Chapter 1
Theoretical background

Introduction and Organisation of Chapter

Good teaching requires supporting all students to attain higher-level cognitive skills (Biggs, 1999), and such an approach is based on how teachers perceive students learning. Effective teaching also supports activities appropriate to achieving curriculum objectives, by encouraging a deep approach rather than a surface approach to learning (Entwistle, 1991). A poor teaching system may result in students using inappropriate learning strategies. A good teaching system is achieved when all aspects of the system concur by aligning learning activities and assessment tasks with curriculum objectives.

An amalgamation of a constructivist approach within an aligned teaching setting, (whereby the focus lies with student learning), by Biggs (1996), resulted in the model of ‘constructive alignment’. This model facilitates improved student-academic outcomes from tertiary institutions. The process of reflecting on teaching outcomes and learning situations by educators may be the best approach to enhance student learning despite institutional conditions and overt student abilities (Orrell, 1991).

To develop a context for the present study, this chapter considers quantitative and qualitative views and approaches of learning and assessment by relating theory to practice. The review is presented in four sections with an initial introduction to issues in higher education curriculum design. The subsequent section provides a detailed account of theories of teaching and learning appropriate to higher education, with a focus on the model of constructive alignment of Biggs (1999). The applications of theoretical frameworks are explained in a section on curriculum development and planning, with a subsection on linking curriculum objectives with teaching and learning activities. A final section on learning in science discusses the multi-faceted aspects of the science discipline and the influence of teaching and learning strategies that might be suitable for its pedagogy.
Issues in Higher Education Curriculum Design

This section is divided into three parts, the first outlines current issues in higher education which have led to reforms in curriculum development. The second examines theories of teaching and learning appropriate to higher education, and assesses the process of curriculum development and planning with a focus on the ‘Constructive Alignment’ of Biggs (1996) as an approach to promote teacher effectiveness and enhance student learning in a university context. A complementary theory of academic literacy is also introduced as having aspects that are also central to the process of learning but are often overlooked during the process of course design.

Higher Education Reforms

There have been major reforms of the roles of tertiary teaching over the past decade, with many tertiary institutions world-wide currently focused on market-driven courses (Kreber, 2005). In Australia, university class sizes have increased, and the ratio of academic staff to students has increased 68% from 1993-2004 (Kreber, 2005). Consequently, student abilities are more widely spread than in the past, but fewer resources are now provided to cope with a current intense national focus of quality of higher education (Dearn, 2006).

A major Australian review in 2002 (Australian Higher Education Quality Assurance Framework) led to reforms of university activities with key developments in areas including high quality, innovative and learner–centred education (Nelson, 2002). The latter requires effective initiatives in good teaching and an effective curriculum to provide all students with the opportunity for successful learning outcomes.

Knowledge construction and levels of thinking are learning goals across a range of delivery methods in education. Through a student centred approach to teaching and learning activities, students are encouraged to be in control of their own learning. Such a student-centred approach is driven by the context of the learning environment (Lindblom-Ylanne, Trigwell, Nevgi, & Ashwin, 2006). However, there is a current trend in tertiary teaching and learning research to coordinate the entire context of teaching (Biggs, 1998; Orrell, 1991). Ramsden (2003) summarised ‘theories of university teaching’ (Ramsden, 2003. p.115) in terms of teacher focus, associated
strategies, typical teaching activities, and the opportunity for reflection on the teaching and learning process. The theory whereby “teaching makes learning possible” (Ramsden, 2003) is the focus of designing an effective curriculum through the context of teaching by engaging and challenging the learner, and systematically adapting the learning environment through evaluation to attain student understanding.

As the system of assessment plays a major (if not, the most important) role in guiding student learning (Biggs, 1996; Ramsden, 1991), it seems logical that teachers should use assessment tasks as a way of communicating to students what skills and learning tasks are considered important. However, assessing learning is difficult because “we do not observe learning directly but rather we observe its products or outcomes as assessment” (Schunk & Ertmer, 2000. p.7).

**Approaches to Learning Theory**

The concept of ‘Approaches to Learning’, often identified as deep and surface learning and related models (after Biggs 1989, 1998; Entwistle, 1991) provide a framework for understanding relationships between the learning context and strategies that result in particular learning outcomes for students. This emerges from a combination of student motivation and their preferred strategies to learning. For example, students can employ varying degrees of deep, surface and achievement approaches within their learning framework.

The learning process for many students, is seen as essentially reproductive; acquiring knowledge, memorizing material and applying the knowledge in exams or practical classes (Marton, 1997). This has been termed a surface approach and is encouraged by many current methods of teaching and assessment (Biggs, 1999). A common view of many tertiary teachers, however, is to promote critical analysis and problem-solving as higher-order thinking skills. Another view of learning held by some teachers includes the achievement of insight, understanding and personal development by students as they develop skills to solve problems and adopt a personal philosophy. This deep approach is much more in line with the aims of curricula developed by many teachers.

