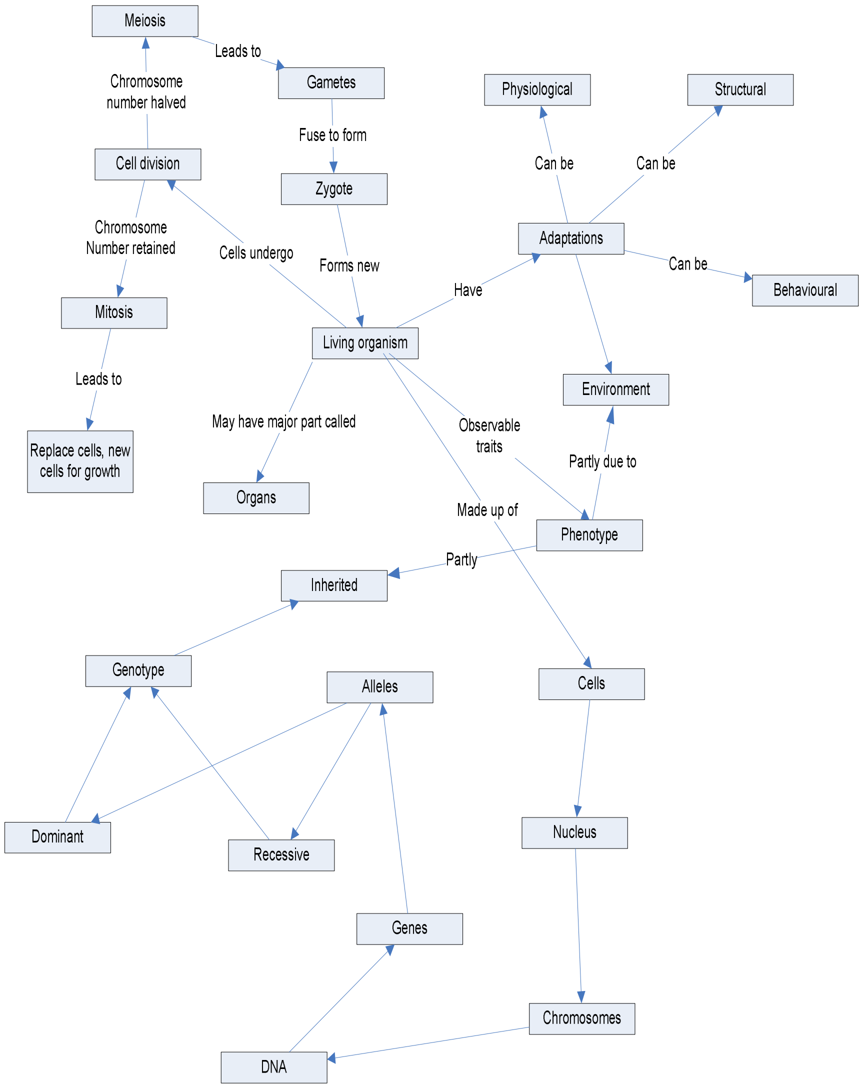
Appendix D Concept Maps for NZ Science Curriculum Levels 4, 5 and 6

Living World Achievement Aim 1: Gain an understanding of order and pattern in the diversity of living organisms, including the special characteristics of New Zealand plants and animals.
Objective line 1 Curriculum Levels 4, 5, 6

Appendix D

Living World Achievement Aim 2: Investigate and understand relationships between structure and function in living organisms.

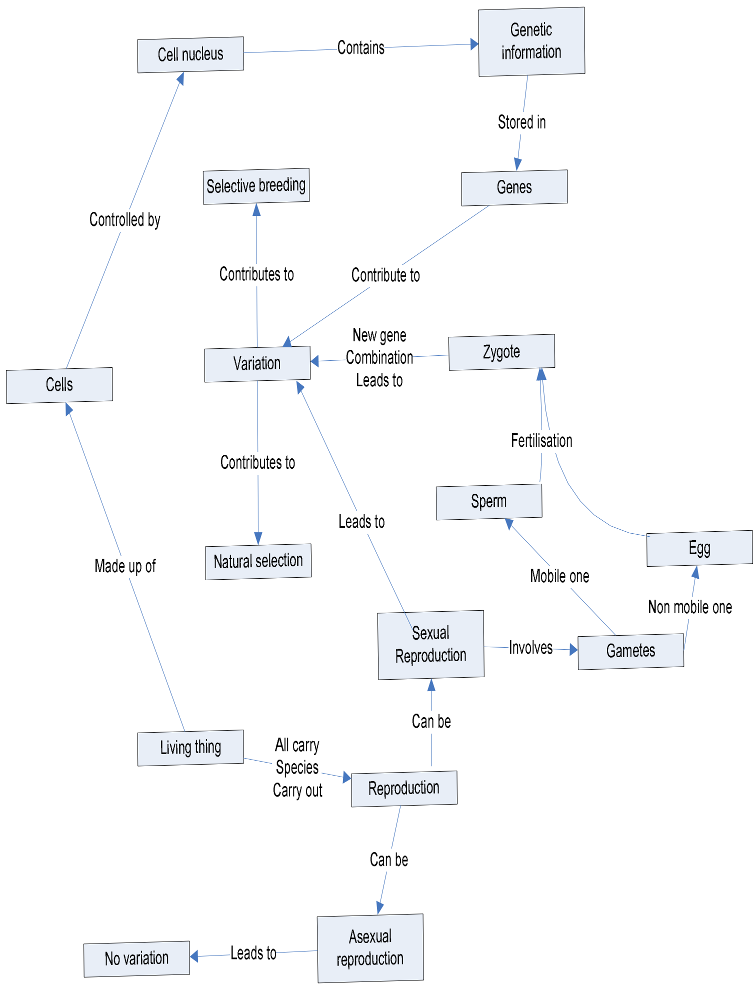
Objective line 2 Curriculum Levels 4, 5, 6



Appendix D

Living World Achievement Aim 3: Investigate and understand how organisms grow, reproduce and change over generations.

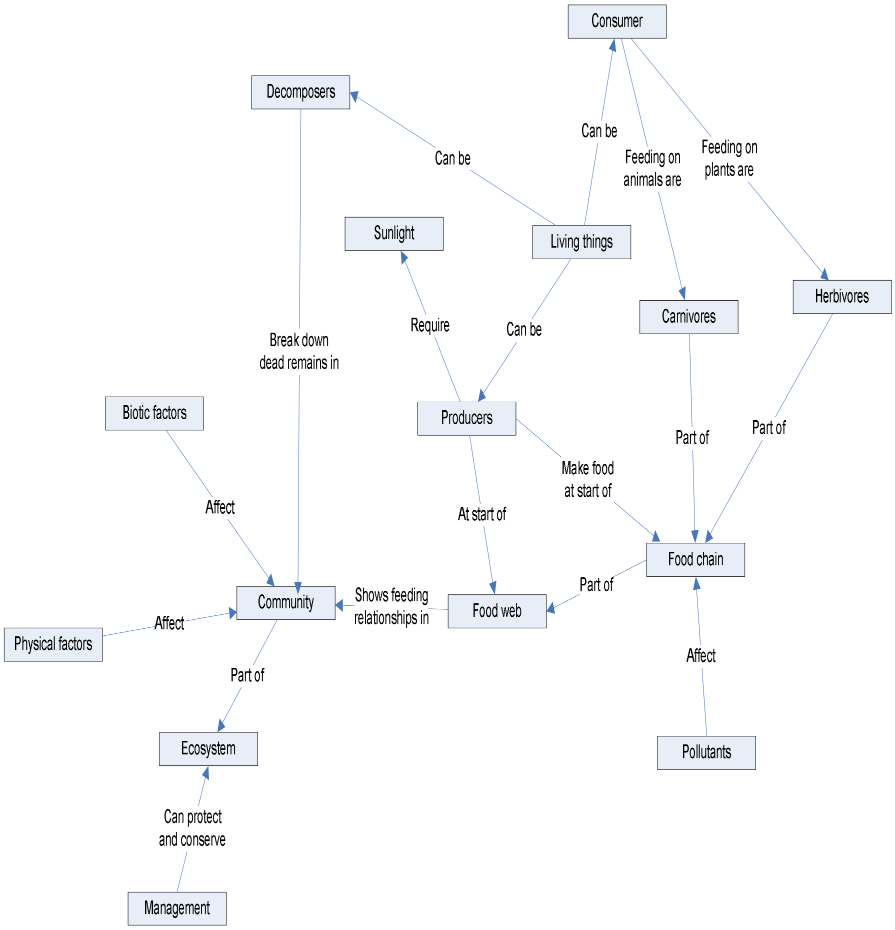
Objective line 3 Curriculum Levels 4, 5, 6



Appendix D

Living World Achievement Aim 4: Investigate local ecosystems and understand the intderdependence of living organisms, including humans, and their relationship with their physical environment.

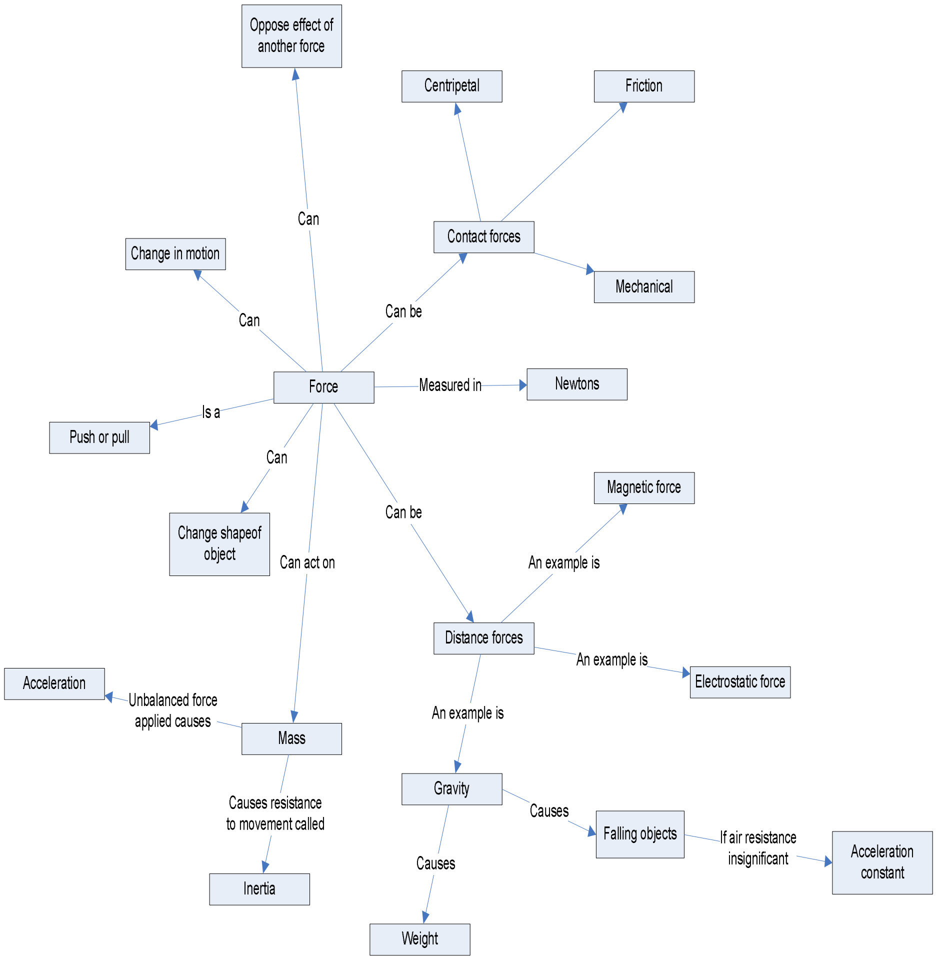
Objective line 3 Curriculum Levels 4, 5, 6



Appendix D

Physical World Achievement Aim 1: Gain an understanding of the nature of physical phenomena from practical investigation and the consideration of scientific models.

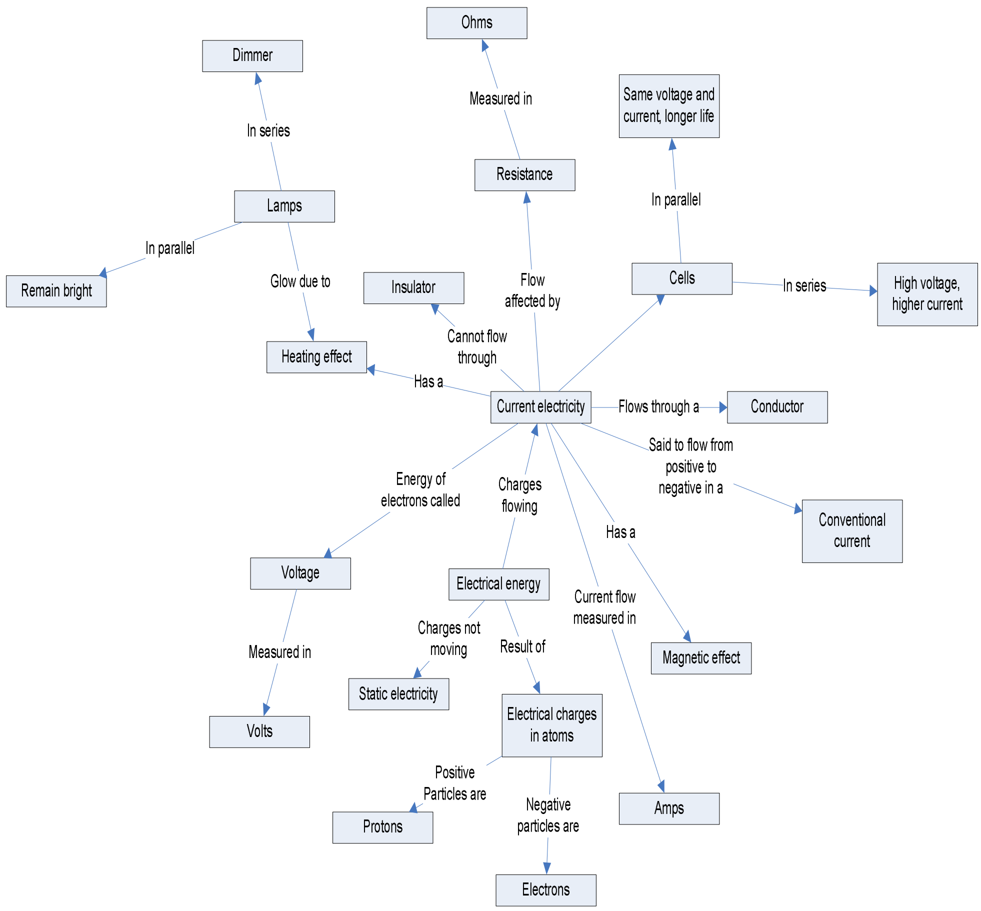
Objective line 1 Curriculum Levels 4, 5, 6.



Appendix D

Physical World Achievement Aim 1: Gain an understanding of the nature of physical phenomena from practical investigation and the consideration of scientific models.

Objective line 1 Curriculum Levels 4, 5, 6.

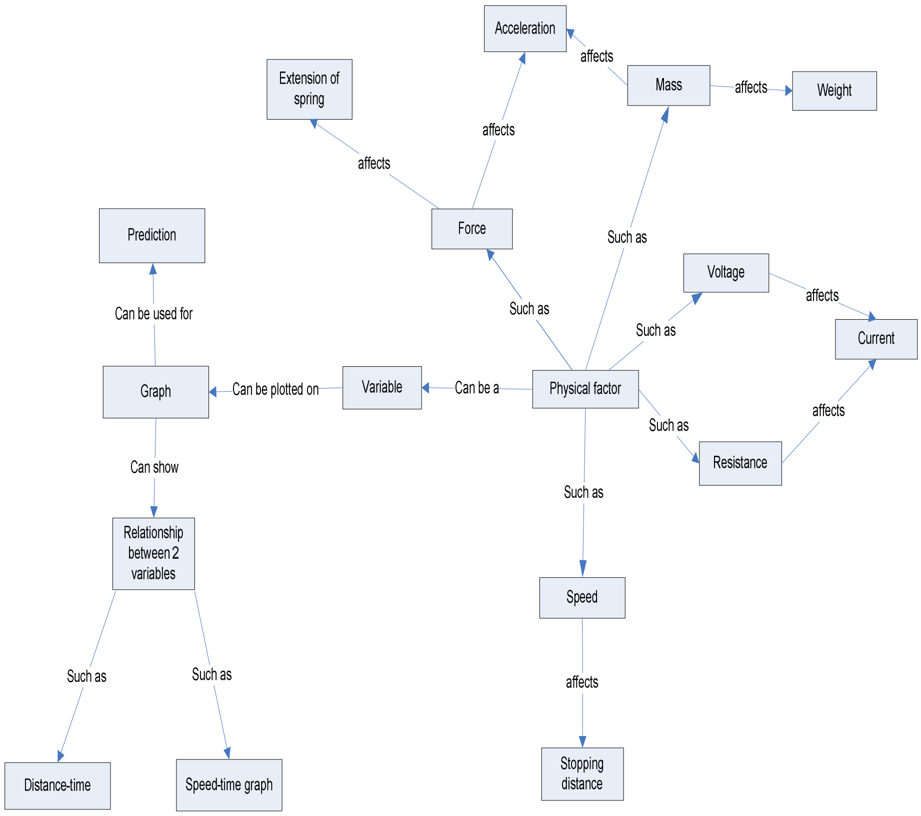


Appendix D

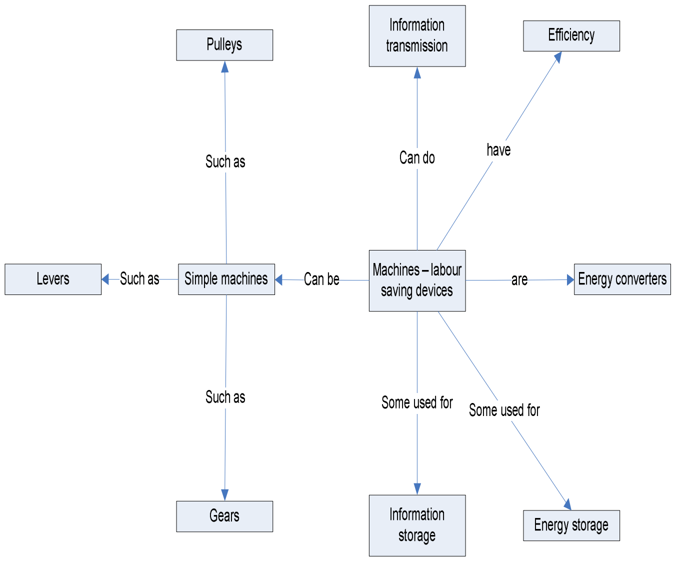
Physical World Achievement Aim 2: Establish scientific concepts of energy and investigate ways in which enrgy changes can be put to use.

Objective line 2 Curriculum Levels 4, 5, 6

Appendix D
Physical World Achievement Aim 3: Explore and establish trends, relationships and patterns involving physical phenomena.
Objective line 4 Curriculum Levels 4, 5, 6



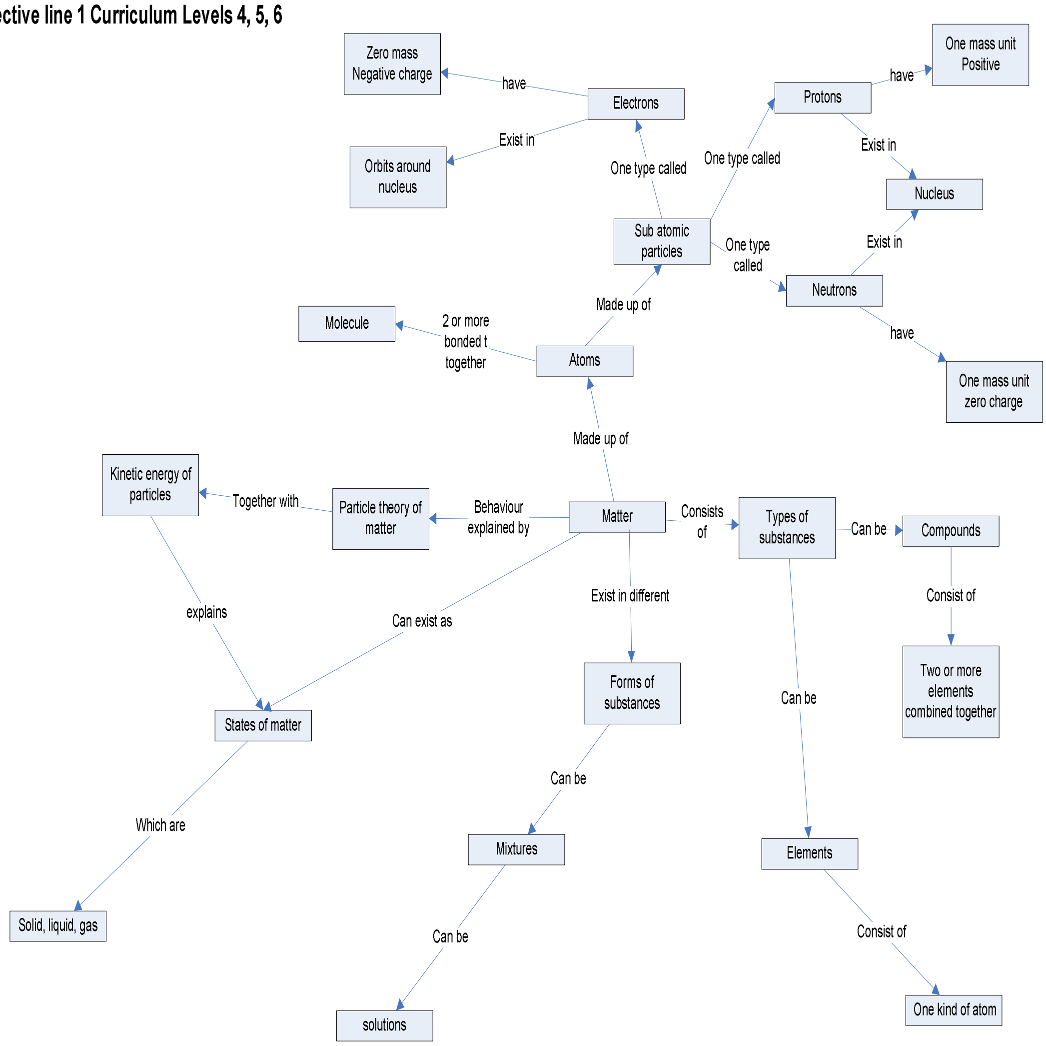
Appendix D
Physical World Achievement Aim 4: Explain how physical phenomena are used in everyday technology and how such technology affects people and their environment.
Objective line 4 Curriculum Levels 4, 5, 6



Appendix D

Material World Achievement Aim 1: Investigate the nature and properties of substances, identify patterns in those properties, and understand why chemists group substances in the ways they do.

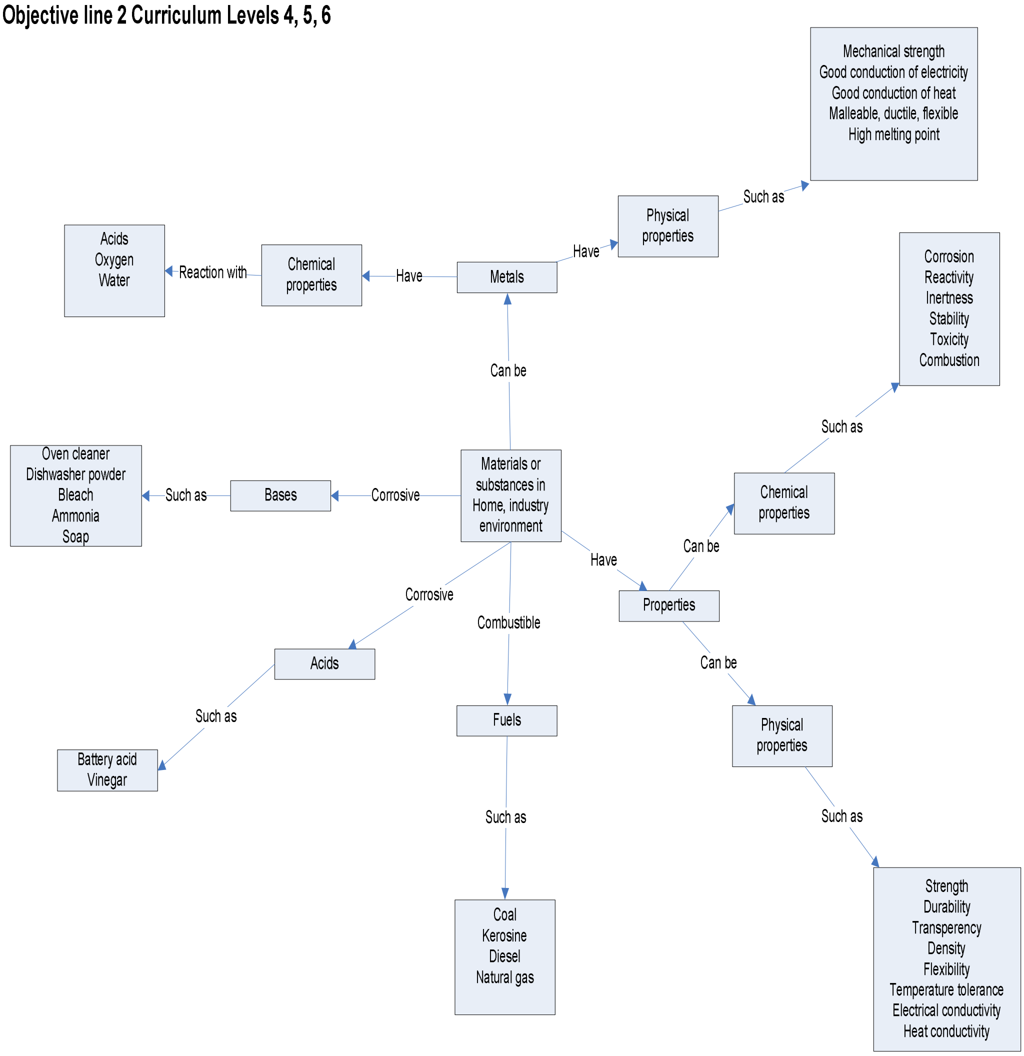
Objective line 1 Curriculum Levels 4, 5, 6



Appendix D

Material World Achievement Aim 2: Apply their knowledge of the properties of substances to the safe and appropriate use in the home, industry and in the environment.

Objective line 2 Curriculum Levels 4, 5, 6

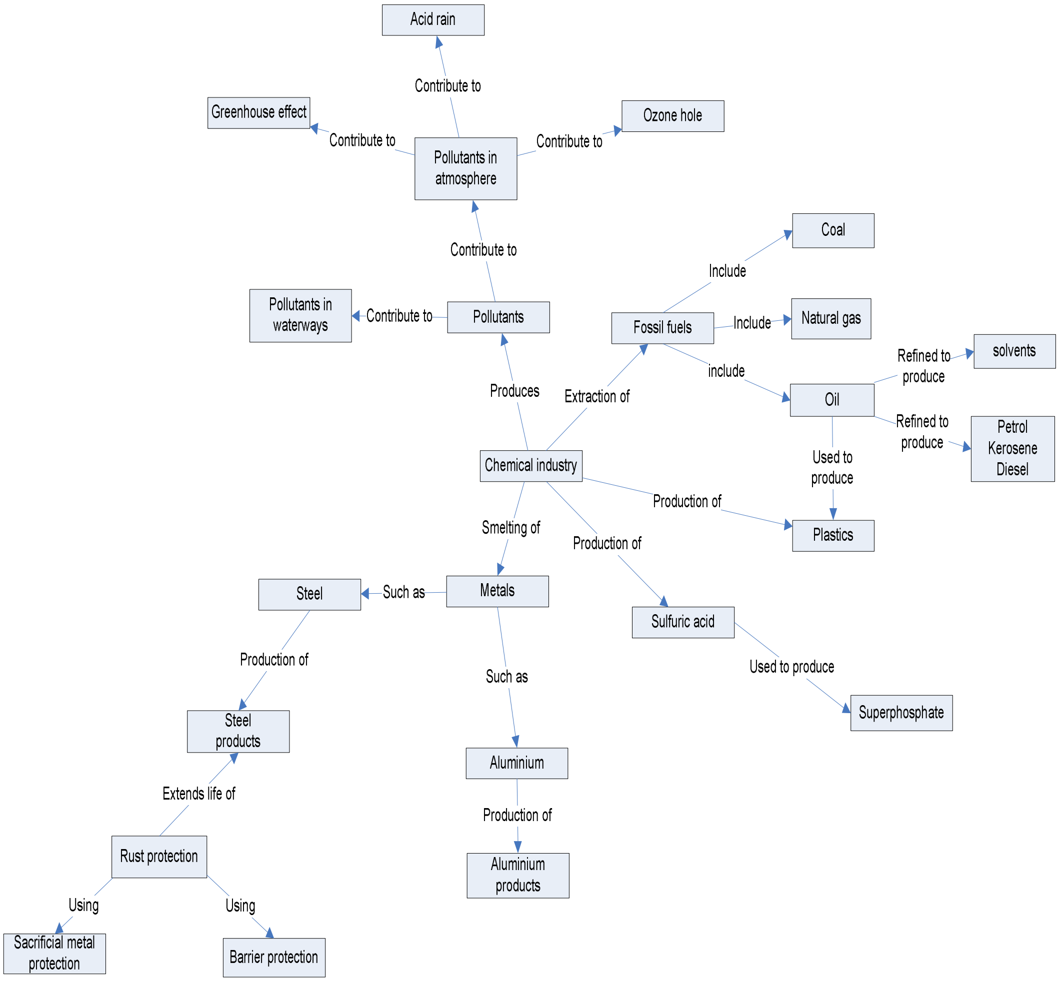


Appendix D

Material World Achievement Aim 3: Investigate reactions, and applications of these, in chemical processes.

Material world objective line 3 curriculum levels 4, 5, 6

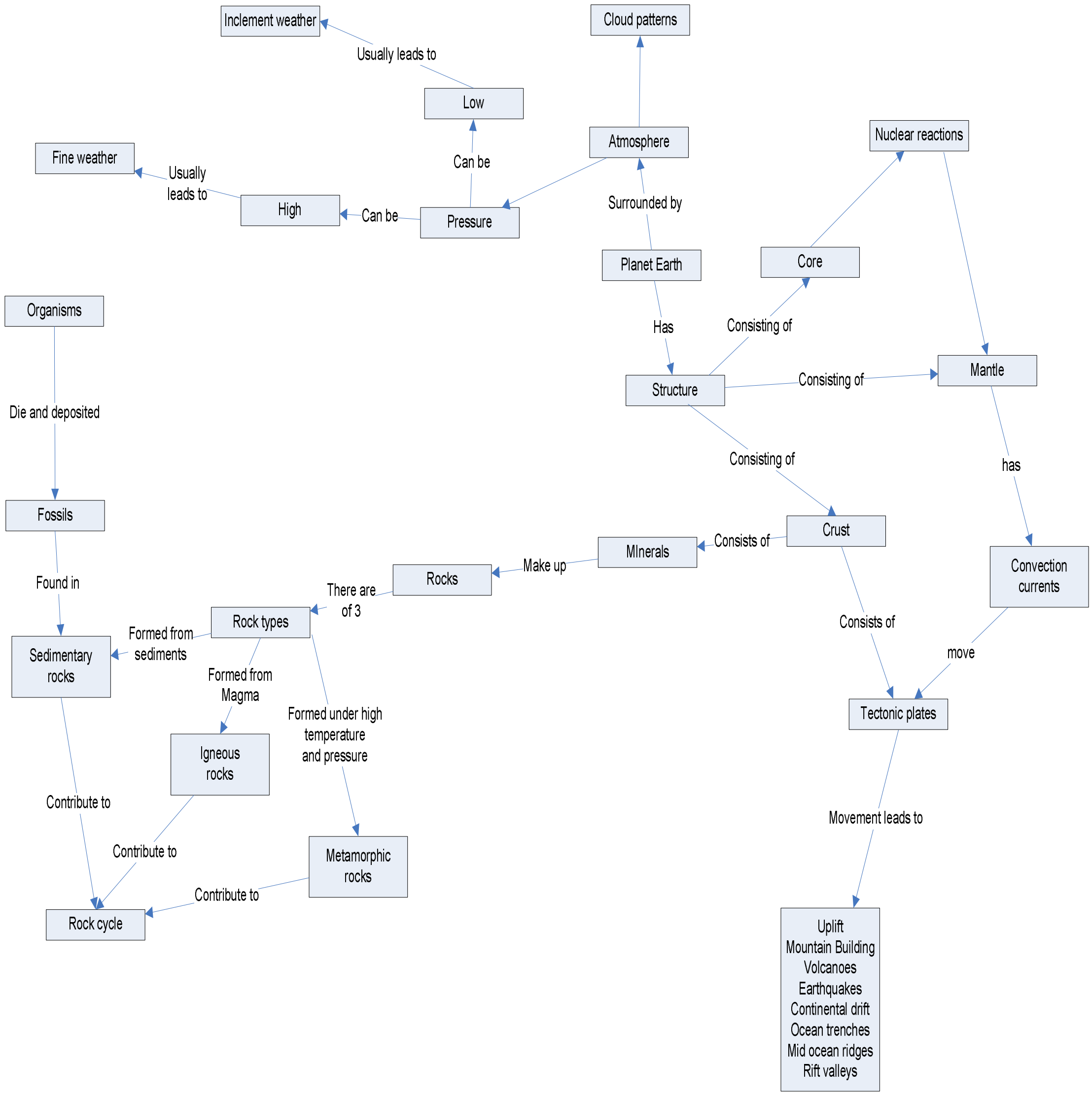
Appendix D
Material World Achievement Aim 4: Make informed decisions about the interrelationship of chemical substances and processes with technology, people and the environment.
Material world objective line 4 curriculum levels 4, 5, 6



Appendix D

Planet Earth and Beyond Achievement Aim 1: Investigate the composition of planet Earth and gain an understanding of the processes which shape it.

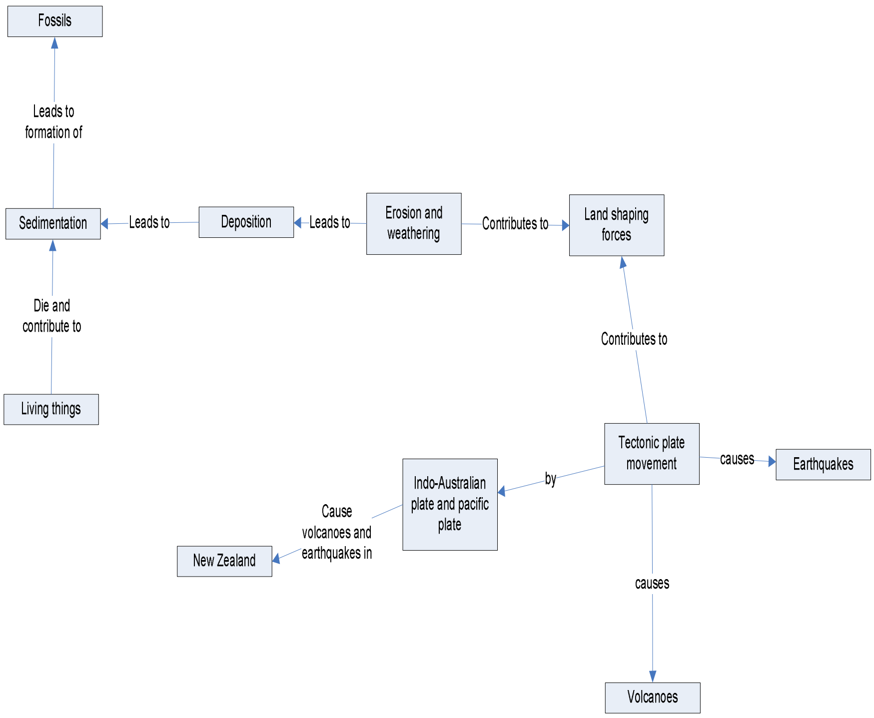
Planet Earth and Beyond objective line 1 curriculum levels 4, 5, 6



Appendix D

Planet Earth and Beyond Achievement Aim 2: Investigate the geological history of planet earth and understand that our planet has a long past and has undergone many changes.

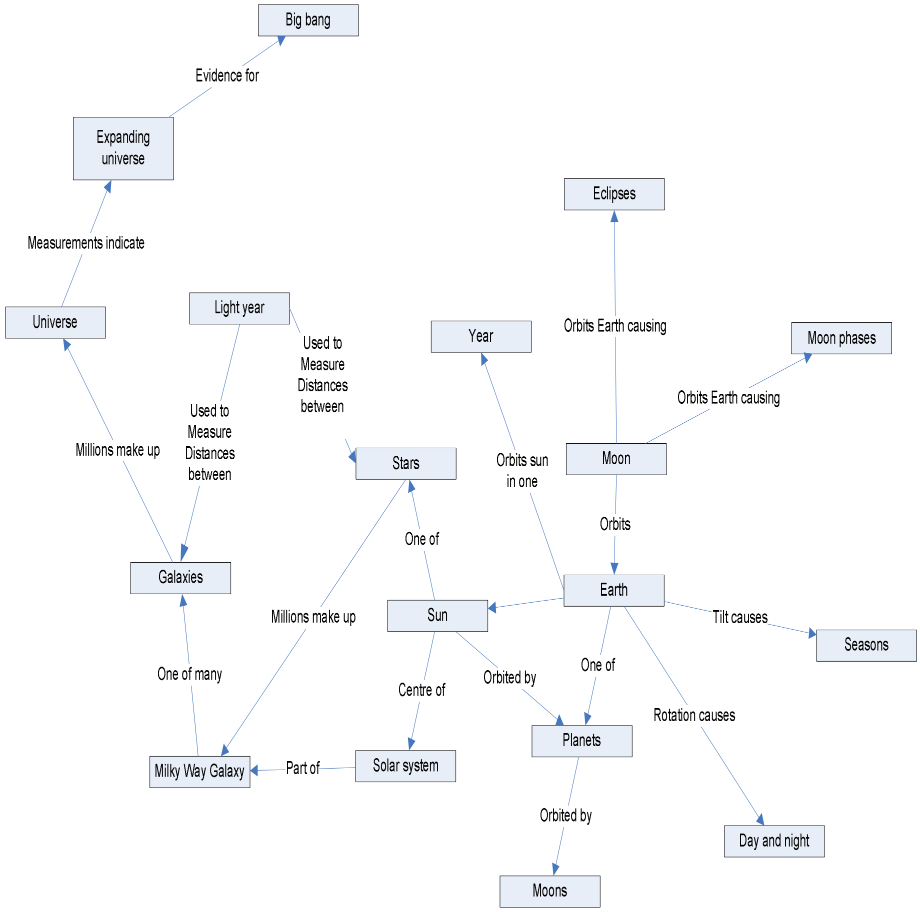
Planet Earth and Beyond objective line 2 Curriculum Levels 4, 5, 6



Appendix D

Planet Earth and Beyond Achievement Aim 3: Investigate and understand relationships between planet Earth and its solar system, galaxy and the universe.

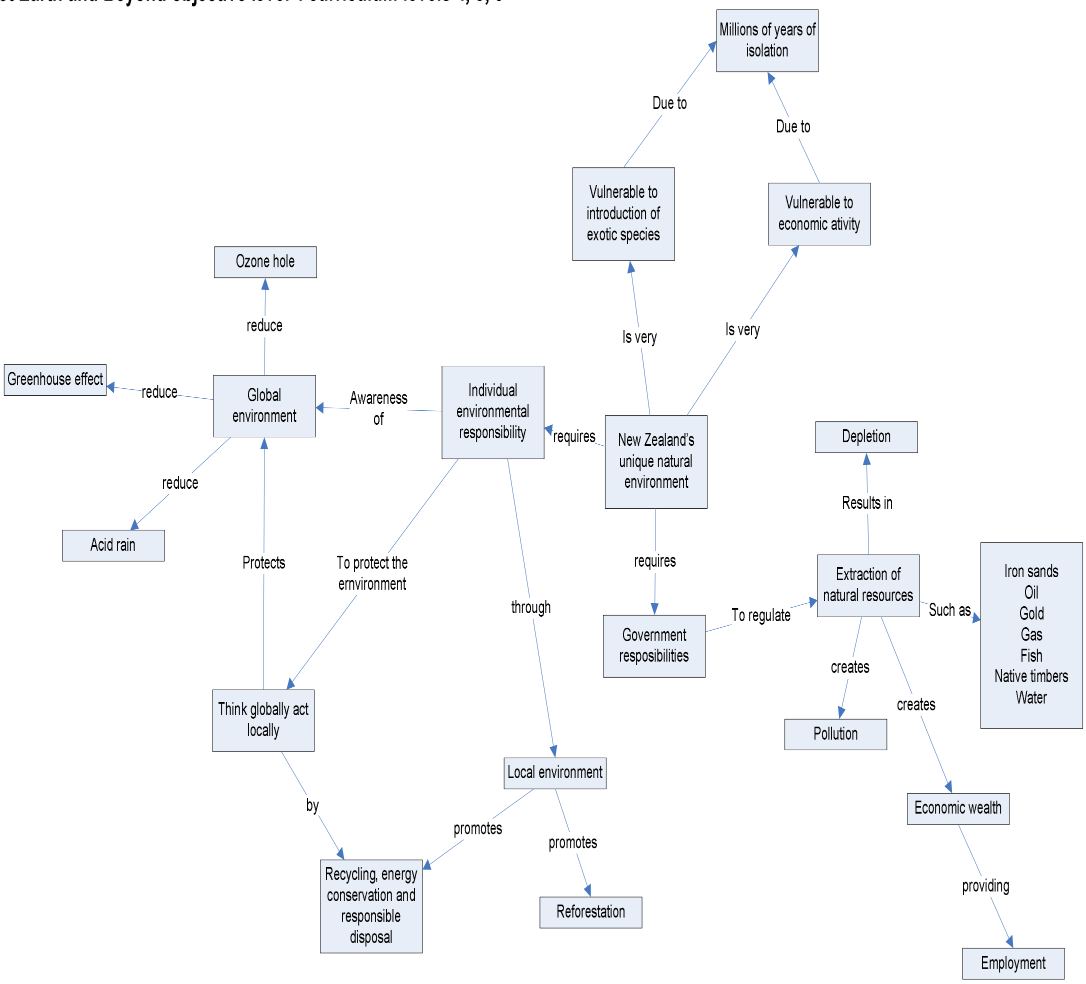
Planet Earth and Beyond objective line 3 curriculum levels 4, 5, 6



Appendix D

Planet Earth and Beyond Achievement Aim 4: Investigate how people's decisions and activities change planet Earth's physical environment and develop a responsibility for the guardianship of planet earth and its resources.

Planet Earth and Beyond objective level 4 curriculum levels 4, 5, 6



Appendix E Propositions for NZ Science Curriculum level 4, 5 and 6 Objectives (CO)

Making Sense of the Living World – Objective line1

Prop No	Proposition	Ques No	CO
1	Living things have special features that distinguish them from non-living things.	3	LW 6-1
2	Living things can be grouped according to similarities in their external features.	1	LW4-1
3	Groups of living things have a number of features in common.	1	LW 4-1
4	Living things are made up of units called cells.	17	LW 5-1
5	Some living things are made up of only one cell.	17	LW 5-1
6	Cells can be classified according to the type of living thing they come	17	LW 5-1
7	Cells consist of cytoplasm, nucleus and cell membrane.	17	LW 5-1
8	Plant cells have a cell wall, plastids and a vacuole	17	LW 5-1
9	Animal cells lack a cell wall, plastids and vacuole.		
10	Single celled living things can be like animal cells, or plant cells, or they	17	LW 5-1
11	Micro-organisms are living things that require a microscope to be seen clearly.	37	LW 6-1
12	Three types of micro-organisms are bacteria, viruses, fungi.	37	LW 6-1
13	Most micro-organisms are decomposers in nature.		
14	Some micro-organisms are harmful, causing disease in humans, animals and plants, said to be pathogenic.		
15	Pathogenic micro-organisms include some bacteria, some fungi and all viruses.		
16	Bacterial disease symptoms are caused by toxins.		
17	Viruses can usually only reproduce inside a specific host cell.	37	LW 6-1
18	Viruses show some of the characteristics of living things when reproducing inside a host cell.	37	LW 6-1
19	Viruses are sub-cellular particles consisting of a nucleic acid core surrounded by a protein coat.	37	LW 6-1
20	The human body has a defensive system against pathogens consisting of barriers to stop entry, white blood cells and antibodies.		

Appendix E Propositions for NZ Science Curriculum level 4, 5 and 6 Objectives (CO)

Making sense of the Living World – Objective line 2

Prop No	Proposition	Ques No	CO
1	The main parts of animals and plants have general functions.	2	LW 4-2
2	Living things have special features that enable them to survive and reproduce.	2	LW 4-2
3	Special features that help survival are called adaptations.	18	LW 6-2
4	Adaptations can be structural, behavioural and physiological.	18	LW 6-2
5	New cells in living things are made by old cells dividing.		
6	There are two types of cell division which result in genes/DNA/chromosomes being passed from one the parent cell to the daughter cells.	38	LW 6-3
7	Living things grow by a type of cell division called mitosis.		
8	Meiosis is the form of cell division concerned with the formation of reproductive cells, egg and sperm.	38	LW 6-3
9	Reproductive cells are called gametes.	38	LW 6-3
10	The male gamete is the sperm cell the female gamete is the egg cell.		
11	Gametes contain half the normal number of chromosomes and genes for a species.	38	LW 6-3
12	Meiosis is the form of cell division that halves of the number of chromosomes in the new cells.	38	LW 6-3
13	Fertilization involves the joining of egg and sperm cells.		
14	When fertilization occurs the normal chromosome number for the species is restored.		
15	Inherited characteristics in living things are passed from one generation to the next in gametes.		
16	Inherited characteristics are coded in DNA in the chromosomes in the nucleus of the cells of a living thing.		
17	Each body cell contains a pair of genes (alleles) that control a particular characteristic.		
18	Alleles can be dominant or recessive.		
19	Dominant alleles express themselves when in single or double dose.		
20	Recessive alleles express themselves when in double dose only.		