The final strategy to learning is termed an achievement approach and is reflected in the external reward of high marks as an impetus for learning within learning situations. All students are capable of employing any of these strategies, but the context presented by
explicit learning outcomes and methodologies can influence the learning strategy which is engaged for a particular situation (Ramsden, 2003).

The Approach to Learning theories have been challenged (Haggis, 2003), as it has been demonstrated that students are resistant to changing their approach to learning, and surface learning can lead to high achievement. Webb (1997) proposed that the deep/surface dichotomy may be too simplistic, as exemplified by the example of the “the paradox of the Chinese learner” who use ‘surface’ strategies for the ultimate goal of a ‘deep’ understanding of an issue (Marton, et al., 1997). To seek ‘understanding’ it may be that the learner moves between surface and deep approaches to reach what is referred to as a deep understanding (Webb, 1997). However, the Approaches to Learning metaphor of deep and surface approaches to learning, and the concept of deep and surface understanding provides a way by which complex pedagogical issues can be accessible to staff for a diversity of disciplines (Entwistle, 1997).

**Theories of Teaching and Learning Appropriate to Higher Education**

This section reviews theories of teaching and learning in a higher educational context. The discussion describes the continuum of learning from a surface level, teacher-centred approach through to a deep level, student-centred approach to learning. Although many teachers strive for the latter, this section provides a discussion of difficulties in realised teaching activities (particularly assessment), resulting in ineffective learning outcomes for many university students. Biggs’ (1989) hierarchical levels of beliefs and methodology are reviewed as a framework for curriculum development and alignment.

**Teacher versus Learner focus**

For many students, learning is seen as essentially reproductive (acquiring knowledge, memorizing material and applying the knowledge in exams or practical classes (Marton, et al., 1997). Many current methods of teaching and assessment encourage a surface approach (Biggs, 1999). In contrast a deep learning approach is much more in line with the aims of many teachers, and the issue arises: how do we maximise the match
between the teachers’ expectations and the student’s achievements? Biggs (1999) emphasised the importance of providing a strong motivational context, engaging learners in stimulating activities, encouraging interactions with others, and providing a well-structured knowledge base in order to promote a deep approach.

As the system of assessment plays a major (if not, the most important) role in guiding student learning (Biggs, 1996; Ramsden, 1991), it seems logical that teachers should use assessment tasks as a way of communicating to students what skills and learning tasks are considered important. After all, there are major pressures on higher education institutions to produce chiefly summative assessment systems, which can be consistently applied and economical to employ (Elton & Johnston, 2002).

The way this assessment is used is critical. If an assessment task is couched in somewhat threatening terms, instead of a manner that encourages and challenges students to achieve, it probably encourages surface learning and promotes the reproductive views of learning as simply acquiring and memorising information. How then do we foster a deep approach to teaching and learning amid a class with heterogeneous learning styles and mixed abilities?

There seems to be a current trend in the research into tertiary teaching and learning that is moving from deficit or blame models to an interactive phase that attempts to coordinate the entire context of teaching (Biggs, 1998; Orrell, 1991). Ramsden (2003) summarised a progression of teaching theories from “teaching as telling” (a deficit model), teaching as organising (a simple interactive model) to a theory that makes learning possible (a complex interactive model). To reflect on the teaching process, we need to know how teachers and students conceive the tasks of learning and teaching. Marton and Saljo (1984) distinguished quantitative and qualitative conceptions of learning that provide useful poles as endpoints to a continuum. The quantitative conception is that learning focuses on how much is learned and teaching is considered largely as a transmission process. Conversely, the qualitative conception envisages learning as involving personal meaning and a way of understanding experience while teaching helps the student restructure experience. This is radically different; the teacher is not so much a source of knowledge as someone who interacts with the student to encourage appropriate construction of this knowledge and experience.
Constructivism is a student-centred learning theory whereby the aim of learning is a process of ‘conceptual change’ and new information is assimilated into existing knowledge (Hewson, 1996). Constructivism is applied both to how people learn, and to the nature of knowledge. It refers to the idea that learners construct knowledge for themselves of which the consequences are that we have to focus on the learner in thinking about learning, and that there is no knowledge independent of the meaning attributed to experience (constructed) by the learner. Activities aimed at raising the status of an idea to improve conceptual change should constantly form part of teaching for conceptual change. It has been widely accepted that experiential learning is the most effective method at changing student’s conceptions (Wheatley, 1991).

Relating these conceptions to student characteristics and the teaching context has resulted in the presage, process and product model (described in Biggs, 1989). Briefly, this 3P model recognises the links between characteristics of the students (e.g., prior knowledge and abilities) and the teaching context (assessment methods and course structure) in the presage phase. Together, the students learning characteristics and the learning context largely dictate the process phase which is how the students approach the task (metalearning). The end result is the product or learning outcome.