Appendix E Propositions for NZ Science Curriculum level 4, 5 and 6 Objectives (CO)

Making sense of the Living World – Objective line 3

Prop No	Proposition	Ques No	CO
1	Each type of living thing (species) shows variation in observable characteristics.	3	LW 4-3
2	Many of the characteristics of an individual are genetically controlled.	3	LW 4-3
3	The characteristics of a living thing are determined by inheritance and modified by the environment.	3	LW 4-3
4	Sexual reproduction leads to mixing of inherited characteristics leading to further variation.	39	LW 6-3
5	Asexual reproduction leads to offspring with same characteristics as parent.		
6	Genetic information is passed from one generation to the next via the gametes.		
7	Genetic information is coded on DNA which is located in the chromosomes.		
8	Chromosomes are located in the nucleus of each cell in the body of a living thing.		
9	Each inherited characteristic of an individual living thing is controlled by a pair of genes coded in the DNA in the chromosomes.		
10	When fertilization occurs, the sperm cell and egg cell each contribute a set of matching chromosomes.		
11	The body cells of an individual living thing contain two copies of each chromosome type and therefore two copies of each gene.	19	LW 5-3
12	The genetic characteristics of a living thing depend on how each gene pair expresses itself.	19	LW 5-3
13	Dominant genes express themselves in double dose only.	19	LW 5-3
14	The genetic characteristics of an individual living thing are decided once fertilization has occurred leading to the formation of that individual.	39	LW 6-3
15	Variation within a species is important to enable the survival of the species in a changing environment.	39	LW 6-3
16	Desirable characteristics can be maintained in animals and plants by selective breeding.	39	LW 6-3
17	Natural selection occurs in nature where individuals with characteristics that make them better adapted to their environment and therefore better able to survive an reproduce and pass those characteristics on to their offspring	39	LW 6-3

Appendix E Propositions for NZ Science Curriculum level 4, 5 and 6 Objectives (CO)

Making sense of the Living World – Objective line 4

Prop No	Proposition	Ques No	CO
1	A food chain shows the feeding relationship of one living thing to another (a sequence of which living thing feeds on which).	4	LW 4-4
2	A food web shows how one type of living thing depends on another for food.	4	LW 4-4
3	A food chain can show how numbers of one type of living thing can affect numbers of other types of living things in the chain.	4	LW 4-4
4	Pesticide poisons directed at one type of living thing can be passed along the food chain to other types of living things.		
5	A community of living things consists of interconnected food chains called a food web	4	LW 5-4
6	Producers e.g. plants make their own food by photosynthesis from simple inorganic substances and sunlight energy.	20	LW 5-4
7	Consumers e.g. animals require ready made foods from plants and other animals	20	LW 5-4
8	Decomposers breakdown the wastes and dead remains from other living things into simple inorganic substances that can be reused by producers and recycled.	20	LW 5-4
9	All living things depend directly or indirectly on photosynthesis.	20	LW 4-4
10	Animals that feed on plants are called herbivores.		
11	Animals that feed on other animals are called carnivores.		
12	The number of a particular type of living things that can be supported in a community depends on biotic and physical factors.	40	LW 6-4
13	Biotic factors include food supply, predators, browsers, disease, parasites, competition from same species and competition from different species.	40	LW 6-4
14	Physical factors include space, soil type, temperature, light, minerals, wind, and water.	40	LW 6-4
15	Biological principles can be applied by people in management of plants and animals e.g. for food production.	40	LW 6-4

Appendix E Propositions for NZ Science Curriculum level 4, 5 and 6 Objectives (CO)

Making sense of the Physical World – Objective line1

Prop No	Proposition	Ques No	CO
1	A force is a push or a pull.		
2	A force can be recognized because it changes the motion of an object, shape of an object or opposes the effect of another force.		
3	Forces can be contact forces or distance forces.		
4	Examples of distance forces are gravity, magnetism and electrostatic force.		
5	Examples of contact forces are friction, mechanical force, centripetal force.		
6	The unit of force is the Newton.		
7	A force can be measured by how much acceleration it causes an object of known mass.		
8	Force is the product of mass and acceleration.		
9	Mass is the quantity of matter in an object.	23	PW 5-2
10	Inertia is the resistance of an object to a change in its motion.	23	PW 5-2
11	All objects fall due to gravity at the same rate.	23	PW 5-2
12	Friction wasted energy in machines but is essential for grip.		
13	Electricity is a form of energy		
14	Electricity is the result of electrical changes in matter.		
15	Electrical charges can move from one place to another.		
16	There are two types of electrical charge, positive and negative.		
17	Some substances (conductors) allow the flow of electricity; some (insulators) do not.		
18	An electric current is the flow of electric charge along a conducting pathway.	5	PW 4-1
19	An electric circuit is a continuous circular conducting pathway.	5	PW 4-1
20	An electric current will only flow if there is an energy difference in the circuit.		
21	In a metal conductor, an electric current is a flow of electrons.		
22	By convention, an electric current is the flow of positive charge from positive to negative.	5	PW 4-1
23	In reality, an electric current is the flow of electrons from negative to positive.		

Appendix E Propositions for NZ Science Curriculum level 4, 5 and 6 Objectives (CO)

Making sense of the Physical World – Objective line1

24	The amount of electricity flowing depends on energy pushing the electrons along (voltage) and how easily the conductor will allow the electrons to flow (resistance).	21	PW 5-1, 6-1
25	The flow of an electric current can be indicated by lamps, diodes, heating effect, magnetic effect.	5	PW 4-1, 5-1, 6-1.
26	The resistance of a wire depends on the thickness, length and temperature of the wire, and on which metal the wire is made off,		
27	Resistance increases if the wire is thinner, longer and hotter.		
28	Cells in series results in higher voltage and current.	41	PW 6-1
29	Cells connected in parallel result in same voltage and current but longer cell life.	41	PW 6-1
30	Bulbs in series have higher resistance, are less bright, and draw less current.	21	PW 5-1
31	Bulbs in parallel have lower resistance, are equally bright and draw more current.	21	PW 5-1

Appendix E Propositions for NZ Science Curriculum level 4, 5 and 6 Objectives (CO)

Making sense of the Physical World – Objective line 2

Prop No	Proposition	Ques No	CO
1	Energy exists in a number of forms e.g. heat, light, kinetic, electrical and potential energy.	22	5-2, 6-2
2	Potential energy is stored energy capable of being brought into action e.g. gravitational potential, chemical potential, and elastic potential.	42	6-2
3	Energy can be converted from one form to another.	22	5-2, 6-2
4	Energy cannot be created or destroyed.	22	5-2, 6-2
5	When energy is converted from one form to another, some energy is always lost from the system to the environment.	22	6-2
6	Heat energy can be transferred in three ways, conduction, convection and radiation.		
7	Light shiny surfaces reflect radiant heat energy; dark rough surfaces absorb radiant energy.		
8	Light shiny surfaces reflect radiant heat energy; dark rough surfaces absorb radiant energy.		
9	Dark surfaces radiate heat better than light surfaces.		
10	Objects have different heat capacities depending on their mass and what they are made of e.g. metals have low heat capacity and water has high heat capacity.		
11	Latent heat is energy involved in the change of state of a substance. It is absorbed when solid melts to liquid and liquid evaporates or boils to gas. It is given out when gas condenses to liquid and when liquid freezes to solid.	6	
12	Household labour saving devices are energy converters.		
13	Temperature is heat concentration.		
14	Fuels contain chemical potential energy.		
15	Renewable energy can be replaced, non-renewable energy cannot be replaced.		
16	Some energy forms are transferred as waves e.g. light and sound.		
17	Waves have wavelength, amplitude and frequency.		
18	Light travels in straight lines.		
19	Light can be reflected.		
20	Light can be refracted		

Appendix E Propositions for NZ Science Curriculum level 4, 5 and 6 Objectives (CO)

Making sense of the Physical World – Objective line 3

Prop No	Proposition	Ques No	CO
1	Cause and effect – one factor affects another e.g. force-acceleration, mass-weight, voltage-current, speed-stopping distance, force-extension.	7 24	4-3 5-3
2	Cause and effect patterns expressed graphically and interpreting graphs to indicate cause and effect.	43	5-3
3	Patterns in physical phenomena can be expressed graphically and graphs used to make predictions.	43	6-3
4	Distance-time, speed-time, force-acceleration, force-extension, voltage-current.	7 24 43	4-3 5-3 6-3

Appendix E Propositions for NZ Science Curriculum level 4, 5 and 6 Objectives (CO)

Making sense of the Physical World – Objective line 4

Prop No	Proposition	Ques No	CO
1	Labour saving devices. Levers, pulleys gears.	44	PW 6-4
2	Energy converters.		
3	Work. Energy, efficiency.		
4	Technology and its beneficial effect on people e.g. optic fibre, digital technologies, information technologies – principles of energy, electricity, light, sound, radiation.	8	PW 4-4
5	Wavelength, frequency, energy conversion and transmission.	25 44	PW 5-4 PW 6-4
6	Magnetic storage, electrical storage, information storage and transmission.	25 44	PW 5-4 PW 6-4

Appendix E Propositions for NZ Science Curriculum level 4, 5 and 6 Objectives (CO)

Making sense of the Material World – Objective line 1

Prop No	Proposition	Ques No	CO
1	Matter can exist in three states – solid, liquid, gas.	26	MW 5-1a
2	Matter can change state when temperature is increased or decreased.	26	MW 5-1a
3	Substances change state particular temperatures – melting point, boiling point.		
4	Substances dissolve in liquids to form solutions.		
5	A solution is a mixture of a substance in a liquid in which particles of the substance cannot be seen.		
6	The particle theory of matter asserts that all substances are made up of particles.	26	MW 5-1a
7	The particles of matter have kinetic energy which increases with increase in temperature.	26	MW 5-1a
8	In solids, the particles are closely packed together but they vibrate.		
9	In liquids the particles are closely packed, but move over each other and collide.	26	MW 5-1a
10	In gases the particles are separated and move around and collide.	26	MW 5-1a
11	Increase in temperature leads to overall increase in particle kinetic energy leading to change of state.	26	MW 5-1a
12	All matter is made up of particles called atoms.	27	MW 5-1b
13	An element is a substance consisting of one kind of atom.	27	MW 5-1b
14	A compound is a substance consisting of two or more elements combined together.	27	MW 5-1b
15	A compound has properties that are different from the elements that make it up.	27	MW 5-1b
16	A mixture is two or more substances not combined together and shows a combination of the properties of the substances that make it up.	27	MW 5-1b
17	An atom is the smallest particle of an element.	27	MW 5-1b
18	An atom is the smallest particle of an element.	28	MW 5-1b
19	Protons have a mass of one unit and a positive electric charge.	28	MW 5-1b
20	Electrons have zero mass and a negative charge.	28	MW 5-1b
21	Neutrons have a mass of one unit and zero electric charge.	28	MW 5-1b
22	An atom has a neutral charge because the number of protons and electrons is equal.	28	MW 5-1b
23	Protons and neutrons are located in the nucleus of the atom.	28	MW 5-1b
24	Electrons orbit at various energy levels.	28	MW 5-1b
25	An atom is mostly empty space.	28	MW 5-1b
26	Elements can be grouped into metals and non-metals.	9	MW 4-1
27	Compounds can be grouped into families with similar chemical properties e.g. metal oxides, metal hydroxides, carbonates, hydrocarbons, alcohols.	45	MW6-1

Appendix E Propositions for NZ Science Curriculum level 4, 5 and 6 Objectives (CO)

Making sense of the Material World – Objective line 2

Prop No	Proposition	Ques No	CO
1	Materials are used by humans according to their properties.	10	MW 4-2
2	Physical properties such as strength, durability, transparency, density, flexibility, temperature tolerance, electrical conductivity, heat conductivity.	10	MW 4-2
3	Chemical properties such as corrosion, reactivity, inertness, stability, toxicity.	10	MW 4-2
4	Metals are elements that show physical properties of being shiny, conduct electricity well, conduct heat well, are flexible, malleable and ductile, are usually mechanically strong and usually have high melting points.		
5	Non metals do not show most of the properties of metals but a few show one or two.		
6	Acids and bases neutralise each other.	29	MW 5-2
7	Acids and bases are chemical opposites.	29	MW 5-2
8	Acids react with bases, metals and carbonates.		
9	Acids react with metals to form a salt plus hydrogen.		
10	Acids react with carbonates to form a salt plus carbon dioxide plus water.	46	MW 6-2
11	Fuels are organic compounds containing carbon.		
12	Fuels burn by combining rapidly with oxygen and release energy.		

Appendix E Propositions for NZ Science Curriculum level 4, 5 and 6 Objectives (CO)

Making sense of the Material World – Objective line 3

Prop No	Proposition	Ques No	CO
1	Physical changes involve a change in form but no new substances formed.	11	MW 4-3
2	Chemical changes involve the formation of a new substance.	11	MW 4-3
3	Physical changes are usually easy to reverse.	11	MW 4-3
4	Chemical changes are usually hard to reverse.	11	MW 4-3
5	Acids react with bases to form salt and water.	30	MW 5-3
6	Reactivity of metals – rusting, corrosion.		
7	Reaction rate is affected by temperature, surface area, concentration and catalyst.	47	MW 6-3
8	Fuels burn to form carbon dioxide, carbon monoxide, carbon and water.		

Appendix E Propositions for NZ Science Curriculum level 4, 5 and 6 Objectives (CO)

Making sense of the Material World – Objective line 4

Prop No	Proposition	Ques No	CO
1	Pollution of atmosphere.	31	MW 5-4
2	Pollution of waterways.		
3	Ozone hole is caused by freons from aerosols and discarded refrigerators.	31	MW 5-4
4	Greenhouse effect is caused by green house gases such as carbon dioxide and methane.	31	MW 5-4
5	Plastic manufacture, metal manufacture, paper manufacture.	12	MW 4-4
6	Chemical reactions acid-base, acid carbonate, redox, combustion.		
7	Corrosion of metals occurs when they react with oxygen in the air.	48	MW 6-4
8	Corrosion of iron is called rusting.	48	MW 6-4
9	Iron rusts by reacting with oxygen and water.	48	MW 6-4
10	Rusting can be prevented by excluding air or water.	48	MW 6-4
11	Rusting can by prevented by coating iron with a more reactive metal.	48	PEB 6-4

Appendix E Propositions for NZ Science Curriculum level 4, 5 and 6 Objectives (CO)

Making sense of the Planet Earth and Beyond – Objective line 1

Prop No	Proposition	Ques No	CO
1	Weather can be predicted from certain factors or cloud formation.	13	PEB 4-1
2	High pressure zones usually lead to fine weather, low pressure zones to wet weather.	13	PEB 4-1
3	Cloud formations such as cumulo-nimbus indicate fine weather, status indicates inclement weather.		
4	Changes to earth's surface caused by effects of atmosphere and water are called erosion.		
5	Earth's structure consists of the crust, the mantle, outer core and inner core.		
6	Convection currents in the mantle cause movement of the tectonic plates leading to continental drift.		
7	Earth's crust is broken up into about a dozen huge tectonic plates.	32	PEB 5-1
8	Collision between tectonic plates leads to earthquakes, mountain building, ocean trenches and volcanoes.	32	PEB 5-1
9	Tectonic plates moving apart cause rift valleys and mid-ocean ridges.		
10	Earth's surface is modified over millions of years by weather and by the action of water and ice.		
11	Earth's crust is made up of minerals which are naturally occurring solid chemicals.	49	PEB 6-1
12	Rocks are mixtures of minerals.		

Appendix E Propositions for NZ Science Curriculum level 4, 5 and 6 Objectives (CO)

Making sense of the Planet Earth and Beyond – Objective line 2

Prop No	Proposition	Ques No	CO
1	Sedimentary rocks are formed in layers and provide evidence of past events.	14	PEB 4-2
2	Fossils are rock replicas of hard parts of past life forms in sediments.	14	PEB 4-2
3	Fossils provide evidence of changes in life forms and geological and past events through geological time.	14	PEB 4-2
4	New Zealand straddles two tectonic plates, the Indo-Australian and the Pacific plates.	32	PEB 5-1
5	Volcanoes occur in New Zealand due to the Pacific plate pushing under the Indo-Australian plate.	32	PEB 5-1
6	Earthquakes in New Zealand are caused by the collision of the Indo- Australian and Pacific plates.	32	PEB 5-1
7	New Zealand formed by uplift due to collision of the Indo-Australian and Pacific plates.		
8	Earth's surface is continually changing due to plate movements and erosion.	33	PEB 5-2
9	Rocks have three origins – igneous, sedimentary and metamorphic.	50	PEB 6-2
10	Over millions of years, the three rock types are converted from one to another in the rock cycle.	50	PEB 6-2

Appendix E Propositions for NZ Science Curriculum level 4, 5 and 6 Objectives (CO)

Making sense of the Planet Earth and Beyond – Objective line 3

Prop No	Proposition	Ques No	CO
1	Earth orbits the sun.	15	PEB 4-3 PEB5-3a
2	The moon orbits Earth.	15	PEB 4-3 PEB5-3a
3	Earth rotates on its axis.	15	PEB 4-3 PEB5-3a
4	Astronomical explanation for day, month year.		
5	Nine planets orbit the sun.		
6	Moons orbit many of the planets.		
7	Solar system contains other orbiting bodies – comets, asteroids.		
8	Changing patterns of night sky caused by Earth rotating, Earth revolving around sun and planets orbiting sun.	34	PEB5-3a
9	The sun is a star.	35	PEB5-3b
10	A star is a mass of hot gases	35	PEB5-3b
11	Stars organized into galaxies.		
12	A light year is the distance light travels in a year.		
13	Star distances are measured in light years.		
14	Galaxies are millions of light years apart.		
15	Measurements show that galaxies are moving apart and universe is expanding.	51	PEB 6-3
16	Big bang theory asserts that universe originated from a single point in space.	51	PEB 6-3

Appendix E Propositions for NZ Science Curriculum level 4, 5 and 6 Objectives (CO)

Making sense of the Planet Earth and Beyond – Objective line 4

Prop No	Proposition	Ques No	CO
1	Local environmental issues should involve members of the local community.	16	PEB 4-4
2	Environmental issues are the responsibility of everyone, not just local and national governments.	16	PEB 4-4
3	New Zealand has a unique natural environment.	36	PEB 5-4
4	New Zealand ecosystems need to be protected as part of our national heritage.	36	PEB 5-4
5	New Zealand's natural communities developed over millions of years in isolation from other major land masses.		
6	Many New Zealand fauna and flora are unique and are vulnerable to man's economic activities and introduction of exotic species.		
7	Issues relating to formation, location and extraction of New Zealand's natural resources such as iron sands, gold, oil, gas, water.	52	PEB 6-4
8	Issues relating to extraction of natural resources are employment of people, producing commodities, exports, pollution conservation for future generations.	52	PEB 6-4

Appendix F

Specification Tables

Specification Tables - Diagnostic survey questions against curriculum objectives in each level and strand.

Specification Table 1

Curriculum Level 4 diagnostic survey items against curriculum objectives in each strand.

No	**Code**	**Living World**				**Physical World**				**Material World**				**Planet Earth and Beyond**			
		1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4
1	LW4-1	*															
2	LW4-2		*														
3	LW4-3			*													
4	LW4-4				*												
5	PW4-1					*											
6	PW4-2						*										
7	PW4-3							*									
8	PW4-4								*								
9	MW4-1									*							
10	MW4-2										*						
11	MW4-3											*					
12	MW4-4												*				
13	PEB4-1													*			
14	PEB4-2														*		
15	PEB4-3a															*	
16	PEB4-3b															*	
17	PEB4-4																*

Appendix F

Specification Table 2

Curriculum Level 5 diagnostic survey items against curriculum objectives in each strand.

No	Item	Living World				Physical World				Material World				Planet Earth and Beyond			
		1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4
1	LW5-1	*															
2	LW5-2		*														
3	LW5-3			*													
4	LW5-4				*												
5	PW5-1					*											
6	PW5-2						*										
7	PW5-1					*											
8	PW5-3							*									
9	PW5-4								*								
10	MW5-1a									*							
11	MW5-1b									*							
12	MW5-1b									*							
13	MW5-2										*						
14	MW5-3											*					
15	MW5-4												*				
16	PEB5-1													*			
17	PEB5-2														*		
18	PEB5-3a															*	
19	PEB5-3b															*	
20	PEB5-4																*

Appendix F

Specification Table 3

Curriculum Level 6 diagnostic survey items against curriculum objectives in each strand.

No	Code	Living World				Physical World				Material World				Planet Earth and Beyond			
		1	2/3	2/3	4	1	2	3	4	1	2	3	4	1/2	1/2	3	4
1	LW6-1	*															
2	LW6-2/3a		*														
3	LW6-2/3b			*													
4	LW6-4				*												
5	PW6-1					*											
6	PW6-2						*										
7	PW6-3							*									
8	PW6-4								*								
9	MW6-1									*							
10	MW6-2										*						
11	MW6-3											*					
12	MW6-4												*				
13	PEB6-1/2													*			
14	PEB6-1/2														*		
15	PEB6-3															*	
16	PEB6-4																*

Appendix G   Questions in diagnostic surveys

Science - Level 4 Student Concepts Survey

Name_______________ ID _____________________

This is a survey to help us find out about the sort of scientific ideas students at your level have. Each question is in 2 parts. The first is a straight choice between A or B. The second part is a space for you to write a reason for your choice of A or B in the first part. Answer the question by putting a ring around A or B and then write a reason for your choice in the space below.

Example:

Scientifically speaking, a tomato is a fruit.

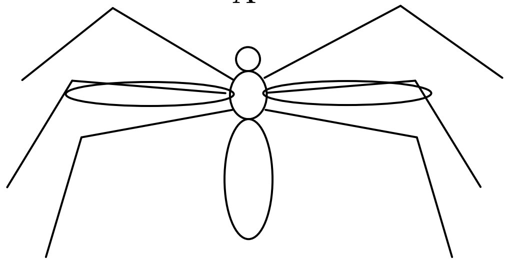
A True   B   False

Because:

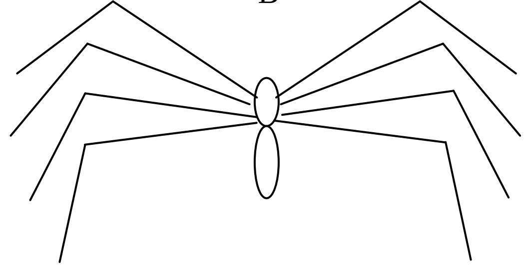
This is not a test. We are interested in your ideas about science.

1. Insects have 6 legs, most of them have wings and their body divided into 3 sections. Arachnids have 8 legs, no wings and their body is divided into 2 sections.

A



B



Animal B is an arachnid.

A) True B) False

Because:

---

2. Adaptations are features of a living thing which help it to survive and reproduce. Many plants produce brightly coloured and scented flowers. This is an adaptation.

A) True B) False

Because:

---

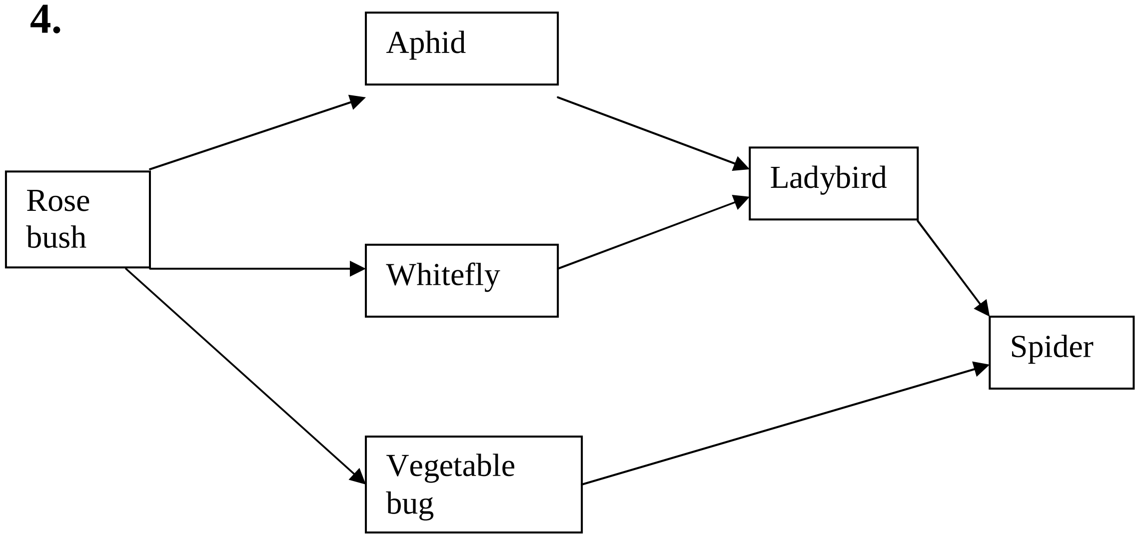
3. In a class of 30 students, 26 were right handed and 4 were left handed. Three of the left handed students had at least one left handed parent. Five of the right handed students had a left handed parent but 21 right handed students had both parents right handed.

Left and right handedness is:

A Genetic B Environmental

Because:

4.

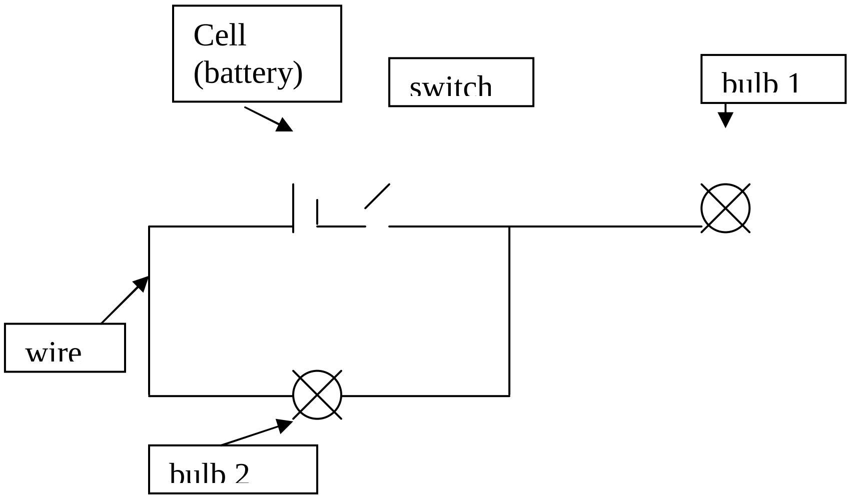


In the food web above, reducing the number of ladybirds would help the rosebush:

A True B False

Because:

5.



In the electric circuit above, when the switch is closed, bulb 1 will light up:

A True B False

Because

---

6. When washing dries on the washing line, liquid water in the wet clothes turns to water vapour in the air:

A True B False

Because:

---

7. The following table gives car speeds and stopping distances.

Speed (kilometers per hour)	Stopping distance (metres)
30	20
40	31
50	42
60	53
70	64
80	75

The figures on this table tell you that the faster the car is going the longer the distance needed for the car to stop:

A True B False

Because:

---

8. Remote controls for TV sets give out a signal which switches the TV on or off, changes channels and the sound volume. Two students were talking about how they thought it might work. Jeremy thought that the remote gave out a small electric current that passed through the air and Wendy thought it gave out a kind of invisible light.

Who do you think was correct?

A Jeremy   B Wendy

Because:

---

9. Graphite is a fairly soft, grey substance that is shiny and brittle (it snaps if you try to bend it). It conducts electricity and can withstand very high temperatures. Graphite is most likely to be a:

A Metal   B Non-metal

Because:

---

10. Over the last 50 years plastics have replaced metals in many items such as food containers. Metal cans (tins) are still widely used but plastics are being used more and more for packaging foods and drinks. At present, metal cans are better for packaging many food types:

A True   B False

Because:

---

11. When a spoonful of salt is added to water, it disappears after stirring and forms a solution. The salt cannot be filtered out of the solution and it does not settle out if the solution is left to stand. If the solution is left to dry out, solid salt is left.

Salt dissolving in water is a **temporary** change:

A True   B False

Because:

---

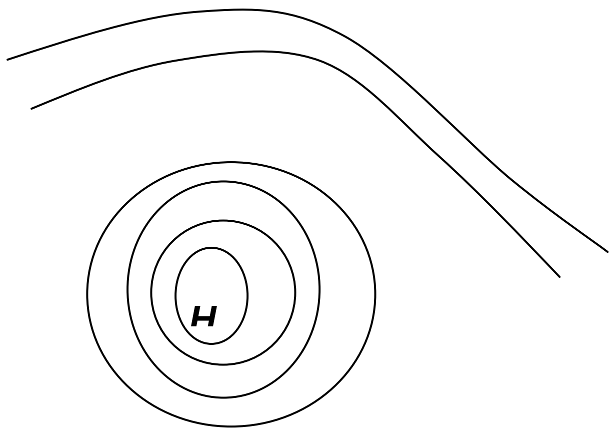
12.   Two students were doing an experiment with different types of plastics. Susan said that most plastics are made from fossil fuels such as oil. Tania said she didn't think that plastics could be made from oil. Who do you think is correct?

A Susan   B Tanya

Because:

---

13. The weather map below shows a high pressure zone in the atmosphere.



The area under this weather system will have fine weather:

A True B False

Because:

---

14. Many of the rocks found on a hillside contained fossil sea shells. This indicated that the area was once part of an ancient seabed.

A True B False

Because:

---

15. A student found a star map from a newspaper that was a year old. She noticed the planet Mars on the map and decided to use it to try to see if she could see Mars in the sky at night time.

This old map could be used to find Mars in the night sky

A True B False

Because:

---

16. Hemi and Aaron were talking about the moon. Hemi said that the moon travels around the earth and the sun. Aaron said that the earth travels around the sun, the moon travels around the earth but the moon doesn't travel around the sun. Who do you think is correct?

A Hemi B Aaron

Because:

---

17. In a tree planting project, students from the local intermediate school spent a day planting New Zealand native trees on a hillside in a reserve. One student, Sandra, said the main reason for planting New Zealand native trees is because they are cheaper than trees that are not native to New Zealand. Do you think she is correct?

A Yes B No

Because:

Appendix G Questions in diagnostic surveys

Science - Level 5 Student Concepts Survey

Name____________________ ID ______________________

This is a survey to help us find out about the sort of scientific ideas students at your level have. Each question is in 2 parts. The first is a straight choice between A or B. The second part is a space for you to write a reason for your choice of A or B in the first part. Answer the question by putting a ring around A or B and then write a reason for your choice in the space below.

Example:

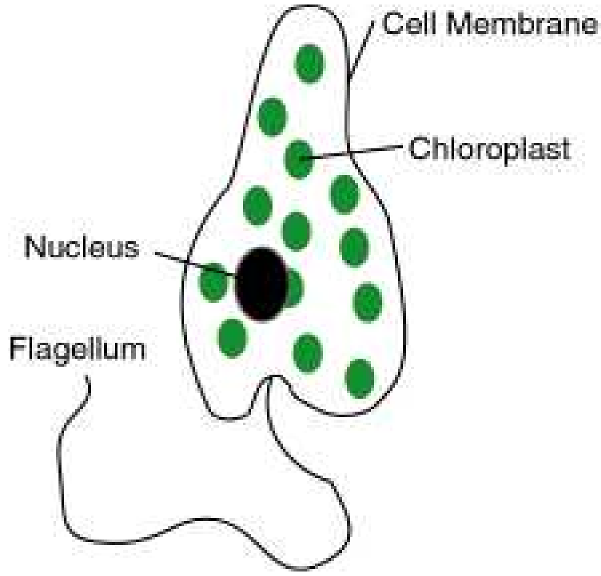
Scientifically speaking, a tomato is a fruit.

A True B False

Because: It has seeds in it

This is not a test. We are interested in your scientific ideas.

1. Euglena is a microscopic single celled organism which lives in ponds. It swims by the action of a flagellum which pulls it along. Its cell consists of cytoplasm, nucleus, chloroplasts and is surrounded by a flexible membrane. It feeds by carrying out photosynthesis but it can also absorb organic nutrients from the water.



Euglena is:

A A plant cell B An animal cell

Because:

---

2. Adaptations are features that help a living thing to survive. There are 3 kinds of adaptations:

Structural which is a body part which helps the living thing to survive

Behavioural which is something the living thing does to help it to survive

Physiological which is a chemical the living thing produces to help it to survive

Plants grow towards light. This helps the plant to carry out photosynthesis better. This growth is caused by the action of a chemical produced in the stem.

A plant growing towards light is a **behavioural** adaptation:

A True B False

Because:

---

3. A pure black guinea pig and a pure white guinea pig were mated. The first generation were all black. When 2 of the black offspring were mated, the second generation were 7 black and 2 white guinea pigs. This shows that the black gene is dominant and the white gene recessive.

A True B False

Because:

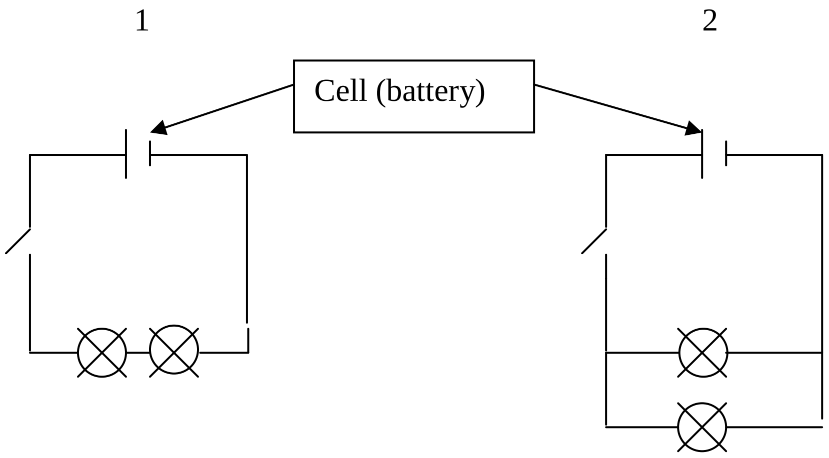
---

4. A living community contains producers, consumers and decomposers. Decomposers are essential to life on planet Earth:

A True B False

Because:

5.



The above circuits have cells of the same voltage and bulbs of the same size. When the switch is closed the bulbs in circuit 1 will be brighter than the bulbs in circuit 2:

A True B False

Because:

---

6. When an electric current lights a bulb in a circuit, electrical energy is turned into light energy which is lost from the circuit:

A True B False

Because:

---

7. If the 2 objects below are dropped at the same time:

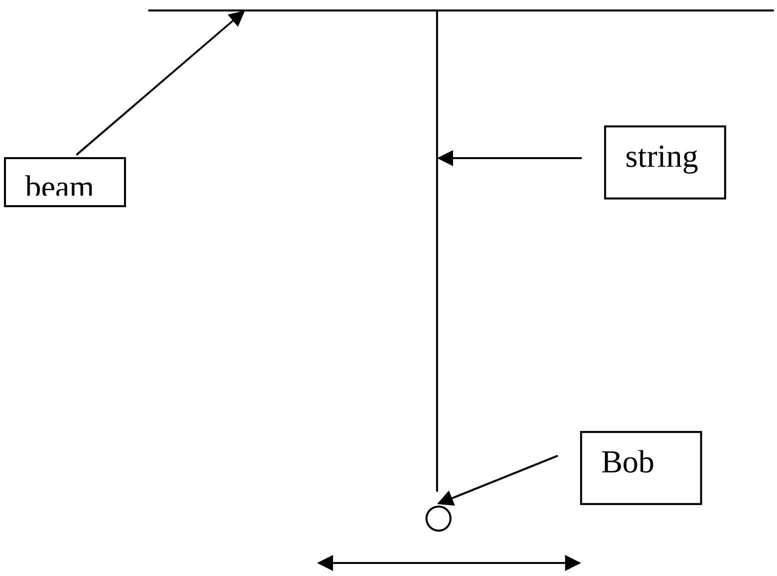
The 1 kg and 10 kg masses will hit the ground at the same time:

A True b False

Because:

---

8. 2 students set up a pendulum made from a length of string hanging from a beam in a door way and a mass hanging on the end (the bob). They were investigating the effect of the bob mass and the string length on the swing time.



The pendulum was set swinging and the student measured the time for 10 swings (each swing was back and forth). The students then divided the time by 10 to get the average time for one swing. They then repeated the experiment a number of times but changed the mass of the bob on the pendulum or the length of the string.

Here are the results:

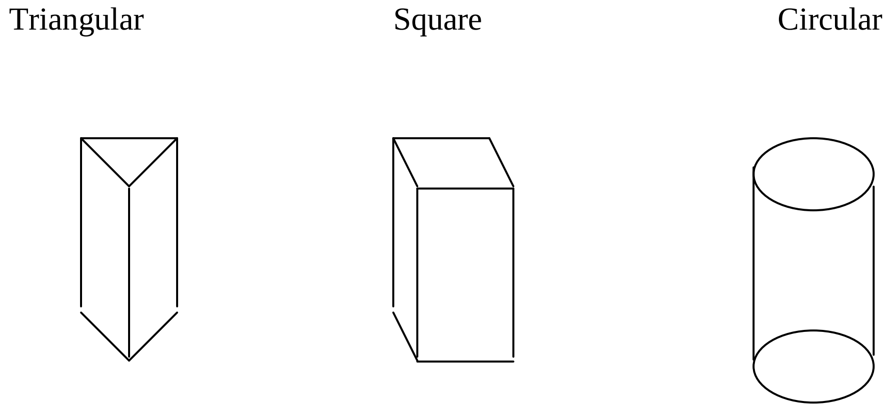
Bob mass (grams)	String length (cms)	Average swing time
50	50	1.2
100	100	2.0
50	100	2.0
100	50	1.2

From these results it can be concluded that swing-time is increased when the mass of the bob is increased **and** when string length is increased:

A True B False

Because:

9. 3 students did an investigation to find out which shape of pillar was the strongest. The 3 shapes tried were triangular, square and a cylinder. Each model pillar was made of the same sized piece of cardboard.



Masses were placed on top of each pillar until it collapsed. The mass under which the pillar collapsed was recorded. Each student did their own investigation and the results were all recorded on the table below.

	Mass which caused pillar to collapse (grams)		
Student	**Triangular**	**Square**	**Circular**
Leon	250	250	300
Jenny	300	300	350
Don	250	350	350
Average	267	300	333

The pillar with the circular end was the strongest:

A True B False

Because:

____

10. A small amount of a liquid called ether is poured into a plastic bag, the air is squeezed out and the bag is tied tightly at the top. The plastic bag is then placed in a tray and hot water is poured over it. The bag inflates and there is no longer any liquid ether in the bag.

This can be explained using the theory that all matter is made up of tiny particles that are too small to see.

A True B False

Because:

---

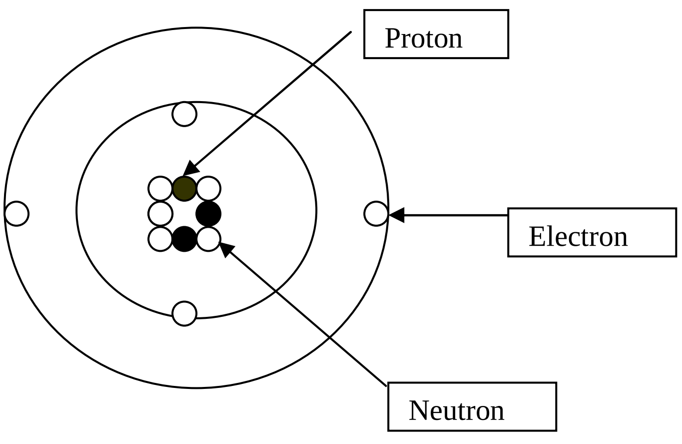
11. Water is a pure substance made up of hydrogen and oxygen. Hydrogen is an explosive gas and oxygen is a gas that helps burning. Scientifically speaking water is:

A an element B a compound

Because:

---

12. Look carefully at the drawing of an atom below.



The number of protons, neutrons and electrons in this drawing of an atom indicate that it is an atom of a naturally occurring element:

A True B False

Because:

---

13. Oven cleaner is a strong base called caustic soda which breaks down fat and grease. If some oven cleaner is sprayed accidentally on to the floor, a safe way to deal with it would be to sprinkle it with citric acid (a weak acid powder used in baking) and then clean up with a wet mop:

A True B False

Because:

---

14. When dilute sulfuric acid reacts with sodium hydroxide, a **salt** is formed:

A True B False

Because:

---

15. A positive effect of burning fossil fuels such as petrol and diesel is that it gives us fast transport of people and goods in vehicles such as cars, trucks, trains and aircraft. Burning these fuels also releases millions of tonnes of carbon dioxide into the air.

This is a negative (bad) effect:

A True B False

Because:

____

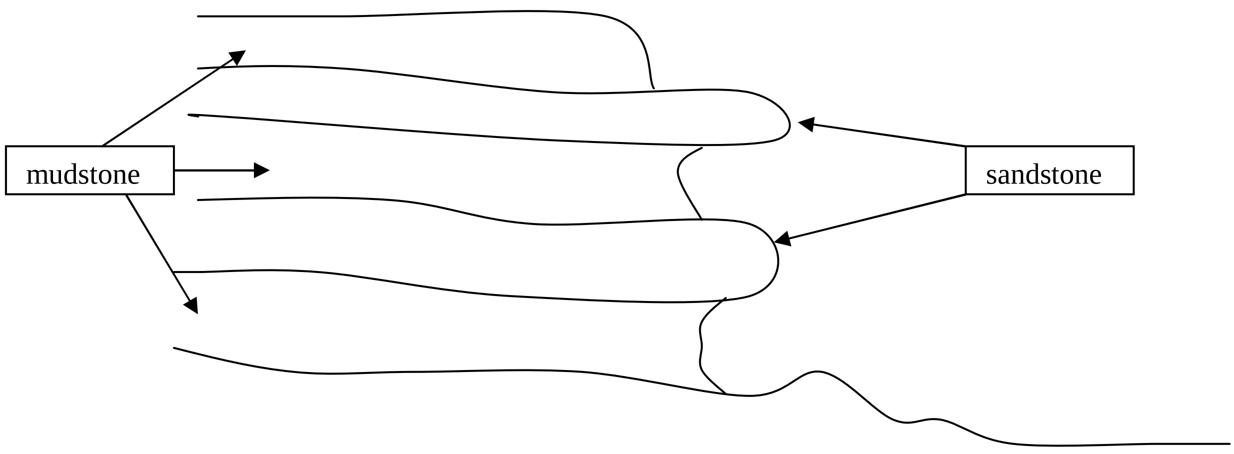
16. New Zealand has more earthquakes than Australia:

A True B False

Because:

____

17. The diagram below shows a cliff section made up of layers of 2 rock types, sandstone and mudstone.



The shape of the cliff indicates that sandstone is a softer rock than mudstone:

A True   B False

Because:

---

18. On a clear night the Southern Cross can be seen to change its position in the night sky from the evening through to early morning. This is because the stars that make up the Southern Cross are moving.

A True   B False

Because:

---

19. Our sun is an average sized star like many thousands of others in the night sky.

A True   B False

Because:

---

20. Huia and Kate were talking about protecting New Zealand’s environment. Huia said that New Zealand’s environment was the responsibility of all New Zealanders. Kate said that there wasn’t much ordinary people could do and that it was the job of the government to protect New Zealand’s environment. Who do you think is right?

A Huia B Kate

Because:

____

Appendix G Questions in diagnostic surveys

Science - Level 6 Student Concepts Survey

Name____________________ ID ____________________

This is a survey to help us find out about the sort of scientific ideas students at your level have. Each question is in 2 parts. The first is a straight choice between A or B. The second part is a space for you to write a reason for your choice of A or B in the first part. Answer the question by putting a ring around A or B and then write a reason for your choice in the space below.

Example:

Scientifically speaking, a tomato is a fruit.

A True B False

Because: It has seeds in it

This is not a test. We are interested in your ideas about science.

1. Viruses are minute particles that can only be seen with an electron microscope. They are able to reproduce only in living cells of a host. Viruses consist of nucleic acid surrounded by a protein coat and they can be crystallized like chemicals. They cannot be grown on agar plates as bacteria can.

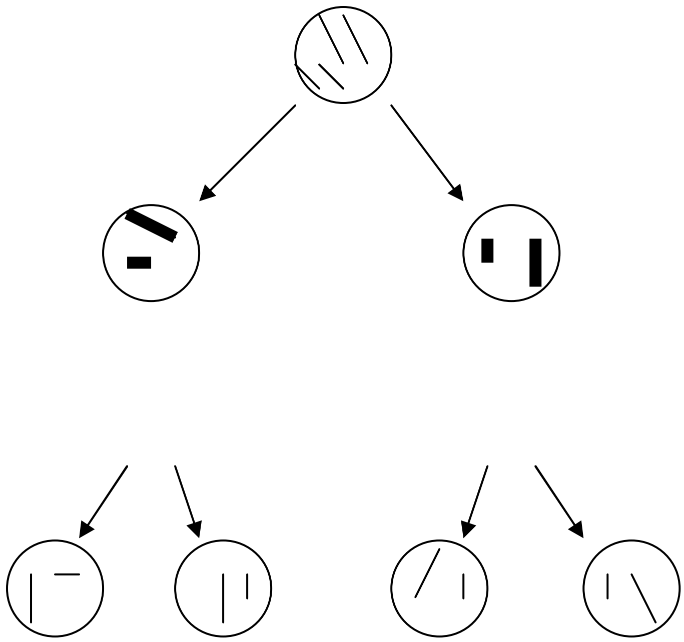
Viruses are:

A Living B Non-living

Because:

---

2. The diagram below shows the stages of a cell dividing. The number of chromosomes in the cells is given.



This cell division is:

A Mitosis B Meiosis

Because:

---

3. Potato plants can reproduce by growing more potatoes (tubers) underground. Each tuber forms a new plant. This is an asexual method of reproduction. Potato plants can also reproduce by producing flowers, fruits and seeds. This is a sexual method because it involves gametes and fertilization.

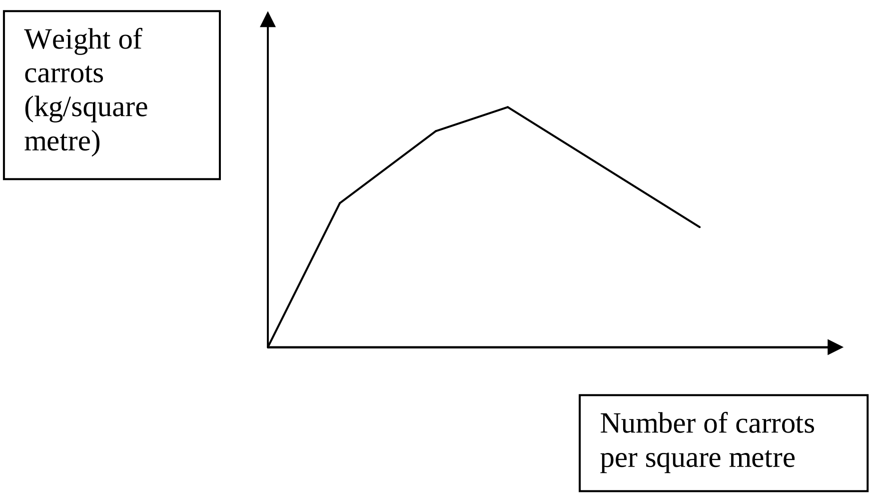
Sexual reproduction is necessary to ensure the survival of the potato species over time.

A True B False

Because:

---

4. A horticulturist experimented with growing carrots to get maximum yield. She found that by growing carrots closer together they reach a smaller size than carrots grown further apart, but she could grow more carrots in a given area. A graph showing the weight of carrots harvested per square metre is shown.