**Beliefs and methods of teaching**

Biggs (1999) identified three hierarchical levels of beliefs and methods about teaching:

1. **“Blame the Student”**: Whereby teaching methods often rely on a transmission of knowledge selecting for “good and bad” students via quantitative assessment tasks.
2. **“Blame the Teacher”**: This develops a variety of class management strategies but does not focus on ‘what the students are learning’?
3. **“What the student does”**: Whereby teaching supports learning not just by transmission of facts, concepts and principles but by helping the students to form an understanding by providing activities to reach an appropriate level of understanding and using assessment to evaluate where this sort of understanding has been achieved.
Level three works by integrating or aligning the desired outcomes/objectives, with effective learning activities, and effective outcomes and assessment. This can be achieved through constructive alignment; requiring students do the “real work, the teachers role is to organise the context to make learning more likely” (Biggs, 1999, p.27). This concept seems rational yet most university education programmes are not aligned for the following reasons (Biggs, 1999):

- Teaching tradition of transmission of knowledge ignores alignment, and often student performance is not compared with the course objectives but relative to quantitative achievement of others.
- Administrative and resource problems with reporting methods other than quantitative student outcomes.
- Lack of knowledge of processes to change the status-quo.

But at what stage of the learning process is alignment failing? At the beliefs and conception of lecturer, the level of teaching and learning, inappropriate or demanding course objectives, methodological shortcoming or assessment problems. Perhaps a combination of each of the above is the most appropriate explanation.

Many studies have implied that the way teaching is carried out in tertiary institutions is dependent on the educational beliefs and presumptions of the academics. The literature on lecturer’s conception of teaching is inconclusive. An examination of intention and strategy in a science teacher’s approach to teaching, a student focused strategy plus a conceptual change intention, and a teacher focus strategy plus an information transfer intention were aligned (Trigwell Prossecer, 1996). In contrast, Murray and MacDonald (1997) found a disjunction between lecturer’s conceptions of teaching and claimed practice, where the attitudes and beliefs of lecturers about teaching were not translated into teaching strategies.

Conflict between espoused theory and practice causes lack of translation of attitudes and beliefs about teaching being translated into teaching strategies. This is due to insufficient or inappropriate training and teaching support for tertiary teaching staff. Samuelowicz and Bain (2001) identified differences between teaching-centred and learning-centred approaches. They used a qualitative questioning technique and an analytical method to provide a framework to compare belief schemes developed from
other studies. Case studies were also used to illustrate a contextualised sense of an individual’s beliefs. Staff values about their role did not always match their objectives or subsequent teaching methods.

Rust (2007) similarly argued that awareness alone does not rectify poor assessment practice and there is a considerable reluctance to change and assessment practices in tertiary teaching institutions. Although it is often accepted that a greater awareness of research into student learning is pivotal for the improvement of learning outcomes, two lines of research are required to improve student outcomes in tertiary situations (after Samuelowicz & Bain, 2001):

- What are the main conceptions held by lecturers and can these be changed?
- How are conceptions and practice better matched?

The latter is addressed by the conceptual alignment framework of Biggs (1989), whereby linkages are made between philosophies and methods of teaching, which enhance the student learning experience.

A complementary theory: Academic Literacy

Printed material, be it on the page or digitised remains the major medium from which many students (endeavour to) learn. Advice is often given on “how to read” but the quality of much reading material requires scrutiny. In the sciences, the impersonal formal nature of the language can make comprehension difficult, and may result in a feeling of inadequacy in the reader (Ramsden, 2003). The way in which writing and textual practices are central to the process of learning are often overlooked by subject specialists and course designers (Lea & Street, 2009; Lea, 2004). Understanding and creating knowledge within a discipline takes place through language. Reading and writing are cultural and social practices which vary depending on the context in which they occur. Writing is part of “the formulation as well as the presentation of thoughts” (Lea & Street, 1998). All students are negotiating a range of texts as part of their studies; through course materials, web-based resources, feedback sheets and assessment. The theory of academic literacy claims that student learning of the main literary practices and discourses of academic disciplines is more complex than just understanding student learning strategies. The increasing use of information and computer technology (ICT) in mainstream course delivery and the multimodal nature of
texts (in the move from page to screen), has given a context that is more textual than ever. Speed and delivery, and access to texts may have improved, but the fundamental written nature of the text itself has not changed (Lea, 2004).

**Applying Theory to Practice: Curriculum Development and Planning**

There are four issues that are central to curriculum development; the first three of these were clarified by Ramsden (2003).

1. *Learning outcome* (Goals and Structure): what do you want the students to learn?
2. *Teaching and learning activities* (Teaching Strategies): how teaching and learning environment are structured to achieve effective learning?
3. *Assessment*: how to find out what has been learned?