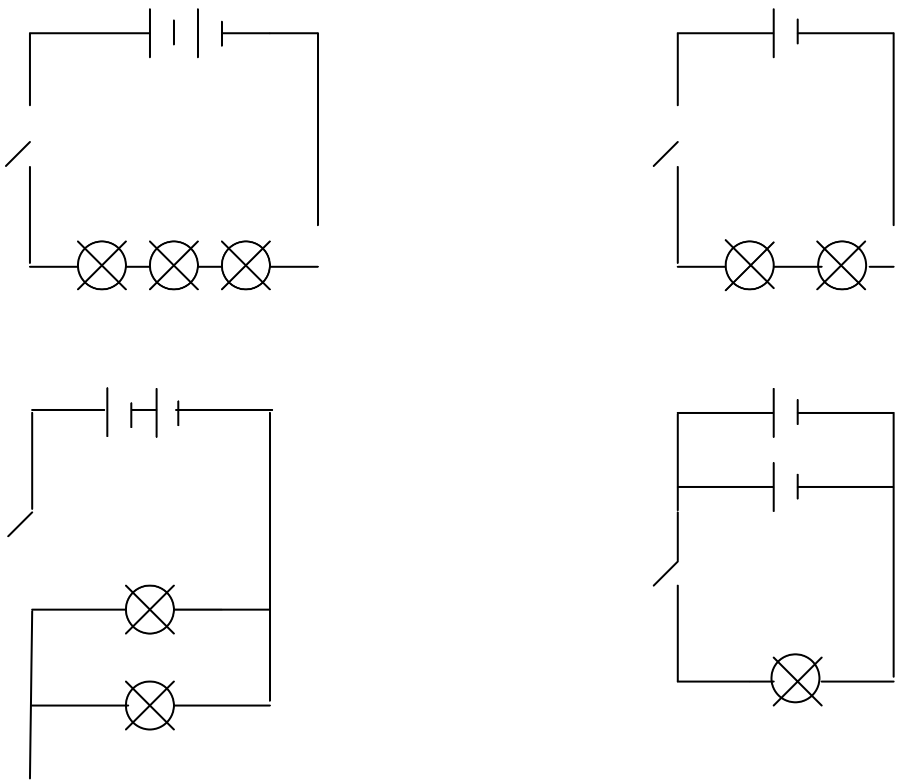
The drop off in the total weight of carrots grown per square metre of soil is competition:

A True B False

Because:

---

5. A student set up these circuits to investigate the effect of increasing the number of **cells** in the circuit on bulb brightness.



The circuits will enable the student to make a valid conclusion from the results:

A True B False

Because:

---

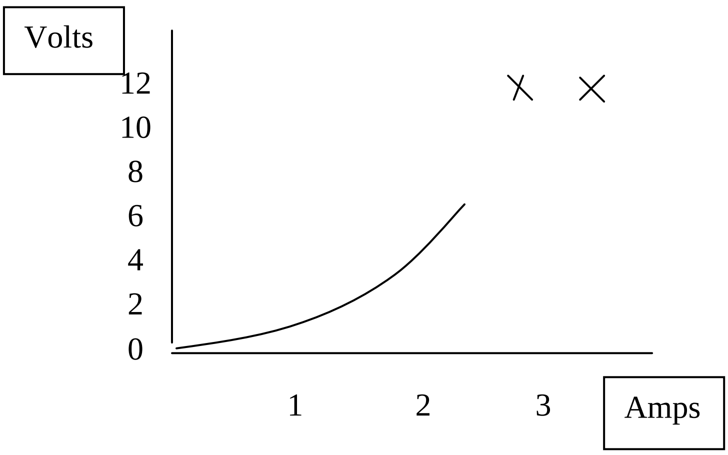
6. Water flows through a hydro-dam. The water flow is used to generate electricity. A student thought that if the water flowing through the dam could be pumped back up to the lake, it could be used to make more electricity when it flowed back through the dam. This would be a sensible way of making a lot more electrical energy:

A True B False

Because:

---

7. The graph below shows the amount of electric current flowing through an electric light bulb at different voltages.



A valid prediction for the current that will flow through the light bulb when the voltage is 12 volts is:

A 2.5 Amps B .0 Amps

Because:

---

8. Optical fibre cable has replaced copper wire cables in many of the world's telephone systems. In optical fibre, the signals are transmitted by pulses of laser light instead of electricity. Light travels much faster than electricity and many more signals can be transmitted at once, making high band-width internet transmission possible. The energy loss over long distances, due to the electrical resistance of copper, is much lower with transmission of light pulses along optical fibre. Optical fibres are made out of very pure glass which requires expensive high precision technology for manufacture. This expense is offset by the fact that the raw material for making the glass fibre is sand, which is much cheaper than copper.

Optical fibre cables have revolutionized telecommunications:

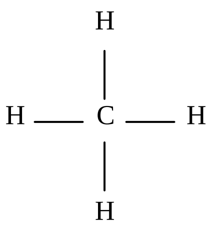
A True B False

Because:

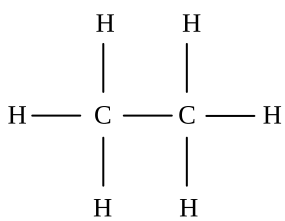
____

9. Here are some structural formulae of some organic compounds.

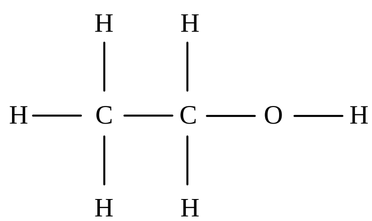
Methane



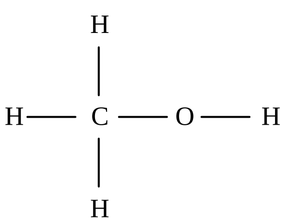
Ethane



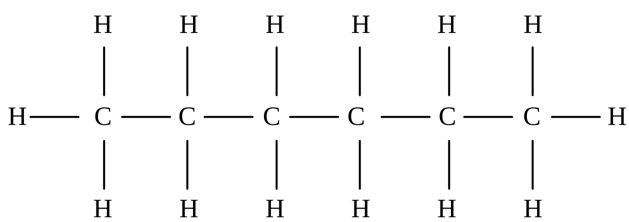
Ethanol



Methanol



Hexane



These organic compounds belong in 2 groups in terms of their chemical properties. Ethane and ethanol belong in the same group:

A True B False

Because:

---

10. A gardener found that his soil had a pH of 5 and he knew that cabbages do not grow well in acid conditions. He added lime (calcium carbonate) and found that his cabbages grew much better.

The lime improved the growth of the vegetables because it is an essential food for plants.

A True B False

Because:

---

11. Marble lumps in hydrochloric acid fizz, giving off carbon dioxide. If the marble lumps are ground up to a powder, then mixed with hydrochloric acid, the fizzing would be much faster:

A True B False

Because:

---

12. Iron can be prevented from rusting by coating it with zinc (galvanizing). Zinc protects iron from rusting even if it does not cover the iron completely:

A True B False

Because:

---

13. The table below shows 4 minerals with their 3 properties compared. The properties are:

- hardness (on a scale of 1 = soft to 10 = very hard)
- colour
- reaction with dilute acid.

Mineral	Hardness	Colour	Reaction with acid
calcite	3	colourless, yellow, orange, brown, green	fizzes
gypsum	2	Colourless, white	no reaction
apatite	5	white, brown, green, yellow, violet	no reaction
quartz	7	colourless, white, pink, blue, black	no reaction

If you were given a piece of mineral and told that it was one of the 4 listed above, you could find out which by noting its colour and testing with acid.

A True B False

Because:

---

14. Rocks that form from volcanic larva are igneous rocks whereas rocks that form on the ocean bed from sediments that cement together are called sedimentary rocks.

Over millions of years igneous rocks can become sedimentary rocks:

A True B False

Because:

---

15. Astronomical measurements show that the galaxies in the universe are moving apart and that the universe is expanding. This evidence supports the 'big bang theory' of the origin of the universe.

A True B False

Because:

---

16. New Zealand's fossil fuels such as coal, oil and gas are non-renewable and should be managed carefully:

A True B False

Because:

Appendix H

Collated student alternative conceptions identified from three search techniques

- Alternative conceptions related to objectives at levels 4, 5 and 6 in the four contextual strands of the New Zealand science curriculum were identified from three search techniques and are listed below.
- The alternative conceptions in non-Italics are those identified from the student surveys and follow up telephone interviews.
- The alternative conceptions in Italics are alternative conceptions predicted by science teachers.
- Some questions have notes for further explanation.

Curriculum Level 4

Question 1

- These are not animals.
- The ability to use information given to classify an organism into a broad group. Students mixed up the combinations of number of legs, number of body sections and presence of wings.

Question 2

- Brightly coloured and scented flowers do not help the plant to survive any better.
- *Brightly coloured and scented flowers are attractive to people who pick them helping the plant to survive.*
- *Flowers make food for the plant helping it to survive.*

Question 3

- Left handed parents teach their children to be right handed.
- *Right handedness is more common than left handedness.*
- *We live in a right handed world so most people choose to be right handed.*

Question 4

- Fewer ladybirds would feed on less of the rose bush.
- The number of ladybirds has no effect on the rose bush since they don't feed on it directly.
- *Reducing the number of ladybirds would reduce the number of aphids helping the rose.*

Question 5

- The electric current will flow round the circuit and out to bulb 1.
- No electric current will flow in the circuit.
- *The electric current will flow to bulb 1 and back to the battery.*

Question 6

- Water dries by droplets going into the air.
- The sun 'sucks' water up.
- Wind blows water drops from clothes.
- *The washing dries mainly because water drips out of the wet clothes ('drip dry').*
- *Heat from the sun boils the water into steam*

Question 7

- Stopping distance increases with speed.
- *As speed goes up the driver's reaction time increases.*
- *It will depend on the type of car the person is driving.*

Question 8

- It must be light because a light goes on the TV when the remote is used.
- It must be electricity because the remote contains a battery.
- It can't be light because you can't see it.
- *It must be electricity because a TV works using electricity.*

Question 9

- Graphite is a metal because it conducts electricity.
- Metals are all strong (too strong to break).
- Metals are hard.
- Metals can withstand high temperatures.

Question 10

- Metal rusts (only iron does, which in the case of tinplate is valid but only when tin layer penetrated).
- Metals are stronger and can withstand heat.
- *Metals conduct electricity.*
- *Plastics are cheaper.*

This question relies on interpretation and application of the information given. There is a tendency for some students to interpretation **some** as **all.**

Question 11

- Salt won't reform from solutions on evaporation.
- Salt will settle from solution in time.
- *Mixture cannot be separated by passing it through a filter.*

Evaporation to some respondents meant the same as drying or setting.

Question 12

- Plastic is an ingredient in crude oil and can be separated out.
- Plastic could not be made from crude oil because it is so different.
- If oil was part of plastic, it would show itself somehow.
- *The elements that make up plastics are different from the elements in fossil fuels.*

Question 13

- Atmospheric pressure pattern represents a layered section of a structure.
- The 'H' represents high atmospheric pressure.
- The 'H' represents high temperature.
- The 'H' means high winds.

Question 14

- The sea in the area dried up leaving many sea shells.
- *The land was flooded and the seashells were left when the flood receded.*
- *Sea shells put there by humans.*

Sea shells in a rock indicates a marine origin. Sea shells had become fossils indicating age. The Earth's surface has changed over time. The time scale from the big bang, to the formation of the Earth, to the evolution of life-forms, to humans is the basis for some alternative conceptions. The biblical influence also contributes to alternative conceptions.

Question 15

- Planets are stars.
- Planets orbit the sun therefore positions in the night sky change form year to year.
- Earth orbits the sun.
- Mars moves independently of Earth.
- Mars is way beyond Earth's atmosphere.
- Earth rotates on its axis and orbits the sun.

Question 16

- Earth orbits the moon.
- The sun orbits Earth.
- The moon orbits Earth.

Question 17

- *Using students gets the job done quickly and cheaply.*
- *Students would learn how to plant trees.*

Use of New Zealand native trees to recreate a natural community helps to preserve New Zealand's unique natural heritage. Community involvement in environmental projects helps people to appreciate it more. The curriculum objectives in this line are as much to do with affective as the cognitive domain in Bloom's Taxonomy.

Curriculum Level 5

Question 1

- Plants absorb organic nutrients.
- An organism is a plant.
- Only animal cells have a nucleus.
- Plants cannot be single celled.
- Cell membrane and cell wall are the same thing.

The terms organic and inorganic contribute to interpretation of this question because of the different meanings of the word 'organic' in science and in the student's everyday world.

Question 2

- A growth response brought about by a chemical is physiological.
- *Growing towards light uses up energy.*
- *An adaptation involving the stem must be structural*

Question 3

- The dominant trait is the more common one.
- *Black is the dominant trait because it is the stronger colour.*
- *If black was dominant then the white trait would not have reappeared.*

Question 4

- Animal life could continue because animals do not use minerals directly from the soil.
- *Decomposers recycle energy in a community.*
- *Life could continue without decomposers because there are enough minerals to keep life going.*

Decomposers perform an essential function for other life forms. The recycling role of decomposers is often not understood.

Question 5

- Electric circuits in parallel circuit shared (split half and half) the electric current.
- Circuits with same components will have same current flowing. irrespective of series or parallel connections.
- The length of wire in a circuit has a significant effect on the current through a bulb.
- *Two bulbs in parallel have more resistance than two bulbs in series.*

Question 6

- Electrical energy is converted to light energy.
- Light energy given out by a light bulb is lost from the circuit.
- Electrical energy in a circuit is a continuous circular flow of current.
- *Electrical energy turns to light energy in the bulb and changes back to electrical energy to continue round the circuit.*
- *Electrical energy turns to light energy but the light turns back to electrical energy when the light is switched off.*

Question 7

- Larger masses fall faster than smaller masses.
- Masses fall at same rates because gravity evens out.
- Masses fall at same speed because they have the same terminal velocity due to air resistance.
- *The 10 kg mass has more air resistance so both masses fall at the same speed.*

Question 8

- Mass affects swing-time of a pendulum.
- Both mass and string length affect the swing time.
- *The swing time increased when the mass of the bob and the string length had the same value (numerical).*

Question 9

- The pillar that held the biggest mass was the strongest.
- The result was inconclusive because of overlap between the 3 shapes.
- Ignoring of evidence and drawing on personal knowledge.
- *Lack of understanding of the significance of mean mass.*

Question 10

- Particles expand when heated.
- Particle number increases when heated.
- Particles cannot be seen so theory doesn't make sense.
- *Heat makes the bag softer so it swells.*

Question 11

- Water is a pure substance so is not made up of anything else.
- Water cannot be a mixture of two gases.
- Water is one of the 4 elements, earth, wind, fire and water.

Question 12

- Neutrons are present in the same number as protons and electrons.
- Outer shell of 8 electrons in natural atoms.
- Element, compound, atom – mixing up of ideas around these.
- *Electrons are in the nucleus.*

Question 13

- Acid is the name for any hazardous substance.
- Substances that 'burn you' are acids.
- All acids 'burn you'.
- *Citric acids would not affect caustic soda.*
- *The caustic soda should be left to evaporate dry.*

Question 14

- Acids react with metals to form hydrogen.
- Salt just means table salt, sodium chloride.
- A salt can only be said to have formed when it is a solid.
- Salts only form when acids react with metals.
- *Sulfuric acid and sodium hydroxide would not react.*

Question 15

- Carbon dioxide damages the ozone layer.
- Carbon dioxide increase in atmosphere will improve the weather.
- Carbon dioxide will help plants because they need it for photosynthesis.

Question 16

- Earthquakes are linked to climate.
- Earthquakes depend on the size of the land mass.
- Earthquakes related to landslips.

Question 17

- Soft rock is squeezed thinner and bulges out behaving like cream in a gateau.
- *The shape of a rock formation is because that is how it was created.*

Question 18

Stars go around the Earth.

- Stars appear to move in the night sky because Earth is orbiting the sun.
- The Milky Way is revolving so the stars are moving.

Galaxies rotate, so the stars within them move. The Sun is not seen as a as star by many students and conversely the stars are not seen as suns. Earth orbits the Sun along with other planets, and moons orbit planets including the Moon that orbits Earth. In addition, planets rotate. This presents a fairly complex system in terms if what an observer on Earth sees. Alternative conceptions around this complexity abound. Set all of this against everyday language such as sunrise, sunset and rising moon it is easy to see how alternative conceptions arise.

Question 19

- The Sun is much larger than the star.
- The Sun is the largest star.
- *The sun shines during the day and stars shine at night.*
- *The stars reflect light from the sun.*

The notion that stars consist of burning gases is a common alternative conception. Burning can just mean 'hot' in everyday the language of many students, but it is important to dispel the notion that combustion is taking place.

Question 20

- Ordinary people can't do anything to help the environment.
- Only the government can help the environment by passing laws.
- New Zealand has a small population so the environment is not threatened.

The desirable attitudinal position in relation to this curriculum objective is that we all have responsibility for our environment, not just the government. Individual responsibility of 'think globally, act locally' is central to this notion, where actions such as responsible disposal of waste and recycling are desirable outcomes.

Curriculum Level 6

Question 1

- Viruses consist of cells.
- Viruses are too small to be alive.

Question 2

- Chromosomes replicate in both divisions.
- The cells formed have the same number of chromosomes as the parent cell.
- *Chromosomes pair up but do not replicate.*

Mitosis is the single division for the exact duplication of genetic material during growth and repair. Meiosis is a process consisting of two divisions in which genetic material replicates once resulting in daughter cells with half the normal number of chromosomes. Its purpose is to produce haploid gametes so that the normal diploid chromosome number is restored on fertilization. The different processes and functions of these two types of cell division contribute to the alternative conceptions identified.

Question 3

- Asexual reproduction is more reliable therefore no need for sexual reproduction.
- Asexual reproduction occurs more quickly therefore no need for sexual reproduction.
- Potatoes are not living.
- Potatoes do not flower.
- *Sexual reproduction is a more complex process therefore less likely to take place.*

Potatoes are not seen as living things by some students. Potatoes are flowering plants and can therefore reproduce sexually by producing seeds, as well as asexually with tubers. Seed reproduction is a sexual method. Sexual reproduction gives variation. Variation is necessary for survival of a species over time. Variation enables species to adapt to environmental change. This represents a sequence of propositions that must be constructed by the learner in order for the need for sexual reproduction to ensure survival of the species.

Question 4

- All carrots receive the same amount of light, minerals and water so they are not competing with each other.
- The carrots will only be in competition if the are in contact with each other.
- *Pests and diseases are more likely to cause the drop off in weight.*

Competition is for any resources a living thing needs such as nutrients, water, light and soil. These factors affect (carrot) growth and size. Competition is more than just a space factor. Competition for resources by a crop occurs above ground as well as below. Competition can be used to control crop size, uniformity and overall yield.

Question 5

- The student can use these circuits to draw conclusions of the effect of changing the number of cells in series or parallel and on bulb brightness.
- Some of the circuits are not correctly connected.
- *Any change in bulb brightness will be caused by the change in the number of cells in the circuit.*

Question 6

- The water would all get used up and there would not be enough left in the river.
- Water could just be made to flow round and round making electricity *every time it flowed back through the dam because energy cannot be destroyed.*
- *Water is not used up as it passes through the dam therefore more energy could be made this way.*

When energy is converted from one form to another, some energy is always lost to the surroundings in a non-useful form e.g. heat and sound. The total energy remains constant, but the capacity to perform work is reduced with every conversion. This 'big idea' is not not well understood by many students. Environmental considerations could be valid if recycling the water resulted in reduction of water flow in the river, but it is not an issue here because pumping water back up to the lake to generate more electrical energy is not energetically feasible.

Question 7

- By extending the graph with a straight line this point (3.5 Amps) is passed through.
- An average figure is calculated using V/I = R.
- *It is not valid to make this prediction from this type of graph since the reading is outside the range of values recorded.*

A graph can be used to make **predictions** by extending a curve, i.e. extrapolation which is more than just drawing a straight line in many cases.

Question 8

- Optical fibre is cheaper to produce than copper.
- Optical fibre conducts electricity much faster than copper.
- *Optical fibre is easier to manufacture.*

Optical fibre transmits signals by light pulses. Transmission of signals by optical fibre is more efficient due to the fact that more signals are transmissible with optical fibre.

Question 9

- Ethanol and ethane both contain two carbon atoms.
- *Ethanol belongs with hexane because both are liquids.*
- *Ethanol belongs with propane because they have similar molecular masses.*

Alkanes consist of carbon and hydrogen only, whereas alcohols consist of carbon, hydrogen and oxygen. Alcohols contain a –OH functional group whereas alkanes do not. The –OH functional group in alcohols confers different properties to the compound. The –OH group is more significant than the number of carbon and hydrogen atoms in the molecule. The significance of the functional group in determinating the properties of an organic compound is not understood by some students.

Question 10

- Vegetables need to absorb calcium carbonate for healthy growth.
- Lime powers soil pH to a level more suitable for plant growth.
- *Lime destroys pest and diseases that retard plant growth.*

Lime is basic and therefore neutralizes acids in soil. Lime increases soil pH and neutralisation of soil acids leads to raising pH. Lime therefore functions as a soil conditioner not as a plant nutrient.

Question 11

- Lumps have more surface area than the powder.
- *Powdered marble only seems to react faster because it gives off a large number of small bubbles.*

- *Hydrogen ions in the acid would collide more often with lumps of marble than with the powder.*

More marble is available for reaction with acid in powder form because in lump form the acid ‘can’t get to the inside’. The mathematical concept of surface area increasing with granularity is often problematic at this level. There is often an ‘indirect’ understanding without the surface area concept.

Question 12

- Rust occurs from inside the iron.
- Rust can only be prevented by covering the iron completely and sealing out the oxygen and water.
- Zinc protects by attracting water away from iron.
- Zinc protects iron by removing electrons from the iron preventing the iron from rusting.

Rusting is a chemical reaction involving electrons. Iron reacts by losing electrons, therefore any metal that loses electrons more easily than iron will corrode preferentially to iron (sacrificial protection). This is a difficult concept for students at this level because requires the construction of a sequence of propositions to lead to full understanding.

Question 13

- The white colour meant that it could have been any of the minerals in the table.
- Calcite is usually brightly coloured.
- *Calcite is softer than gypsum.*

The ability to think in terms of a combination of properties to distinguish the four minerals is the challenge to the student. Colour alone is not enough, comparative hardness is not enough and acid reaction can only identify calcite.

Question 14

- Rocks can’t change over time.
- Igneous rocks form from volcanoes and sedimentary rocks form under the sea so one cannot form into the other.

- Sedimentary rocks form when igneous rocks are submerged by sea.
- If larva from volcanoes flows into the sea, they will form sedimentary rock.

Erosion and deposition lead to sediments in the sea which over time form sedimentary rocks. Sedimentary rocks thus form from other rock types including igneous. The time scale is not understood by many students

Question 15

- The universe is expanding so this proves that it started form one huge lump of matter and energy.
- *The galaxies are not moving away from each other, they only appear to be.*
- *The universe had no beginning, it has always existed.*

The galaxies moving apart suggests that they could have started from an initial mass of matter and energy which exploded. It therefore **supports** the big bang theory but does not **prove** it, however. Alternative conceptions relating to this are to do with the nature of science as well as notions of how the origin of the universe. The solar system is only the system around one star, the Sun, in the Milky Way galaxy. The Milky Way galaxy is one of millions of galaxies in the universe. The concepts relating to the of organization and scale of the universe are the issue here.

Question 16

- There are unlimited reserves of fossil fuels on Earth, they just have to be found.
- Fossil fuels will be replaced by sustainable, non-polluting forms of energy.
- *Fossil fuels are slowly replaced so if they are used carefully they will have time to replace what we use.*

To use up Earth's energy resources without careful management and planning is irresponsible and unfair to future generations. This continues the affective nature of this objective line.

Appendix I

On-line diagnostic instrument (Word form version)

Science Concepts Diagnostic Instrument

Name ID

Each question is in 2 parts. The first is a straight choice between A or B. The second part is a reason for your choice in the first part. Answer each question by left clicking with your mouse as follows:

- click on the first grey answer box and then click to choose A or B ☐

- then click on the second grey answer box and then click to choose reason 1, 2, 3 or 4

It is only possible to select one choice (A or B) and one reason (1, 2, 3 or 4).

There is also a box below each question **if** you wish to write anything further e.g. if none of the reasons fit your thinking. If you decide to write in this box, it will expand as you write.

Here is an example:

Scientifically speaking, a tomato is a fruit:

A True *B False* A

Because:

1. *It is round and brightly coloured.*
2. *It does not grow on a tree.*
3. *It contains seeds.*
4. *It has a savoury flavou*r.

3

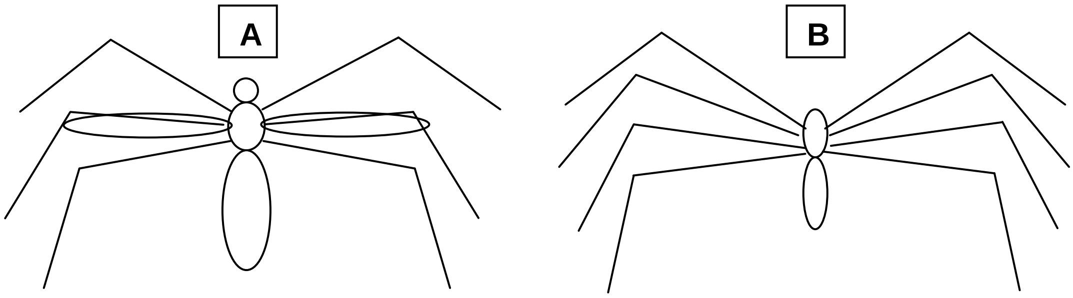
The scientifically correct answer for this question is **A3** – scientifically speaking, a tomato is a fruit because it contains seeds.

When you have chosen your answers to both parts of a question, please scroll with the single down arrow at the bottom right of your screen to the next question.

There are 52 questions. (The numbers in brackets after each question number indicate the curriculum objective the question focuses on. Please ignore them).

Good luck!

1.(LW4-1) Insects have 6 legs, a body divided into 3 sections and most of them have wings. Arachnids have 8 legs, no wings and a body divided into 2 sections.



Animal B is an arachnid:

A) True *B) False* □

Because:

1. *It has 8 legs, body divided into 2 sections and wings.*
2. *It has 6 legs body divided into 3 sections and wings*
3. *It has 6 legs body divided into 3 sections and no wings*
4. *It has 8 legs, body divided into 2 sections and no wings*

□

2.(LW4-2) Adaptations are features of a living thing which help it to survive and reproduce. Many plants produce brightly coloured and scented flowers. This is an adaptation.

A) True *B) False* □

Because:

1. *Bright, scented flowers don't help the plant to survive any better.*
2. *Bright, scented flowers attract pollinating insects which help the plant to reproduce.*
3. *Bright, scented flowers are attractive to people who pick them, helping the plant to survive.*
4. *Bright, scented flowers make extra food for the plant, helping it to survive.*

☐

3.(LW4-3) In a class of 30 students, 26 were right handed and 4 were left handed. Three of the left handed students had at least one left handed parent. Five of the right handed students had a left handed parent but 21 right handed students had both parents right handed.

This indicates that left and right handedness is:

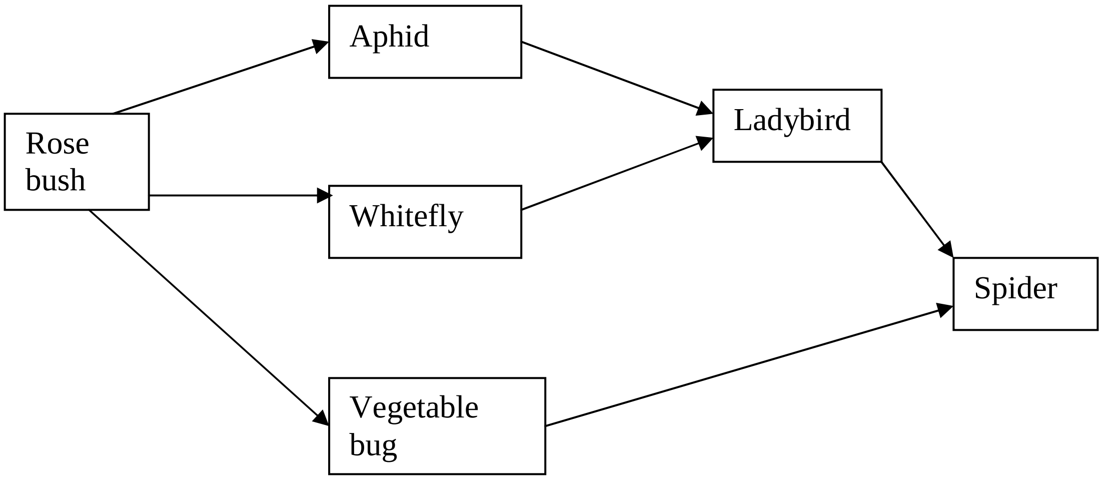
A Inherited *B Non-inherited* ☐

Because:

1. *Left handedness tends to run in families.*
2. *Left handed parents teach their children to be right handed.*
3. *Right handedness is more common than left handedness.*
4. *We live in right handed world so most people choose to be right handed.*

☐

4.**(LW4-4)**



In the food web above, reducing the number of ladybirds would benefit the rosebush:

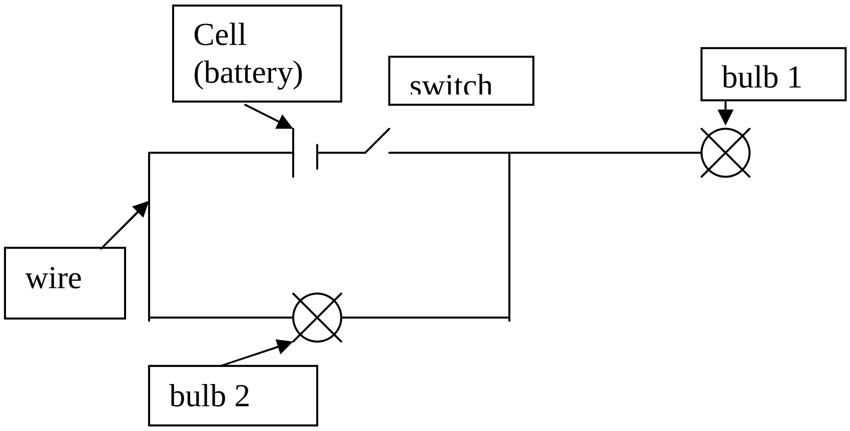
A True *B False* □

Because:

1. *Fewer ladybirds would increase the number of aphids and whitefly which would feed on more of the rose bush.*
2. *Fewer lady birds would feed on less of the rose bush.*
3. *The number of ladybirds has no effect on the rosebush since they don't feed on it directly.*
4. Reduction in the number of ladybirds would cause a reduction in the number of aphids and whitefly which would feed on less of the rose bush.

□

5.(PW4-1)



In the circuit above, when the switch is closed, bulb 1 will light up:

A True *B False* □

Because:

1. *The electric current will flow around the circuit and out to the bulb.*
2. *No electric current will flow in the circuit.*
3. *The bulb is not part of the circuit, so the current cannot flow through it.*
4. *The electric current will flow to the bulb and back to the battery.*

□

6.(PW4-2) When washing dries on the washing line, liquid water in the wet clothes turns to water vapour in the air:

A True *B False* □

Because:

1. *The washing dries mainly because all of the water drips out of the wet clothes due to gravity.*

2. *The washing dries mainly because heat energy from the sun changes the liquid water in the wet clothes into water vapour in the air.*
3. *The washing dries mainly because the wind shakes the water out of the wet clothes until they are dry.*
4. *The washing dries mainly because heat from the sun boils the water into steam.*

□

7.(PW4-3) The following table gives car speeds and stopping distances.

Speed (kilometers per hour)	Stopping distance (metres)
30	20
40	31
50	42
60	53
70	64
80	75

The figures on this table tell you that the faster the car is going, the longer the distance needed for the car to stop:

A True *B False* □

Because:

1. *As speed goes up the driver's reaction time increases.*
2. *Stopping distance is always less than speed.*
3. *It depends on the type of car and who is driving it.*
4. *As speed goes up, stopping distance goes up.*

□

8. (PW4-4) The remote control for a TV set gives out a signal which switches the TV on or off , changes channels and volume. Two students were talking about how they thought it might work They observed that the signal cannot pass through objects that are in the way but it does sometimes seem to reflect off objects on to the TV set. Jeremy thought that the remote gave out an electrical signal and Wendy thought it gave out a kind of invisible light.

Who do you think was correct?

A Jeremy *B Wendy* □

Because:

1. *It must be light because a light on the TV goes on when the remote is used.*
2. *It must be electricity because the remote contains a battery and batteries give out electricity.*
3. *It must be electricity because a TV works using electricity.*
4. *It must be light because the signal cannot pass through things that get in the way but it does sometimes seem to reflect off objects on to the TV set.*

□

9.(MW4-1) Sodium is a fairly soft, shiny, grey, substance. It conducts electricity well. It melts at 98°C.

A Metal *B Non-metal* □

Because:

1. *It conducts electricity well.*
2. *It melts easily.*
3. *It is shiny.*
4. *It is fairly soft.*

☐

10.(MW4-2) Over the last 50 years plastics have replaced metals in many items such as food containers. Metal cans (tins) are still widely used. Foods such as meat, fish and baked beans are cooked in the can before the lid is sealed on. Plastics are being used more and more for packaging foods and drinks. They are cheaper and do not corrode. Metal cans are still better for packaging foods such as meat, fish and baked beans:

A True *B False* ☐

Because:

1. *Metals corrode and plastics do not.*
2. *Metals are stronger and can withstand heat.*
3. *Metals conduct electricity.*
4. *Plastics are cheaper.*

☐

11.(MW4-3) When a spoonful of salt is added to water, it disappears after stirring to form a solution. The salt cannot be filtered out of the solution and it does not settle out if the solution is let to stand. If the solution is left to dry out, solid salt is left.

Salt dissolving in water is a **temporary** change:

A True *B False* □

Because:

1. *This change cannot be reversed by passing the solution through a filter.*
2. *This change can be reversed by allowing the water to evaporate.*
3. *This change cannot be reversed by allowing the salt to settle out of the solution.*
4. *The salt changes to another substance when it dissolves.*

□

12.(MW4-4) Most plastics are made from fossil fuels.

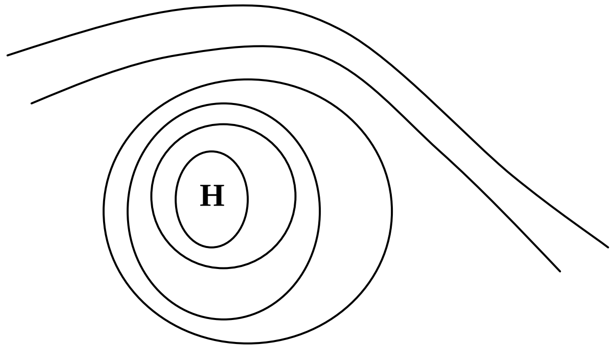
A True *B False* □

Because:

1. *Compounds from fossil fuels can be combined to form completely new substances such as plastics.*
2. *Plastics are completely different from fossil fuels so could not be made from them.*
3. *Plastics exist in fossil fuels and can be separated out.*
4. *The elements that make up plastics are different from the elements that make up fossil fuels.*

□

13.(PEB4-1) The weather map below shows a high pressure zone in the atmosphere.



The area under this weather system will have fine weather:

A True *B False* ☐

Because:

1. *It is a high-pressure zone which usually causes fine weather.*
2. *It is a hot zone that warms up the area beneath it.*
3. *It is a zone high up in the atmosphere that causes cold weather.*
4. *It is a high-wind zone that brings windy weather.*

☐

14.(PEB4-2) Many of the rocks found on a hillside contained fossil sea shells. This indicated that the area was once part of an ancient sea bed.

A True *B False* ☐

Because:

1. *Millions of years ago sea creatures died and their shells were deposited in ocean sediments which were raised by tectonic plate movements to form land above the sea.*
2. *The shells were left from Maori hangis on the site hundreds of years ago.*
3. *The land had been flooded and the shells were left when the flood receded.*
4. *Thousands of years ago the land was covered by sea which dried up leaving many sea shells.*

☐

15.(PEB4-3). The moon travels across the sky at night and the sun travels across the sky during the day. This shows that the sun and the moon both travel around planet Earth.

A True *B False* ☐

Because:

1. *Earth travels around the sun and around the moon, so the sun and moon appear to move across the sky.*
2. *Earth is at the centre of the solar system and the sun and moon both go around Earth so they can be seen crossing the sky.*
3. *Earth travels around the sun, and the moon travels around Earth, so the sun and moon appear to cross the sky.*
4. *Earth rotates on its axis each day/night cycle so the sun and moon appear to move across the sky.*

☐

16.(PEB4-4) In a tree planting project, students from the local intermediate school spent a day planting New Zealand native trees on a hillside in a reserve. One student, Sandra, said the main reason for involving students was to get the job done quickly. Do you think she is correct?

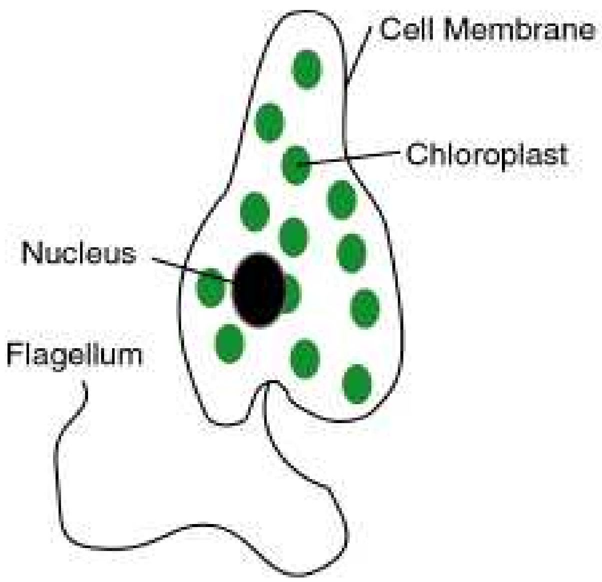
A Yes *B No* ☐

Because:

1. *A large number of school students could get the job done more quickly than a contractor.*
2. *Involving school students in a tree planting project helps them to value their local environment.*
3. *The students would learn how to plant trees.*
4. *Getting students to do the job would be cheaper than employing a contractor.*

☐

17.(LW5-1) The picture shows a microscopic, single celled organism which lives in ponds. It swims by wiggling a flagellum which pulls it along. Its cell contains chloroplasts and is surrounded by a flexible membrane. It feeds by carrying out photosynthesis and absorbs minerals from the water.



Euglena is:

A) A plant cell *B) An animal* ☐

Because:

1. *It has chloroplasts and can photosynthesise*
2. *It has a thick cell wall*
3. *It has a flagellum and can move*
4. *It requires ready made organic food* ☐

18.(LW5-2) Adaptations are features that help a living thing to survive. There are 3 kinds of adaptations:

Structural which is a body part which helps the living thing to survive

Behavioural which is something the living thing does to help it to survive

Plants grow towards light. This helps the plant to carry out photosynthesis better. This growth is caused by the action of a chemical produced in the stem.

A plant growing towards light is a <u>behavioural</u> adaptation:

A True *B False* ☐

Because:

1. *It is something the plant does to help it to survive.*
2. *It occurs in the stem which causes the bending so it is a structural adaptation.*
3. *Growing towards the light is not an adaptation because it wastes energy which is not good for the plant, so doesn't help it survive.*
4. *Plants can't think so it is not a behavioural adaptation.*

☐

19.(LW5-3) A pure black guinea pig and a pure white guinea pig were mated. The first generation were all black. When 2 of the black offspring were mated, the second generation were 7 black and 2 white guinea pigs. **This shows that the black gene is dominant and the white gene recessive.**

A True *B False* ☐

Because:

1. *The white trait reappeared in the second generation but was masked in the first.*
2. *There were fewer white individuals than black in the offspring.*
3. *If black was dominant then the white trait would not have reappeared.*
4. *Black is a stronger colour than white therefore black is dominant.*

☐

20.(LW5-4) A living community contains producers, consumers and decomposers. Decomposers are essential to life on planet Earth:

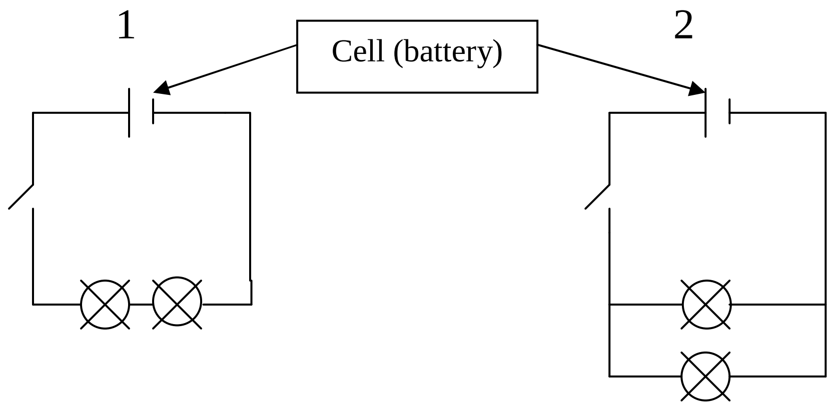
A True *B False* ☐

Because:

1. *Decomposers recycle minerals in living communities.*
2. *Decomposers recycle energy in living communities.*
3. *Life could continue without decomposers because there are plenty of minerals in the environment.*
4. *Animal life could continue because animals do not use minerals directly from the soil.*

☐

21.(PW5-1)



The above circuits have cells of the same voltage and bulbs of the same size.

When the switch is closed the bulbs in circuit 1 will be brighter than the bulbs in circuit 2:

A True *B False* □

Because:

1. *2 bulbs in parallel have less resistance than 2 bulbs in series.*
2. *The electric current splits between the 2 bulbs in parallel making them dimmer.*
3. *There are 2 bulbs in each circuit therefore they will be equally bright in both circuits.*
4. *The current in circuit 1 has less distance to go so it has more energy to make the bulbs brighter.*

□

22.(PW5-2) When an electric current lights a bulb in a circuit, electrical energy is turned into light energy which is lost from the circuit:

A True *B False* □

Because:

1. *Electricity keeps flowing around the circuit, so none of its energy is lost to the light.*
2. *Electrical energy turns to light energy as it passes through the bulb, but turns back to electrical energy to flow round the rest of the circuit, so energy is not lost.*
3. *Electrical energy turns into light energy but the light turns back to electrical energy when the light is turned off.*
4. *The electric current loses some of its energy in the bulb which gives it out as light energy.*

□

23.(PW5-1) If the 2 objects below are dropped at the same time:

The 1 kg and 10 kg masses will hit the ground at the same time:

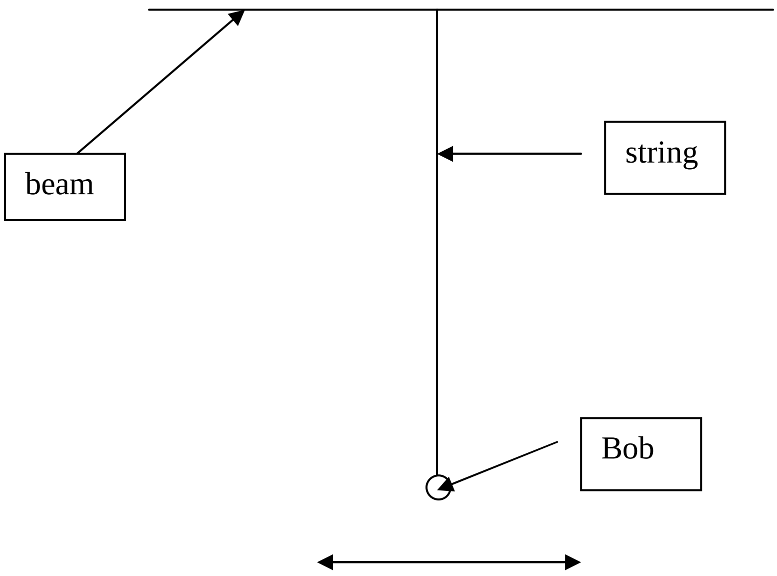
A True *B False* □

Because:

1. *The 10 kg mass has 10 times the force of gravity acting on it, therefore it will fall faster.*
2. *The 10 kg mass has 10 times the force of gravity acting on it but also 10 times the inertia, so both masses fall at the same speed.*
3. *The 1 kg mass has less volume therefore falls faster than the 10 kg mass.*
4. *The 10 kg mass has more air resistance therefore both masses fall at the same speed.*

□

24.(PW5-3) 2 students set up a pendulum made from a length of string hanging from a beam in a door way and a mass hanging on the end (the bob). They were investigating the effect of the bob mass and the string length on the swing time.



The pendulum was set swinging and the student measured the time for 10 swings (each swing was back and forth). The students then divided the time by 10 to get the average time for one swing. They then repeated the experiment a number of times but changed the mass of the bob on the pendulum or the length of the string. Here are the results:

Bob mass (grams)	String length (cms)	Average swing time (secs)
50	50	1.2
100	100	2.0
50	100	2.0
100	50	1.2

From these results it can be concluded that swing-time is increased when the mass of the bob is increased **and** when string length is increased:

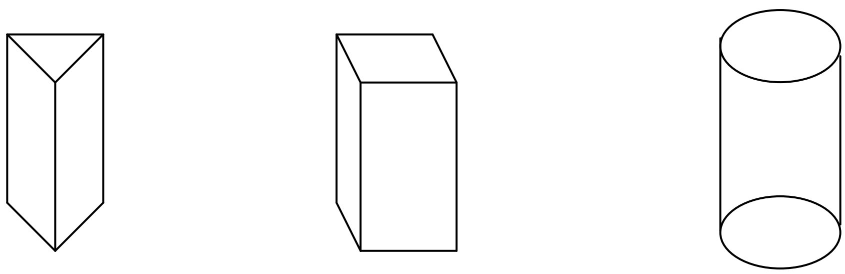
A True *B False* □

Because:

1. *The swing-time increased only when string length was increased and the mass of the bob had no effect.*
2. *The swing-time increased when both the string length and the mass of the bob were increased.*
3. *The swing-time increased only when the mass of the bob increased and the string length had no effect.*
4. *The swing time increased when string length and the mass of the bob were the same value as each other.*

25.(PW5-4) 3 students did an investigation to find out which shape of pillar was the strongest. The 3 shapes tried were triangular, square and a cylinder. Each model pillar was made of the same sized piece of cardboard.

Triangular Square Circular



Masses were placed on top of each pillar until it collapsed. The mass under which the pillar collapsed was recorded. Each student did their own investigation and the results were all recorded on the table below.

	Mass which caused pillar to collapse (grams)		
Student	**Triangular**	**Square**	**Circular**
Leon	250	250	300
Jenny	300	300	350
Don	250	350	350
Mean	267	300	333

The pillar with the circular end was the strongest:

A True *B False* ☐

Because:

1. *The circular ended pillar supported a bigger mass than the others.*
2. *The square ended pillar supported the largest mass.*
3. *The results were inconclusive because there was overlap between the amount of mass the 3 shapes could support.*
4. *The circular ended pillar supported the biggest mean mass.*

☐

26.(MW5-1a) A small amount of a liquid called ether is poured into a plastic bag, the air is squeezed out and the bag is tied tightly at the top. The plastic bag is then placed in a tray and hot water is poured over it. The bag inflates and there is no longer any liquid ether in the bag.

This can be explained by the theory that all matter is made up of tiny particles too small to see.