The importance of a forth issue, *Evaluation*, was emphasised by Cowan, George, and Pinheiro-Torres (2004) to determine whether the learning outcomes have been achieved developed and assessed effectively, reliably and validly. This was represented with two approaches:

- *Individual Evaluation*: how to assess the effectiveness of teaching, and make future improvements?
- *Institutional Evaluation*: A final evaluation stage was identified that emphasised the difference between change at the individual and institutional level (Ramsden, 2003), through accountability, staff development and institutional change. Cowan et al. (2004) stressed that curriculum development will call for concurrent staff development whereby the learning outcome drives all other facets of curriculum development.

Curriculum Development is not a linear process of

*goals* - *design* - *assessment* - *evaluation*

but a central hub from which aligned teaching strategies, assessment and evaluation can be achieved (Cowan et al., 2004). The following sections describe each issue in turn.
The Learning Outcome

Teachers often focus on what they will be teaching as content, rather than what the student will be learning. All content and activities of a course requires educational justification for the students. Clarification of what forms of knowledge and how they are to be applied is key to formulating curriculum objectives (Biggs, 1999). Ramsden (2003) argued that the key to university teaching is that which is determined by the cognitive changes that are required by the students.

Teachers often recognised two elements of a subject that are intended for student learning, the substantive, content driven ideas of the subject, and the procedural ideas related to the discipline (Ramsden, 2003). The purpose of expressing these elements as aims and objectives is to assist teachers to consider critically student progress and to make clear to the students what they need to learn to succeed. Expressing the concepts that students need to understand, and how they go about understanding them, is difficult if viewed from a “transmission of knowledge” viewpoint. Further, Ramsden (2003) highlighted three common mistakes in presenting course goals and structure which encourages surface approaches by giving an erroneous message to the student.

Often objectives become meaningless as a section with the aim of $xyz$ may have objective of to “gain understanding of $xyz$”, is pointless. From the learners perspective an appropriate objective may be “to explain the meaning and function of $x$ and $y$ in relation to $z$, and explain the significance of this in relation to $w$”. The relevance of all these terms may not be immediately apparent to the student but expression in this way will help the learner direct attention at what is relevant from the course presentation and materials.

Second, goals that are provided in a vague content-free way also give no assistance to student learning; e.g., ‘to improve written communication skills’, ‘to become an independent learner’. Such general aims only gain meaning when integrated in the discipline. Finally, those goals which only describe observable student behaviours, excludes learning attributes which are not easily measured.

To achieve effective objectives we need a framework to describe how understanding is developed by the learner. In learning new knowledge, understanding increases in both quantitative and qualitative complexity. Understanding is qualitative in that the content
which is retained is increased, as the details become integrated into a cognitive framework. The SOLO framework (Structure of the Observed Learning Outcome; Biggs & Collis, 1982) described a hierarchy by which a learner’s performance grows in complexity when mastering new material. Based on the 1982 version, there are five levels of the SOLO taxonomy, with a Prestructural level representing an inappropriate understanding of knowledge; Unistructural and Multistructural levels represent a quantitative increase in knowledge. As understanding is extended, qualitatively Relational and Extended Abstract levels are reached. The SOLO taxonomy can be used when formulating objectives by providing a hierarchy of tasks and procedures, and by defining the ability of applying principles from known to abstract situations.

**Criterion referenced objectives**
Levels of understanding can be described as verbs in ascending order of cognitive complexity (Biggs & Collis, 1982). A decision can be made where in the hierarchy student learning is minimally acceptable. A qualitative extension of this provides scope to the “best possible performance you could hope for” (within the unit) (Biggs, 1999). Such criterion referencing of objectives clearly portrays meaningful course expectations to the students and provides a step towards an aligned framework for assessment.

By using the SOLO framework (Biggs & Collis, 1982; 1991), an hierarchical explanation can be provided to define priorities of levels of understanding when stating objectives. The learning objectives need to be consciously linked to the learning activities designed for students to achieve. It has often been assumed that students should first understand concepts, facts and theories before applying them to actual problems. However, Laurillard (1987) demonstrated that the understanding of concepts does not facilitate application by students. In a study of the best methods to teach generic skills (e.g., critical reasoning and communication) a cross curricula approach (multiple exposures to core skills in different subject contexts) was found to be most valuable in achieving student learning of these skills (Leggett, Kinnear, Boyce, & Bennett, 2004). Providing an opportunity to analyse genuine problems may make the understanding of techniques and concepts more attainable and rewarding. This is the key principle of problem-based learning (Boud, 1985).
Teaching and Learning Activities

From the perspective of the theory of teaching and learning, teachers aspire to realise sound teaching strategies which encourage students to relate unfamiliar material to their existing cognitive structures in a purposeful way. The aim is to discourage surface learning approaches and encourage deep learning.

Methods are offered to help students engage dynamically with unfamiliar subject matter and become conscious of discrepancies between their current conceptions and the conceptions of the subject in question. This process facilitates cognitive change. Biggs (1999) stressed that this involves making use of the students existing knowledge base emphasising structural connections between topics and confronting student misconceptions. Most importantly the aspiration is to place students in control of their own learning.