A True *B False* ☐

Because:

1. *The number of particles increased to take up more room when the hot water was poured over the bag.*
2. *The particles move apart taking up more room so that liquid ether becomes ether gas when the hot water is poured over the bag.*
3. *We cannot see the particles therefore the theory doesn't make sense.*
4. *The heat from the hot water makes the bag soften and swell due to air pressure.*

☐

27.(MW5-1b) Water is a pure substance made up of hydrogen and oxygen. Hydrogen is an explosive gas and oxygen is a gas which helps burning. Scientifically speaking water is:

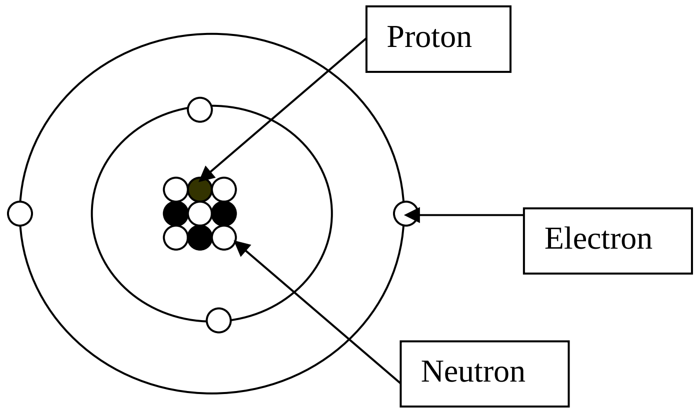
A an element *B a compound* ☐

Because:

1. *It is a pure substance.*
2. *It is made up of the elements hydrogen and oxygen combined together.*
3. *It is a mixture of two gases.*
4. *It is one of the 4 elements along with earth, wind and fire.*

☐

28.(MW5-1b) Look carefully at the drawing of an atom below.



This drawing represents an atom of an element:

A True *B False* ☐

Because:

1. *The number of neutrons should equal the number of protons.*
2. *The electrons should be in the nucleus.*
3. *The number of protons should equal the number of electrons.*
4. *There should be 8 electrons.*

☐

29.(MW5-2) Oven cleaner is a strong base called caustic soda which breaks down fat and grease. If some oven cleaner is sprayed accidentally on to the floor, a safe way to deal with it would be to sprinkle it with citric acid (a weak acid powder used in baking) and then clean up with a wet mop:

A True *B False* ☐

Because:

1. *Citric acid would make the mixture more dangerous.*
2. *Citric acid has no effect on caustic soda.*
3. *Caustic soda should just be left to evaporate dry.*
4. *Citric acid will neutralize the caustic soda turning it into harmless products.*

□

30.(MW5-3) When dilute sulfuric acid reacts with sodium hydroxide, a **salt** is formed:

A True *B False* □

Because:

1. *acid + metal > salt + hydrogen*
2. *dilute sulfuric acid does not react with sodium hydroxide*
3. *acid + base > salt + water*
4. *salt is sodium chloride which is not formed in this reaction*

□

31.(MW5-4) A positive effect of burning fossil fuels such as petrol and diesel is that it gives us fast transport of people and goods. Burning these fuels also releases millions of tonnes of carbon dioxide into the air.

This is a negative (bad) effect:

A True *B False* □

Because:

1. *Carbon dioxide provides food for plants increasing their growth.*
2. *Carbon dioxide destroys the ozone layer making the ozone hole bigger.*
3. *Carbon dioxide is improving our weather.*
4. *Carbon dioxide is causing the greenhouse effect, global warming and climate change.*

□

32.(PEB5-1) New Zealand has more earthquakes than Australia:

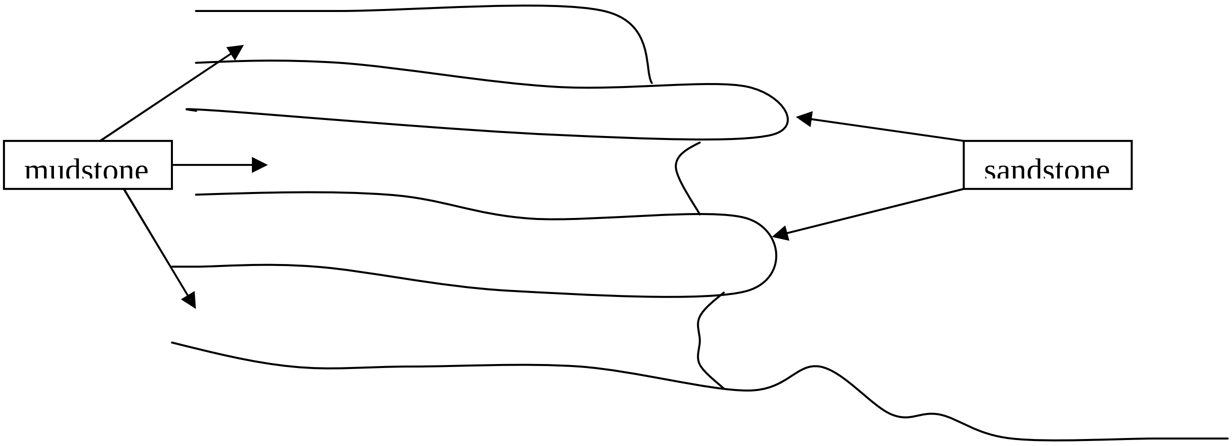
A True *B False* □

Because:

1. *New Zealand has more rainfall that lubricates the rocks beneath the surface of the earth, so they slip over each other causing earthquakes.*
2. *Australia has a larger land area making it more stable, therefore fewer earthquakes.*
3. *New Zealand lies on a tectonic plate boundary and when the plates move against each other, earthquakes occur.*
4. *Australia has a hotter, drier climate, so when the land heats up, it expands causing earthquakes.*

□

33.(PEB5-2) The diagram below shows a cliff section made up of layers of 2 rock types, sandstone and mudstone.



The shape of the cliff indicates that sandstone is a softer rock than mudstone:

A True *B False* □

Because:

1. *The pressure of the rocks above squeezed the sandstone out of the cliff face so sandstone must be softer.*
2. *The mudstone has been worn away by wind and rain more than sandstone, therefore mudstone must be softer.*
3. *The mudstone layers are thicker than the sandstone, so sandstone must be softer because it has been squashed more.*
4. *The cliff shape was caused the way the rock layers formed, not by different hardness to the sandstone and mudstone.*

□

34.(PEB5-3a) The Southern Cross can be seen to change its position in the night sky from the evening through to early morning. This is because the stars that make up the southern cross are moving.

A True *B False* ☐

Because:

1. *All stars orbit around Earth so they move across the sky at night.*
2. *Earth turns on its axis, so stars appear to move across the sky at night.*
3. *Earth is moving around the sun so stars appear to move across the sky at night.*
4. *The Southern Cross moves because the Milky Way is revolving.*

☐

35.(PEB5-3b) Our sun is an average sized star like many thousands of other stars in the night sky.

A True *B False* ☐

Because:

1. *The sun is much larger than the stars.*
2. *Most stars are like our sun, consisting of large masses of hot gases which give out their own heat and light energy.*
3. *The sun shines during the day, but stars shine at might.*
4. *The stars reflect light from the sun.*

☐

36.(PEB5-4) Huia and Kate were talking about protecting New Zealand's environment. Huia said that New Zealand's environment was the responsibility of all New Zealanders. Kate said that there wasn't much ordinary people could do and that it was the job of the government to protect New Zealand's environment. Who do you think is right?

A Huia *B Kate* □

Because:

1. *We all have a responsibility to help protect the environment for future generations.*
2. *Ordinary people can't do anything to help the environment.*
3. *The government has to pass laws to protect the environment to have any effect.*
4. *New Zealand's environment doesn't need protecting because there aren't enough people to damage it.*

□

37.(LW6-1)Viruses are particles that can only be seen with an electron microscope. They are able to reproduce only in living cells of a host. Viruses are made up of substances called nucleic acids and proteins and they can be crystallized like chemicals. They cannot be grown on agar plates as bacteria can.

Viruses are:

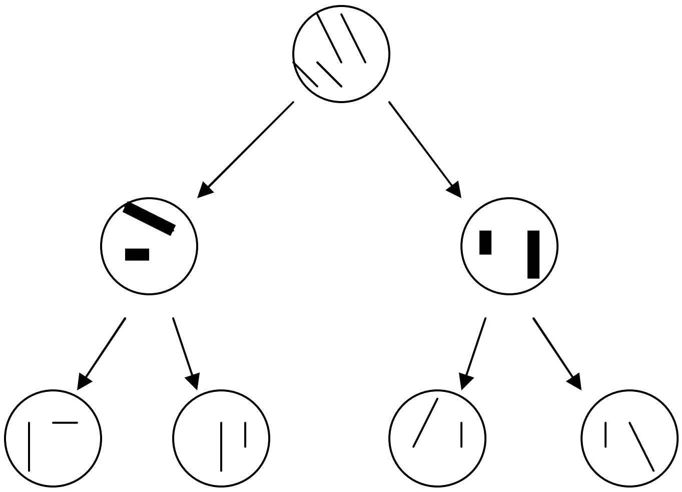
A) Living *B) Non-living* □

Because:

1. *They can reproduce inside the host cells.*
2. *They are made up of living cells*
3. *They can be crystallized like chemicals.*
4. *They are too small to be alive.*

□

38.(LW6.2)The diagram below shows the stages of a cell dividing. The number of chromosomes in the cells is given.



This cell division is:

A Mitosis *B Meiosis* □

Because:

1. *The cells formed have the same number of chromosomes as the parent cell*
2. *The cells formed contain half the number of chromosomes of the parent cell*
3. *The chromosomes replicate in both divisions*
4. *The chromosomes pair up but do not replicate*

☐

39.(LW6-3) Potato plants can reproduce by growing more potatoes (tubers) underground. Each tuber forms a new plant. This is an asexual method of reproduction. Potato plants can also reproduce by producing flowers, fruits and seeds. This a sexual method because it involves gametes and fertilization.

Sexual reproduction is necessary to ensure the survival of the potato species over time.

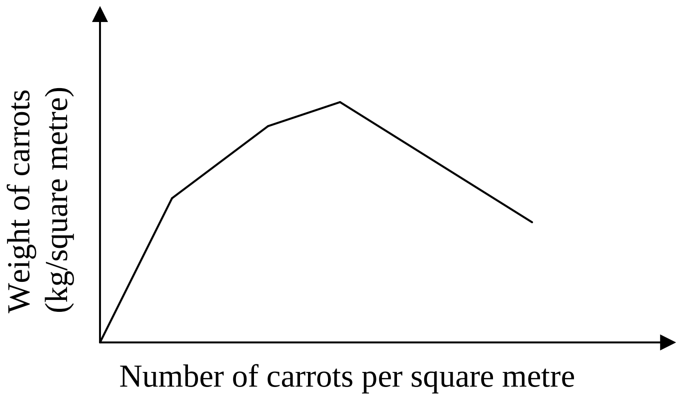
A True *B False* ☐

Because:

1. *Sexual reproduction of potatoes is a more complicated process and less likely to take place.*
2. *Asexual reproduction of potatoes occurs more quickly.*
3. *Asexual reproduction in potatoes is more reliable in good conditions for growth.*
4. *Sexual reproduction produces variation in the offspring which may survive in a changing environment.*

☐

40.(LW6-4) A horticulturist experimented with growing carrots to get maximum yield. She found that by growing carrots closer together they reach a smaller size than carrots grown further apart, but she could grow more carrots in a given area. A graph showing the weight of carrots harvested per square metre is shown.



The drop off in the total weight of carrots grown per square metre of soil is competition:

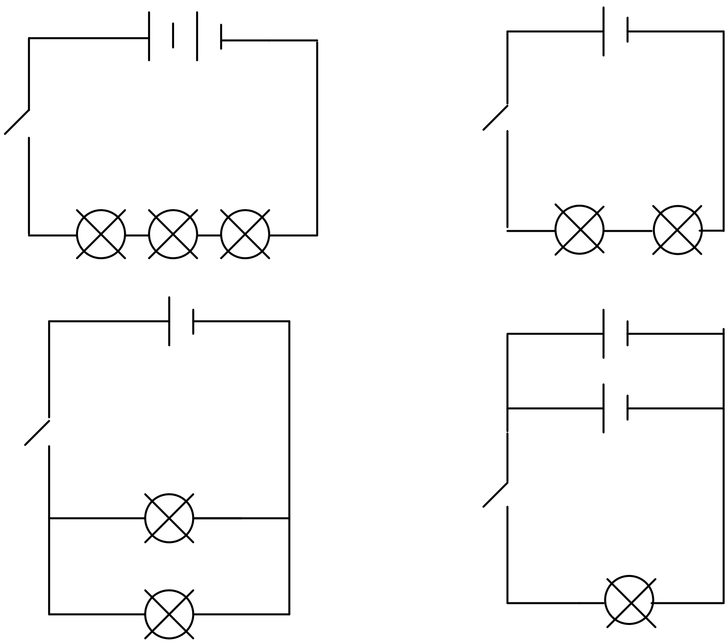
A True *B False* ☐

Because:

1. *All carrots receive the same amount of light, minerals and water so there is no competition.*
2. *As long as the carrots are not in contact with each other underground, there is no competition.*
3. *Carrots growing closer together compete for limited light, minerals and water which retards their growth.*
4. *The drop off in weight of carrots per square metre is more likely to have been caused by pests and disease.*

☐

41.(PW6.1) A student set up these circuits to investigate the effect of increasing the number of **cells** in the circuit on bulb brightness.



The circuits will enable the student to make a valid conclusion from the results:

A True *B False* □

Because:

1. *Any change in bulb brightness will be caused by the change in number of cells in the circuit.*
2. *More than 1 variable is being changed therefore a valid conclusion cannot be reached.*
3. *The student can use the 4 circuits to draw conclusions on the effect of changing the number of cells in series or parallel on bulb brightness.*
4. *Some of the circuits are not correctly connected so a valid conclusion cannot be reached.*

□

42.(PW6-2) Water flows through a hydro-dam and the water flow is used to generate electricity. A student thought that if the water flowing through the dam could be pumped back up to the lake, it could be used to make more electricity when it flowed back through the dam. This would be a sensible way of making a lot more electrical energy:

A True *B False* □

Because:

1. *Water is not used up as it passes through the dam therefore more energy could be made this way.*

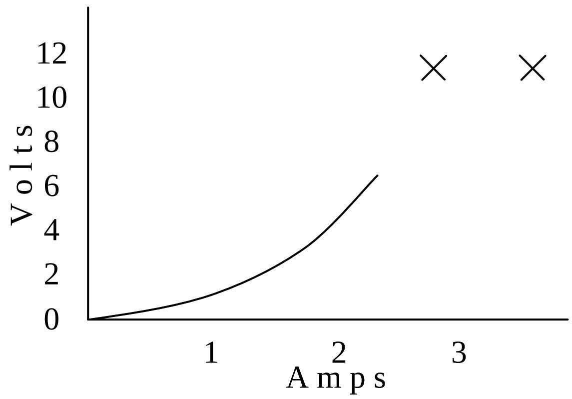
2. *More energy would be used in pumping the water back up to the lake than would be made when it flowed back through the dam.*

3. *Water could just be made to flow round and round making electricity every time it flowed back through the dam because energy cannot be destroyed.*

4. *The water would all get used up and there wouldn't be enough left in the river.*

□

43.(PW6-3) The graph below shows the amount of electric current flowing through an electric light bulb at different voltages.



A valid prediction for the current that will flow through the light bulb when the voltage is 12 volts is:

A *2.7 Amps* *B* *3.7 Amps* □

Because:

1. *By extending the curve of the graph this point is passed through.*
2. *By drawing a straight line extension of the graph this point is passed through.*
3. *A best fit straight line passes through this point*
4. *An average figure is calculated for resistance using V/I = R, then the current for 12 volts is calculated from I = V/R.*

□

44.(PW6-4) Optical fibre cable has replaced copper wire cables in many of the world's telephone systems. In optical fibre, the signals are transmitted by pulses of laser light instead of electricity. Light travels much faster than electricity and many more signals can be transmitted at once, making high band-width internet transmission possible. The energy loss over long distances is much lower with transmission of light pulses along optical fibre than for electricity along copper wires. Optical fibres are made out of very pure glass which requires expensive high precision technology for manufacture. This expense is offset by the fact that the raw material for making the glass fibre is sand, which is much cheaper than copper.

Optical fibre cables have revolutionized telecommunications:

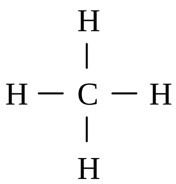
A *True* *B* *False* □

Because:

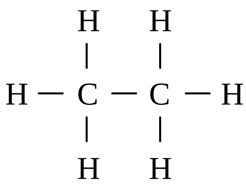
1. *Optical fibre is cheap to manufacture from sand which is a cheap raw material.*
2. *Optical fibres transmit a much larger number of signals, more quickly, than copper.*
3. *Optical fibre cable is easier to manufacture.*
4. *Optical fibre conducts electricity much faster than copper.*

45.(MW6-1) Here are some structural formulae of some organic compounds.

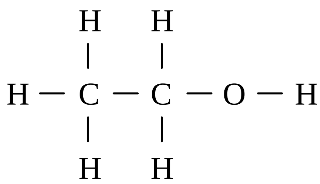
Methane



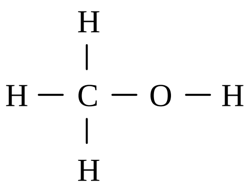
Ethane



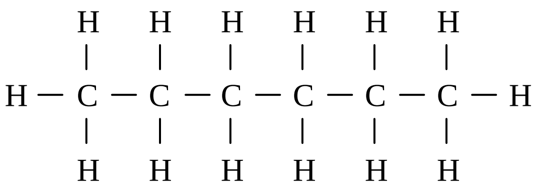
Ethanol



Methanol



Hexane



These organic compounds belong in 2 groups in terms of their chemical properties. Ethane and ethanol belong in the same group:

A True *B False*

Because:

1. *Ethanol and ethane both contain 2 carbon atoms.*
2. *Ethanol contains an –OH group making it more like methanol.*
3. *Ethanol belongs with hexane because they are both liquids.*
4. *Ethanol belongs with propane because they have similar molecular masses.*

□

46.(MW6-2) A gardener found that his soil had a pH of 5 and he knew that cabbages do not grow well in acid conditions. He added lime (calcium carbonate) and found that his cabbages grew much better.

The lime improved the growth of the cabbages because it is an essential food for plants.

A True *B False* □

Because:

1. *Cabbages need to absorb calcium carbonate for healthy growth.*
2. *Lime lowers soil pH to a level more suitable for cabbage growth.*
3. *Lime destroys pasts and diseases which retard cabbage growth.*
4. *Lime neutralizes soil acids, raising the pH to a level more suitable for cabbage growth.*

□

47.(MW6-3) Marble lumps in hydrochloric acid fizz, giving off carbon dioxide. If the marble lumps are ground up to a powder, then mixed with hydrochloric acid, the fizzing would be much faster:

A True *B False* □

Because:

1. *Lumps of marble have a larger surface area and react faster.*
2. *Powdered marble only seems to react faster because it gives off a large number of smaller bubbles.*
3. *Hydrogen ions in the acid would collide more often with lumps of marble giving a faster reaction.*
4. *Powdered marble has a larger surface area and reacts faster*

□

48.(MW6-4) Iron can be prevented from rusting by coating it with zinc (galvanizing). Zinc protects iron from rusting even if it does not cover the iron completely:

A True *B False* □

Because:

1. *Zinc only seals out oxygen so if any iron is exposed to the air, oxygen contacts the iron causing rusting.*
2. *Zinc protects iron by passing electrons to the iron preventing the iron atoms from reacting.*
3. *Zinc protects iron by removing electrons from the iron preventing the iron atoms from rusting.*
4. *Zinc only seals out water so if any iron is exposed to the air water contacts the iron causing rusting.*

□

49.(PEB6-1) The table below shows 4 minerals with their 3 properties compared. The properties are:

- hardness (on a scale of 1 = soft to 10 = very hard)
- colour
- reaction with dilute acid.

Mineral name	Hardness	Colour	Reaction with acid
calcite	3	colourless, white, yellow, orange, brown, green	fizzes
gypsum	2	colourless, white	no reaction
apatite	5	white, brown, green, yellow, violet	no reaction
quartz	7	colourless, white, pink, blue, black	no reaction

If you were given a piece of a mineral that was harder than gypsum, white in colour and reacted with acid. This mineral was calcite.

A True *B False* □

Because:

1. *It was white, so could have been any of the minerals listed.*
2. *It reacted with acid which none of the other minerals would.*
3. *Calcite is softer than gypsum.*
4. *Calcite is usually brightly coloured.*

□

50.(PEB6-2) Rocks that form from volcanic larva are igneous rocks whereas rocks that form on the ocean bed from sediments that cement together are called sedimentary rocks.

Over millions of years igneous rocks can become sedimentary rocks:

A True *B False* □

Because:

1. *Igneous rocks form from volcanoes and sedimentary rocks form on the ocean bed, therefore they are quite separate.*
2. *If larva from volcanoes flows into the sea it solidifies to form sedimentary rock.*
3. *The 2 rock types are quite different and one cannot form from the other.*
4. *Igneous rock from a volcano is eroded to form particles that get washed down to the sea, deposited as sediments and cement together over time to form sedimentary rock.*

□

51.(PEB6-3) Astronomical measurements show that the galaxies in the universe are moving apart and that the universe is expanding. This evidence supports the 'big bang theory' of the origin of the universe.