The current application of traditional university teaching methods such as lecture-tutorial-laboratory-class methods used in the sciences and social sciences are often inappropriately applied rather than inappropriate methods per se (Ramsden, 2003). Biggs (1999) categorised teaching and learning activities into those that are teacher-directed, peer-directed (through student-student interaction) and self-directed. These are associated with different aspects of learning: explaining, clarifying and comprehension respectively, forming opportunity for a continuum from surface to deep understanding. Most traditional university teaching activities remain at the teacher-directed, explanation and encourage surface learning, predominantly due to the teaching of large classes (Ramsden, 2003).

Lectures and Large Class Teaching

If knowledge is seen as a commodity to be transmitted to the student then the standard one hour lecture is a cost effective strategy for transmitting information (Ramsden, 2003). This is completely teacher-centred with few opportunities for student participation in deep learning, but with a little innovation may be enriched through increasing the cognitive range of the lecture by changing activity after 20 minutes (Biggs, 1999). Alternatives to lecturing for accommodating high student to staff ratios have been successful when active learning has been incorporated into the class situation. Within a small class, listeners can have greater opportunity for self-directed learning.
through clarification of ideas by way of discussions; however, achieving this requires substantial planning for a large class.

Engaging peer partnerships during large class learning situations can change the form of learning available from that presented in a totally teacher-controlled setting (Biggs, 1999). For example, a teacher-controlled lecture setting is ‘learnt’ through reception of selected content. Using learning partners for discussion during that setting allows for resolution of cognitive conflict of new ideas and discussion of application of that content.

**Problem Based Learning**

Problem-based learning (PBL) approaches originated in the 1960s and are most common in professional disciplines with implementation across single units and whole programmes (Poliquin & Maufette, 1997). In PBL, the premise for learning is a “problem, query or puzzle that the learner wishes to solve” (Boud, 1985, p.13). The problems form the core of a PBL curriculum rather than being added as active learning examples. The problems define what is to be learned, and in doing so the learner can acquire discipline content and skills, together with self learning skills of a specific faculty. Students exposed to PBL utilise deep learning approaches more often than surface approaches as they progress through a programme (e.g., McKay & Kember, 1997; Newble & Clarke, 1985). PBL taught students often have greater reasoning skills than traditionally taught students (McKay & Kember, 1997), with concomitant improvements in self direction.

**Learning outside the classroom: Online teaching and course materials**

In Australia, approximately 14% of university students study in “distance-mode” (Jones & Pritchard, 2000), including programs that bring education and skills to developing countries via the internet. Distance education, however, adopts a different philosophy from on-campus learning, in that instead of assembling students in one location, it reaches out to students wherever they wish to study (Guri-Rosenblit, 1999). In distance education the learner is physically separated from the instructor for much of the learning process. In distance education the classroom setting is not the primary means of learning, the institution rather than the teacher becomes the primary instructor (Guri-Rosenblit, 2005) and the student is taught as an individual rather than a group.
More recently, technology has been integrated into almost all forms of education, making the distinction between distance and on-campus learning less pronounced (Stella & Gnanam, 2004). By participating in courses through on-line or e-learning, on-campus students can take part in a learning program on or away from campus, lessening the historical gap between internal and external students. More than ever, tertiary level ‘distance education’ can now emulate conventional university education.

In a traditional context, a campus (site) visit enables peers to get a feel for ‘institutional ambiance’ through physical interaction with university management, faculty, students and alumni, and in the learning setting such as the contact between staff and peers. In distance education where the learning environment is physically distributed (Stella & Gnanam, 2004), the key elements of the learning environment are access to educators and information resources over a ‘distributed site’.

In learning outside the classroom through external (distance) studies and flexible (mixed on and off-campus) studies, the learner takes responsibility for their own scholarship. Printed material be it on the page or digitised remains the major medium from which many students (endeavour to) learn. Advice is often given on “how to read” but quality of much reading material requires scrutiny. In the sciences the formal nature of the language can make understanding difficult, and cause feelings of poor confidence by the reader (Ramsden, 2003). Despite problems with published curriculum materials, the teacher plays a crucial role in mediating even the best texts by modifying the curriculum to meet particular learning needs of the students.

**Linking curriculum objectives with teaching and learning activities – are they aligned?**

The aim of curriculum development is to be clear on what sort of learning takes place, and Biggs (1999) suggested we “tune our teaching methods to elicit from students the learning activities most likely to produce the desired learning outcomes”. A study of how generic skills were developed by students, by Bath, Smith, Stein, and Swann (2004), demonstrated quality assurance in outcomes ensuring alignment of espoused and realised curriculum. Their research links this to student learning through an action-learning method of teaching to achieve the graduate attributes of critical thinking, intellectual curiosity, problem solving, and logical and independent thought. Their
survey measured student perceptions of how much their experiences helped them develop skills and abilities aligned with graduate attributes. By examining the student perceptions they captured developments not explicitly intended by the curriculum.

Teaching within any given context, be it large classes or on- or off-campus is entirely dependent on the context and resources available. Effective learning is only achievable for most students where the human resource implements a learning environment which enhances learner controlled study skills and meta-cognitive learning skills through encouraging self management and independent learning.

Assessment
Aligned assessment is associated with qualitative and quantitative learning outcomes. Assessment often is described in two categories; *formative* assessment which gives insight into realised student learning (Cowan et al., 2004), and can be used for feedback to improve individual learning and teaching strategies, and *summative* assessment, used to grade students at the end of a unit or course (Biggs, 1999). Summative assessment can also have a formative function. Formative assessment is present during the ongoing development of teaching and learning activities, and supports and enhances learning. Students often focus on summative assessment as the keystone of the curriculum (Ramsden & Moses, 1992). Thus learning is focused on what students’ believe will be tested. Assessment reinforces learning when teaching is aligned with learning outcomes (Biggs, 1999). Three processes are involved

- selecting criteria for the assessment;
- selecting the evidence that would support those criteria; and
- making a judgement about the extent to which the criteria have been met.

Historically, the most common assessment framework is quantitative where performance is reduced to aggregates of units, or ranks on a ratings scale. Quantitative assessment is may be norm referenced whereby the teacher controls the assessment environment, thus assessment items constructed with quantitative assumptions about learning do not reflect the nature and diversity of what a student has learned. Presenting clear assessment requirements to students as resulted in a strong shift to criteria-based assessment (Sadler, 2005).
To match social constructivist learning theory (Wheatley, 1991), where we know that existing knowledge and beliefs can enable or impede new learning, the alternative model of assessment is to use qualitative view of looking at what knowledge has been gained (Shephard, 2000). In this criterion referenced model, assessment is integral to the curriculum development process. The assessment grade describes how well student performance matches the objectives (Biggs, 1999). A learning outcome is marked holistically and independent of other students. To achieve this, assessment items need to be open-ended performance tasks from which students can reason critically, to solve complex problems and apply their knowledge in a real world context. However, Sadler (2005) argued that the use of criteria-based assessment is ambiguous in practice. He recognised the need for both a ‘standards’ based (a fixed reference of level and attainment) and ‘criteria’ based assessment (as qualitative) approach to achieve a high quality assessment and grading system for higher education.

**Formative assessment**

For assessment to assist in learning it needs to be integrated in the learning process rather than postponed to the end point of instruction. Intrinsic motivation, confidence building and substantive feedback need to be applied to promote collaboration rather than competition between students (Elton & Johnston, 2002). Further, for assessment to enhance the learning process the classroom culture needs to shift from one where performance on a test is independent from real learning. If students and teachers have a shared expectation in ‘problem solving’, this enhances a learning cycle of collaboration between the teacher and learner (Shephard, 2000).

Self and peer assessment increases student responsibility for their own learning and enhances collaboration in the teacher learner relationship. By sharing responsibility for learning the student gains an appreciation that learning standards are not unpredictable or subjective (Hounsell, McCune, Hounsell & Litjens, 2008; Gipps, 1999). A study by Klenowski (1995) showed that students participating in self evaluation became more interested in the assessment criteria than their grade. Students competent in self evaluation became more honest with their work, were better equipped for peer assessment, and could defend their own opinions.
Reliability and validity in assessment

Traditionally, reliability and validity of assessment are based on the quantitative model. Reliability is about replication in judgment of student performance. Validity is the accuracy of a test to measure what was planned (Messick, 1989). An aligned, or appropriately criterion referenced test is valid. For example, how do we distinguish between truly understanding a concept by being able to transfer knowledge and use it in real situations in contrast to memorisation? Learning is more likely to occur if students have the opportunity to practice with a variety of applications (Bransford, 1979).

In essence, assessment should support worthwhile learning. Students tend to gain higher marks from coursework assignments than from examinations (James & Flemming, 2005). Coursework is also a better predictor of long-term learning of course materials than examinations (Conway, Cohen, & Stanhope 1992; Marton & Saljo, 1976). When there are financial and logistical course constraints, however, coursework is the first assessment item to be taken away. To reconcile both administrative and pedagogical pressures, assessment items need to achieve student engagement in quality learning and without generating excessive marking (Gibbs & Simpson, 2004/5).

Sectional versus holistic assessment

The differences in the use of sectional and holistic analysis are grounded in the theoretical approach of the teaching methodology. A positivists or interventionists methodology strips context of extenuating variables so that a truth can be uncovered (Elton & Johnston, 2002). Here, an assessor assumes that numerical scores can be allocated to a particular objective quality of a predetermined outcome. The scores are criteria or norm referenced coming from interpretative guidelines validated by previous research. From this viewpoint individual tasks tend to be scored separately and extended assessment items tend to be analysed as a sum of individual sections (Cresswell, 1998).