A True *B False* □

Because:

1. *The galaxies are all moving away from one another, so they may all have exploded from a single point in space.*
2. *The galaxies are not really moving away from each other, they only appear to be.*
3. *The universe didn't have a beginning, it's always been there.*
4. *The universe is expanding so this proves that the it started as one huge lump of matter and energy.*

□

52.(PEB6-4) New Zealand's fossil fuels such as coal, oil and gas are non-renewable and should be managed carefully:

A True *B False* □

Because:

1. *They are not replaced so should be used efficiently while new energy sources are developed for future generations.*
2. *They can be used up because new reserves of these fuels will be found before the present known reserves run out.*
3. *They can be used up because new ways of producing energy will be found for future generations.*
4. *They should be used efficiently so that new fossil fuels have time to form by natural processes to replace what gets used up.*

□

Appendix J

Item validation by external referencing to national curriculum level benchmarks

Key:

Q no.	**Question number in instrument**
CO	**Curriculum objective**
ARBS	**Assessment Resource Bank: Science**
NE	**National Exemplars**
NCEA	**National Certificate of Educational Achievement**
LW1	**Making sense of living world objective line 1**
PW2	**Making sense of physical world objective line 2**
MW3	**Making sense of material world objective line 3**
PEB	**Making sense of planet Earth and beyond objective line 4**

Item no.	Objective line	Proposition number	Benchmark instrument	Benchmark code or name
1	LW1	2,3	ARBS	LW0033
2	LW2	1,2	ARBS	LW0577 LW0506 LW0531 LW0550
3	LW3	1,2,3	ARBS	LW1048
4	LW4	1,2,3,5	ARBS NE	LW2000 Balancing Act
5	PW1	18,19, 22, 25	ARBS	PW3653 PW4062
6	PW2	6	ARBS	PW3603
7	PW3	1,4	ARBS	PW3509 PW4110
8	PW4	4	NE	Colourful messages
9	MW1	26	ARBS	MW5071 MW5090
10	MW2	1,2,3	ARBS	MW6648
11	MW3	1,2	ARBS	MW6310
12	MW4	5	ARBS	MW6875
13	PEB1	1,2	ARBS	PE7513
14	PEB2	1,2,3	ARBS	PE8002 PE8015
15	PEB3	1,2,3	ARBS	PE9000 PE9018
16	PEB4	1,2	ARBS	PE9503

Appendix J (continued)

Items validation by external referencing to national curriculum level benchmarks

Item no.	CO	Proposition number	Benchmark Instrument	Benchmark code
17	LW1	5,6,7,8,9	ARBS	LW0005
18	LW2	3,4,	ARBS	LW0540 LW0582
19	LW3	11,12,13	ARBS	LW1012
20	LW4	6,7,8,9	NE	Cola and Kowhai
21	PW1	24	ARBS	PW2539 PW2546
22	PW2	3,4,5	ARBS	PW3004 PW3029
23	PW1	9,10,11	ARBS	PW2515
24	PW3	4	ARBS	PW4081
25	PW4	6	ARBS	PW4525
26	MW1	1,2,6,7,9,10,11	ARBS	MW5093
27	MW1	12,13,14,15,16, 17	ARBS	MW5012 MW5027
28	MW1	18,19,20,21,22, 23,24,25	ARBS	MW5015
29	MW2	6,7	ARBS	MW6333
30	MW3	5	ARBS	MW6259
31	MW4	1,3,4	ARBS	MW6892
32	PEB1	7,8	ARBS	PE8516
33	PEB2	8	ARBS	PE8501
34	PEB3	8	ARBS	PE9010
35	PEB3	9,10	ARBS	PE9088
36	PEB4	3,4	ARBS	PE9534

Appendix J (continued)

Items validation by external referencing to national curriculum level benchmarks

Item no.	CO	Proposition number	Benchmark Instrument	Benchmark code
37	LW1	18,19,20,	NCEA	90188
38	LW2	6,8,9, 11,12	NCEA	90188
39	LW3	4,14,15, 16,17	NCEA	90188
40	LW4	12,13, 14,15	NCEA	90188
41	PW1	28,29	NCEA	90191
42	PW2	2	NCEA ARBS	90191 PW3001
43	PW3	2,3,4	NCEA	18988
44	PW4	1,5,6	NCEA	90726 v2
45	MW1	27	ARBS	MW5021
46	MW2	10	NCEA ARBS	90189 MW5649
47	MW3	7	ARBS	MW6256
48	MW4	7,8,9, 10,11	NCEA	90189
49	PEB1	11	NCEA	90190
50	PEB2	9,10	NCEA	90190
51	PEB3	15,16	NCEA	90192
52	PEB4	7,8	NCEA	90728 v2

Appendix K

An example of returned responses from a student

Name: Student

ID: xxxxxxxx

email: email@xtra.co.nz

recipient: Jim.Law@tcs.ac.nz

question1a: B

question1b: 4

question1comment:

question2a: A

question2b: 2

question2comment:

question3a: B

question3b: 3

question3comment:

question4a: B

question4b: 3

question4comment:

question5a: B

question5b: 3

question5comment:

question6a: A

question6b: 2

question6comment:

question7a: A

question7b: 4

question7comment:

question8a: B

question8b: 4

question8comment:

question9a: A

question9b: 1

question9comment:

question10a: A

question10b: 2

question10comment:

question11a: A

question11b: 2

question11comment:

question12a: B
question12b: 2
question12comment:
question13a: A
question13b: 2
question13comment:
question14a: A
question14b: 1
question14comment:
question15a: B
question15b: 3
question15comment:
question16a: B
question16b: 2
question16comment:
question17a: A
question17b: 1
question17comment:
question18a: A
question18b: 1
question18comment:
question19a: A
question19b: 1
question19comment:
question20a: A
question20b: 1
question20comment:
question21a: B
question21b: 1
question21comment:
question22a: A
question22b: 4
question22comment:
question23a: B
question23b: 1
question23comment:
question24a: B
question24b: 1
question24comment:
question25a: A

question25b: 4
question25comment:
question26a: A
question26b: 2
question26comment:
question27a: B
question27b: 2
question27comment:
question28a: B
question28b: 1
question28comment:
question29a: A
question29b: 4
question29comment:
question30a: A
question30b: 1
question30comment:
question31a: A
question31b: 4
question31comment:
question32a: A
question32b: 3
question32comment:
question33a: B
question33b: 2
question33comment:
question34a: B
question34b: 2
question34comment:
question35a: A
question35b: 2
question35comment:
question36a: A
question36b: 1
question36comment:
question37a: A
question37b: 1
question37comment:
question38a: B
question38b: 2

question38comment:

question39a: B

question39b: 4

question39comment:

question40a: A

question40b: 3

question40comment:

question41a: B

question41b: 4

question41comment:

question42a: B

question42b: 2

question42comment:

question43a: B

question43b: 1

question43comment:

question44a: A

question44b: 2

question44comment:

question45a: A

question45b: 2

question45comment:

question46a: A

question46b: 4

question46comment:

question47a: A

question47b: 4

question47comment:

question48a: A

question48b: 2

question48comment:

question49a: B

question49b: 3

question49comment:

question50a: A

question50b: 4

question50comment:

question51a: B

question51b: no answer

question51comment: There was no big "Big Bang" and the galaxies were put there on purpose so they can't be moving apart.

question52a: A

question52b: 4

question52comment:

Submit: Send this work

Appendix L

An example of student responses marked using the marker spreadsheet

Question	Attempted	Right	CO	Name	Student
1	attempted		LW4	ID	
2	attempted	LW4	LW4	email	email@xtra.co.nz
3	attempted		LW4	recipient	Jim.Law@tcs.ac.nz
4	attempted		LW4		
5	attempted	PW4	PW4		
6	attempted	PW4	PW4		
7	attempted	PW4	PW4		
8	attempted	PW4	PW4		
9	attempted		MW4		
10	attempted	MW4	MW4		
11	attempted	MW4	MW4		
12	attempted		MW4		
13	attempted	PEB4	PEB4		
14	attempted	PEB4	PEB4		
15	attempted		PEB4		
16	attempted	PEB4	PEB4		
17	attempted	LW5	LW5		
18	attempted	LW5	LW5		
19	attempted	LW5	LW5		
20	attempted	LW5	LW5		
21	attempted	PW5	PW5		
22	attempted	PW5	PW5		
23	attempted		PW5		
24	attempted	PW5	PW5		
25	attempted	PW5	PW5		
26	attempted	MW5	MW5		
27	attempted	MW5	MW5		
28	attempted		MW5		
29	attempted	MW5	MW5		
30	attempted		MW5		
31	attempted	MW5	MW5		
32	attempted	PEB5	PEB5		
33	attempted	PEB5	PEB5		
34	attempted	PEB5	PEB5		
35	attempted	PEB5	PEB5		
36	attempted	PEB5	LW6		

37	attempted	LW6	LW6
38	attempted	LW6	LW6
39	attempted		LW6
40	attempted	LW6	LW6
41	attempted		PW6
42	attempted	PW6	PW6
43	attempted		PW6
44	attempted	PW6	PW6
45	attempted		MW6
46	attempted		MW6
47	attempted	MW6	MW6
48	attempted	MW6	MW6
49	attempted		PEB6
50	attempted	PEB6	PEB6
51			PEB6
52	attempted		PEB6

Appendix M

Instrument scientifically correct answers

Question	Tier 1 answer	Tier 2 answer	Alternative correct answer	Curriculum objective
1	A	4		LW4
2	A	2		LW4
3	A	1		LW4
4	B	1		LW4
5	B	3		PW4
6	A	2		PW4
7	A	4		PW4
8	B	4		PW4
9	B	2		MW4
10	A	2		MW4
11	A	2		MW4
12	A	1		MW4
13	A	2		PEB4
14	A	1		PEB4
15	B	4		PEB4
16	B	2		PEB4
17	A	1	or B3	LW5
18	A	1		LW5
19	A	1		LW5
20	A	1		LW5
21	B	1		PW5
22	A	4		PW5
23	A	2		PW5
24	B	1		PW5
25	A	4		PW5
26	A	2		MW5
27	B	2		MW5
28	A	3		MW5
29	A	4		MW5
30	A	3		MW5
31	A	4		MW5
32	A	3		PEB5
33	B	2		PEB5
34	B	2		PEB5
35	A	2		PEB5
36	A	1		PEB5
37	A	1	or B3	LW6
38	B	2		LW6
39	A	4		LW6
40	A	3		LW6
41	B	2		PW6
42	B	2		PW6
43	A	1		PW6

44	A	2	PW6
45	B	2	MW6
46	B	4	MW6
47	A	4	MW6
48	A	2	MW6
49	A	2	PEB6
50	A	4	PEB6
51	A	1	PEB6
52	A	1	PEB6

Appendix N
Spreadsheet of correct responses to items

		Items																	
		Level 4 section																	
Year	**Respondent**	*1*	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*	*10*	*11*	*12*	*13*	*14*	*15*	*16*	T1	**%**
9	1	✔	✔			✔	✔	✔				✔		✔			✔	8	50
9	2	✔	✔		✔		✔	✔	✔	✔		✔	✔				✔	10	63
9	3		✔	✔	✔	✔	✔	✔			✔	✔		✔			✔	10	63
9	4	✔	✔					✔	✔				✔	✔	✔		✔	8	50
9	5	✔	✔	✔	✔	✔	✔	✔	✔	✔		✔		✔			✔	12	75
9	6		✔		✔		✔	✔	✔				✔	✔			✔	8	50
9	7	✔	✔		✔		✔				✔	✔		✔	✔		✔	9	56
9	8	✔	✔	✔		✔		✔	✔		✔			✔			✔	9	56
9	9	✔	✔	✔	✔	✔		✔	✔		✔	✔	✔	✔	✔		✔	13	81
9	10	✔	✔		✔		✔	✔			✔			✔	✔		✔	9	56
9	11	✔	✔	✔			✔	✔			✔	✔	✔	✔			✔	10	63
9	12	✔	✔		✔	✔	✔	✔		✔	✔	✔		✔			✔	11	69
9	13	✔	✔												✔			3	19
9	14	✔	✔		✔		✔	✔		✔		✔	✔	✔	✔		✔	11	69
9	15	✔	✔		✔		✔	✔	✔	✔				✔		✔	✔	10	63
9	16	✔					✔	✔			✔	✔		✔		✔	✔	8	50
		□	□	□	□	□	□	□	□	□	□	□	□	□	□	□	□		
10	17	✔	✔	✔			✔	✔			✔		✔	✔	✔		✔	10	63
10	18	✔	✔	✔		✔	✔	✔	✔	✔				✔	✔		✔	11	69
10	19	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔		✔	✔		✔	14	88
10	20	✔	✔	✔	✔		✔	✔				✔	✔	✔			✔	10	63
10	21	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔		✔	✔	✔	✔	15	94
10	22	✔			✔	✔	✔	✔		✔		✔	✔	✔		✔	✔	11	69
10	23		✔	✔	✔		✔	✔					✔	✔	✔		✔	9	56
10	24	✔	✔		✔		✔	✔	✔			✔		✔	✔		✔	10	63
10	25	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔		✔	15	94
10	26	✔	✔	✔	✔	✔		✔	✔		✔	✔	✔	✔	✔		✔	13	81
10	27	✔	✔			✔	✔	✔		✔		✔			✔		✔	9	56
10	28	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔		✔	15	94
10	29	✔	✔	✔	✔	✔	✔	✔	✔		✔	✔	✔	✔	✔		✔	14	88
10	30	✔	✔		✔		✔	✔			✔	✔		✔		✔	✔	10	63

10	31	✓	✓	✓	✓	✓	✓	✓		✓	✓	✓		✓	✓		✓	13	81
10	32				✓	✓								✓	✓		✓	5	31
		□	□	□	□	□	□	□	□	□	□	□	□	□	□	□	□		
11	33		✓		✓	✓		✓	✓		✓	✓		✓	✓	✓	✓	11	69
11	34	✓	✓			✓	✓	✓	✓	✓	✓	✓	✓	✓			✓	12	75
11	35	✓	✓	✓	✓	✓			✓	✓			✓	✓	✓		✓	11	69
11	36	✓	✓	✓	✓	✓	✓		✓		✓	✓		✓			✓	11	69
11	37	✓	✓		✓	✓	✓		✓		✓	✓	✓	✓	✓		✓	12	75
11	38	✓	✓		✓	✓		✓	✓	✓	✓		✓	✓				10	63
11	39	✓						✓	✓	✓		✓	✓	✓			✓	8	50
11	40		✓	✓		✓	✓	✓	✓	✓	✓	✓	✓	✓	✓		✓	13	81
11	41	✓	✓	✓	✓	✓	✓	✓	✓	✓			✓	✓	✓		✓	13	81
11	42		✓			✓	✓	✓	✓	✓	✓	✓		✓	✓		✓	11	69
11	43	✓	✓		✓		✓	✓	✓	✓	✓		✓	✓	✓		✓	12	75
11	44	✓	✓	✓			✓	✓	✓	✓	✓	✓		✓	✓		✓	12	75
11	45	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	16	100
11	46	✓	✓	✓	✓		✓	✓	✓	✓	✓	✓	✓	✓			✓	13	81
11	47	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓		✓	✓	✓	✓	15	94
Question Total		40	43	24	33	28	37	41	30	25	29	33	24	44	29	8	45		
%		85	91	51	70	60	79	87	64	53	62	70	51	94	62	17	96		

Appendix N (continued)

Items

Level 5 section

17	*18*	*19*	*20*	*21*	*22*	*23*	*24*	*25*	*26*	*27*	*28*	*29*	*30*	*31*	*32*	*33*	*34*	*35*	*36*	**T2**	**%**
	✔	✔	✔				✔	✔							✔	✔	✔	✔	✔	10	50
✔	✔							✔	✔						✔	✔	✔	✔	✔	9	45
✔	✔	✔						✔	✔	✔					✔		✔	✔	✔	10	50
	✔			✔	✔		✔	✔	✔											6	30
✔			✔					✔							✔	✔	✔	✔	✔	8	40
✔					✔		✔					✔		✔	✔	✔	✔		✔	9	45
✔	✔		✔	✔					✔			✔		✔	✔		✔	✔	✔	11	55
	✔		✔						✔					✔	✔	✔			✔	7	35
✔			✔				✔	✔	✔	✔					✔	✔	✔	✔	✔	11	55
✔	✔	✔	✔		✔					✔		✔		✔	✔				✔	10	50
✔	✔		✔		✔		✔	✔	✔					✔	✔		✔	✔		11	55
✔	✔	✔						✔			✔		✔		✔				✔	8	40
																		✔		1	5
✔	✔		✔		✔		✔	✔	✔		✔		✔		✔				✔	11	55
	✔		✔	✔													✔		✔	5	25
✔	✔	✔										✔			✔		✔		✔	7	35
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✔	✔			✔		✔	✔		✔	✔			✔	✔	✔			✔	✔	12	60
✔	✔		✔		✔	✔		✔	✔	✔	✔	✔		✔	✔	✔	✔	✔	✔	16	80
✔	✔		✔	✔	✔					✔		✔		✔	✔	✔	✔		✔	12	60
	✔	✔	✔	✔				✔				✔			✔	✔			✔	9	45
✔			✔		✔		✔	✔			✔	✔	✔		✔	✔	✔		✔	12	60
✔	✔		✔				✔	✔		✔		✔		✔	✔	✔	✔		✔	12	60
✔			✔	✔			✔	✔		✔	✔	✔	✔		✔	✔			✔	12	60
✔	✔	✔	✔		✔			✔		✔	✔			✔	✔	✔	✔	✔	✔	14	70
✔	✔	✔	✔					✔	✔			✔	✔		✔	✔		✔	✔	12	60
✔			✔				✔	✔	✔	✔					✔	✔	✔	✔	✔	11	55
✔		✔				✔		✔	✔	✔				✔	✔	✔	✔	✔	✔	12	60
✔			✔	✔	✔	✔	✔	✔	✔	✔		✔		✔	✔	✔	✔	✔	✔	16	80
✔	✔	✔	✔	✔			✔	✔			✔	✔	✔		✔	✔	✔	✔	✔	15	75
✔	✔	✔	✔		✔	✔											✔		✔	8	40

✔	✔		✔	✔	✔					✔		✔		✔	✔	✔	✔		✔	12	60
✔	✔		✔		✔							✔			✔		✔	✔	✔	9	45
□	□	□	□	□	□	□	□	□	□	□	□	□	□	□	□	□	□	□	□		
✔		✔		✔	✔			✔				✔		✔	✔		✔		✔	10	50
✔		✔	✔	✔	✔			✔	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔	17	85
✔	✔	✔	✔	✔			✔	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔	18	90
✔		✔	✔	✔	✔	✔	✔	✔	✔		✔	✔	✔	✔	✔	✔	✔	✔		17	85
✔		✔	✔		✔	✔	✔	✔	✔	✔		✔	✔	✔	✔	✔	✔	✔	✔	17	85
	✔	✔	✔		✔	✔	✔	✔	✔		✔			✔	✔	✔	✔	✔	✔	15	75
	✔				✔	✔	✔	✔				✔		✔	✔		✔	✔	✔	11	55
✔	✔	✔	✔	✔	✔	✔			✔	✔		✔	✔		✔	✔	✔		✔	15	75
✔	✔		✔	✔	✔	✔	✔	✔		✔	✔	✔		✔	✔	✔	✔	✔	✔	17	85
✔	✔	✔	✔	✔	✔		✔	✔	✔	✔		✔		✔	✔	✔	✔	✔	✔	17	85
✔		✔	✔	✔	✔				✔		✔	✔	✔	✔	✔	✔	✔	✔	✔	15	75
✔	✔	✔			✔		✔	✔	✔	✔		✔	✔	✔	✔	✔	✔	✔	✔	16	80
✔	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔		✔	✔	✔	✔	✔	✔	19	95
✔	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔		✔	✔	✔	✔	✔	✔	✔	✔	19	95
✔	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔	20	100
39	33	24	35	21	27	14	24	33	26	23	15	29	16	27	43	32	37	30	43		
83	70	51	74	45	57	30	51	70	55	49	32	62	34	57	91	68	79	64	91		

Appendix N (Continued)					**Items**														
					Level 6 section													**Grand Total**	
37	*38*	*39*	*40*	*41*	*42*	*43*	*44*	*45*	*46*	*47*	*48*	*49*	*50*	*51*	*52*	**T3**	**%**	**GT**	T%
					✔		✔		✔			✔			✔	5	31	23	44
			✔									✔				2	13	21	40
✔	✔	✔		✔		✔		✔						✔	✔	8	50	28	54
																0	0	14	27
		✔	✔		✔	✔	✔	✔		✔		✔				8	50	28	54
✔					✔							✔	✔		✔	5	31	22	42
		✔				✔	✔					✔	✔	✔	✔	7	44	27	52
✔					✔		✔	✔								4	25	20	38
✔	✔	✔				✔	✔		✔	✔		✔	✔		✔	10	63	34	65
						✔				✔	✔			✔	✔	5	31	24	46
			✔		✔		✔	✔				✔		✔	✔	7	44	28	54
✔	✔		✔					✔				✔			✔	6	38	25	48
																0	0	4	8
✔	✔		✔	✔			✔			✔						6	38	28	54
		✔				✔						✔				3	19	18	35
			✔	✔			✔	✔	✔			✔	✔			7	44	22	42
□	□	□	□	□	□	□	□	□	□	□	□	□	□	□	□				
✔	✔					✔		✔					✔			5	31	27	52
✔			✔	✔	✔		✔	✔	✔						✔	8	50	35	67
✔			✔	✔	✔		✔	✔		✔		✔	✔	✔	✔	11	69	37	71
✔		✔	✔	✔	✔	✔	✔	✔	✔				✔	✔		11	69	30	58
✔			✔	✔	✔	✔	✔	✔		✔		✔	✔			10	63	37	71
			✔	✔	✔	✔	✔	✔	✔	✔		✔		✔	✔	11	69	34	65
✔	✔			✔		✔	✔					✔				6	38	27	52
✔			✔				✔		✔			✔			✔	6	38	30	58
✔		✔		✔	✔		✔		✔			✔	✔	✔	✔	10	63	37	71
✔	✔	✔				✔	✔		✔	✔		✔	✔		✔	10	63	34	65
✔		✔			✔		✔					✔			✔	6	38	27	52
✔	✔	✔	✔	✔	✔	✔	✔		✔	✔		✔			✔	12	75	43	83
✔	✔		✔	✔			✔	✔	✔			✔			✔	9	56	38	73
✔			✔		✔		✔		✔	✔		✔			✔	8	50	26	50

✔			✔	✔	✔		✔	✔		✔		✔	✔	✔	✔	11	69	36	69
					✔	✔						✔	✔	✔		5	31	19	37
□	□	□	□	□	□	□	□	□	□	□	□	□	□	□	□				
	✔	✔	✔		✔	✔		✔		✔	✔	✔	✔		✔	11	69	32	62
✔	✔	✔	✔	✔	✔	✔	✔	✔		✔		✔	✔			12	75	41	79
✔	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔		✔	✔		✔	14	88	43	83
✔	✔	✔	✔	✔			✔	✔	✔	✔		✔		✔	✔	12	75	40	77
✔		✔	✔	✔	✔	✔	✔	✔		✔		✔	✔	✔	✔	13	81	42	81
✔		✔		✔	✔	✔	✔	✔		✔		✔	✔	✔	✔	12	75	37	71
✔		✔	✔	✔			✔	✔				✔	✔		✔	9	56	28	54
✔	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔		✔	✔	✔		14	88	42	81
✔	✔			✔	✔	✔	✔	✔	✔	✔		✔	✔		✔	12	75	42	81
✔	✔		✔		✔		✔			✔	✔		✔		✔	9	56	37	71
✔		✔	✔	✔		✔	✔	✔	✔			✔	✔	✔	✔	12	75	39	75
✔		✔	✔	✔	✔	✔	✔	✔		✔		✔	✔	✔	✔	13	81	41	79
✔	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔		✔		✔	✔	14	88	49	94
	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔	15	94	47	90
	✔	✔	✔	✔	✔		✔	✔	✔	✔		✔	✔	✔	✔	13	81	48	92
32	19	23	29	26	28	25	36	28	20	24	4	37	25	19	32				
68	40	49	62	55	60	53	77	60	43	51	9	79	53	40	68				

Appendix O

Letters requesting parental permission

1. **Diagnostic survey permission (mailed as hard copy)**

Permission letter to parents of Year 8-11 students
<Date>
Dear <Parent/Guardian name>

I am currently working towards a Science Education Doctorate through Curtin University, Western Australia. For my main research thesis I intend to develop a set of science diagnostic tests. This research is designed to develop suitable tests to ascertain students' understanding of scientific concepts before and after instruction. The study involves students answering questions on pen and paper surveys which may be followed by brief interviews.

The surveys have been completed as part of year <Year> and this letter is to ask permission to use these surveys in my research and to interview <Student name> at a later date, if required. Confidentiality would be assured and the results of the study would be available to you.

Your permission to use data from your <Student name>'s responses and to allow <him/her> to participate in a follow-up phone interview would be greatly appreciated. <Student name> would only be rung once and can withdraw from the interview at any time. There are no consequences for students who choose not to participate. If you are willing to allow <Student name> to participate in this research, could you please complete and return the form below. Please contact me if you require more information on 2325667.

Thank you
James Law

____

I would be prepared to allow data from my <Student name>'s survey responses to be included in your research on diagnostic tests and consent to a brief follow up phone interview at a convenient time.

Student name:______________________
Parent/Guardian's name:_________________________ Date:________
Signature:______________ Phone number:_________________

2. **Diagnostic instrument permission (sent by email).**

Permission letter to parents of Year 9-11 students
<Date>
Dear <Parent/Guardian name>

I am currently working towards a Science Education Doctorate through Curtin University, Western Australia. For my main research thesis I have developed a science diagnostic test. The test is designed to ascertain students' understanding of scientific concepts before and after instruction. The study involves students answering questions in an on-line multi-choice test.

Your permission to use <Student name>'s diagnostic test responses in my research would be very much appreciated. Confidentiality and anonymity would be assured and the results of the study would be available to you. The results of the test will be stored in a locked filing cabinet and destroyed after the research has been assessed. There are no consequences for students who choose not to participate. If you are willing to allow <Student name> to participate in this research, could you please complete the form below and return by email. I will then send you the link to the test to enable <Student name> to access and complete it. Please contact me if you require more information on 2325667.

Thank you

James Law

I would be prepared to allow data from my <Student name>'s test responses to be included in your research on diagnostic tests.

Student name:______________________
Parent/Guardian's name:_________________________ Date:________