When multiple outcomes are assessed together to give a holistic integrated impression of a students’ work, an interpretivist rather than positivist approach to assessment is inherent. The lucidity and trail of evidence leading to interpretations is more important than specific criteria for marking. Holistically assessed tasks are therefore most likely to be the outcome of active and student-centred learning (Elton & Johnston, 2002).
Marking from an interpretivist viewpoint is done via textual and contextual information available about a student. For example a teacher’s knowledge about an individual learning process and group skills (e.g., leadership, empathy) are incorporated in the outcome. Thus from an interpretivist perspective, a qualitative approach to student assessment would be favoured over the numerical scoring of tasks (Elton & Johnston, 2002). The concept of such informed judgment forms the basis of Eisner’s *Connoisseurship* approach to communicative and interpretive understanding. However, a holistic judgment cannot just be a subjective “I know a fail or distinction when I see one” (Eisner, 1993). Holistic judgment may be best expressed through guidelines on a number of dimensions expressed in qualitative statements (Elton & Johnson, 2002; Toohey, 1999). The guidelines themselves can either be written in a positivist framework, or by an informed community in an interpretivist manner. Finally, holistic assessment may be qualitative or converted to numerical or ranked grades, and consideration needs to be made as to the nature of summative assessment?

**Evaluating the outcome of teaching**

Although teaching conceptions may be aligned with student-centred approaches to learning, and teachers may be involved development of pedagogical knowledge; beliefs and the teaching methodology used are not often aligned at a personal level (Kember & Kwan, 2000; Samuelowicz & Bain, 2001). This may be due to context driven influences, and the lack of critical reflection by most lecturers on specific teaching episodes (Cowan et al., 2004).

Implementing an instructional method is much more context driven, and often viewed as inflexible, restraining effective student-centred and deep learning approaches to teaching activities. This discrepancy is explained in a model of teacher thinking that demonstrates relationships among different conceptions that influence teaching actions (McAlpine, Weston, Berthiamume, & Fairbank-Roch, 2006). McAlpine et al. (2006) argued that personal beliefs and espoused values about teaching are not as contextually situated as most aspects of thinking. Most intermediary thinking draws on beliefs and links to context, and is used in goal setting and knowledge use. At a procedural and concrete level of implementing an instructional method, thinking is much more context driven and less flexible due to the dominance of student-teacher interaction.
Summary of the practice of curriculum development

To achieve effective objectives we need a framework to describe how understanding is developed by the learner. In learning new knowledge, understanding increases in both quantitative and qualitative complexity. Clear expression of learning objectives assists teachers to critically consider student progress and to make clear to the students what they need to learn to succeed. Assisting the learner in taking responsibility for their own scholarship is thus the most important aspect of teaching and learning activities. This is more often seen in learning outside the classroom through external studies, and mixed on and off-campus studies.

Aligned assessment is associated with qualitative and quantitative measures of learning outcomes. When teaching is aligned with learning outcomes assessment reinforces learning. Due to context and institutional constraints a balance is required between achieving consistent outcomes and outcomes concerned with evaluating the achievement of learning. In addition to assessment for monitoring student learning, classroom assessment can be used to evaluate and improve teaching practices. Promoting student learning and assisting lecturers in their teaching involve identical principals (Prosser, Martin, Trigwell, Ramsden & Middleton, 2000). By having a process by which to help students we can understand how to improve teaching.

Learning in Science?

There has been a tendency to value instrumental (objective) over communicative (e.g., values and ethics) and emancipatory (critical reflection) knowledge in tertiary science education. The science discipline incorporates different types of knowledge: instrumental, practical, communicative and emancipatory, which influence the types of learning and evaluation strategies that might be suitable for their pedagogy (Cranton, 2006).

This section begins with a description of the issues of teaching and learning in tertiary science and assesses the process of curriculum development and planning with a focus on the ‘Constructive Alignment’ of Biggs (1996). Frameworks of knowledge domains
are discussed as a conceptual perspective from which to pursue the learning and assessment of scientific inquiry.

**Issues of teaching and learning in tertiary science**

Learning outcomes in science disciplines such as ecology and environmental science often focuses on the progression of independence by the student, in scientific research design and report writing. Student outcomes are expected to be multi-faceted; from an understanding and application scientific method to a contextual framework.

The acquisition and development of concepts in science, for an individual, is a multi-faceted process. First, many concepts in science are highly complex and require the understanding of a number of subordinate concepts. These in turn, rely on the individual to make meaningful linkages between the concepts. It is the structure of the relationships between concepts which are the key to successful application in science (Driver, 1983). Yet learning in science is not just about acquiring and integrating concepts, it incorporates instrumental, practical, communicative and emancipatory types of knowledge (Cranton, 2006).

There are fundamental differences, however, between conducting scientific research and learning a discipline of science. There has been a tendency to teach and evaluate instrumental knowledge through quantitative and objective means, such as doing empirical research. In contrast, interpretive methods of learning and evaluations are more common in the communicative domain. With this focus there are no objectively verifiable truths and validity is determined through consensus within a social group of informed persons. In the emancipatory domain we are interested in how self reflection and development are achieved. Emancipatory methods may be suited to advance level graduates. Here creativity would be valued in challenging current understanding (Cranton, 2006). Creativity, however, is one of the least practiced and assessed domains of learning in the sciences throughout schooling and undergraduate courses (Yager & McCormack, 1989). This approach may be helped by a mentor relationship between teacher and students whereby the student is assisted in understanding, interpreting actions and challenging the *status quo*.

For the assessment of student learning, Cranton (2006) argued that it may not be possible to be truly objective in the evaluation of student learning, which is a
psychological and social process. In striving for objectivity can personal preferences and values of the curriculum designer be accounted for? Interpretive methods common in the arts may be relevant in some aspects of the sciences. Report writing, oral presentations and (I would now assume) online debates fall into this category. The trustworthiness of an interpretive evaluation is “founded on the professionalism, experience, knowledge, authentic and ethical behaviour of the educator” (Cranton, 2006. p.8). This reflects a holistic approach outlined above.

**Knowledge domains and learning in science**

Action learning and social implications are frequently allied to encompass the multifaceted nature of knowledge acquisition, in the sciences. To acknowledge this, Yager and McCormack (1989) placed assessment methods in science and technology education in five domains. Each of the domains below, are independent ways of conceptualising the forms of knowledge encompassed by scientific disciplines.

- Information Domain
- Process of Science Domain
- Creativity Domain
- Attitudinal Domain
- Applications and Connections Domain

The *Information Domain* is about knowledge and understanding. Science instruction in this area, aims to assist students in knowledge of currently accepted explanations of natural phenomena. This domain includes facts, principles, and theories.

The practice that characterises the human actions that result in the new knowledge which becomes the concepts (above) is represented by the *Process of Science* domain. These skills are attained through inquiry procedures such as classifying, measuring, predicting and most importantly hypothesis testing.

One critical domain, in terms of the questioning and testing of ideas central to the scientific method, which has been given little attention in schools, is the * Creativity Domain*.

The *Attitudinal Domain* is a significant area in the current climate of complex social and political frameworks surrounding energy supply and environmental issues. This domain
focuses on developing personal sensitivity and respect for other people and the environment and exploring arguments for multi-faceted issues.

Finally, knowledge and skills from all the domains are transferable to the Applications and Connections Domain. Some dimensions of this domain are using scientific principles and processes for solving technological or environmental problems, understanding and evaluating reports (both mass media and scientific) on scientific developments, management at local, regional or national levels to resolve problems, and ultimately workplace skills.

From a pragmatic perspective both an analytical/deterministic and holistic/communicative approach to the learning and assessment of the scientific inquiry needs to ensue. For this thesis a framework which incorporates three themes as a starting point is proposed: Theoretical, Practical and Functional. The theoretical concurs with the theoretical domain of Yager and McCormack (1989) and contains instrumental knowledge. The Practical theme concurs with the processes of the science domain (Yager & McCormack, 1989), but also incorporate ideas of the creativity domain. This theme encompasses scientific research methodology and integrates possibilities for new exploratory procedures. The Functional theme would incorporate ideas from both the Attitudinal and Application and Connections Domains above. Management of areas such as technology development and environmental issues require respect for persons, biophysical environs on different sides of issues to provide balanced multi-faceted debate for moral application of scientific outcomes.

In conclusion, to benefit learning of complex issues, which involve critical and abstract thinking, incorporating outcomes which encompass an understanding of empirical, interpretive and even emancipatory knowledge may be of value to curriculum development, in tertiary science disciplines. Exploiting an interpretive framework incorporating theoretical, practical and functional aspects of the sciences may provide a tool towards a holistic perspective of assessment.
Summary and Conclusion

This review has described quantitative views of learning and approaches to assessment, and discussed alternative qualitative approaches to learning by relating theory to practice (Biggs & Collis, 1982; Marton & Saljo, 1984). The latter views show the need for moving from teaching discrete techniques and correct answers to expression of skills within an ordered but provisional system whereby teaching focuses on the relationship between students experience and new concepts (Prosser et al., 2000).

There are two extremes on a continuum of teaching and learning; a surface level, teacher centred approach through to a deep level, student centred approach to learning. Although many teachers strive for the latter, discrepancies between espoused beliefs and understanding about pedagogy, and teaching and realised teaching activities result in ineffective learning outcomes for many university students (Kane et al., 2004). By using Biggs’ (1989) hierarchical levels of beliefs and methodology, curriculum alignment can be used as a framework to better support curriculum development to enhance student centred learning.

In concordance with Ramsden (2003) and Biggs (1999), the learning outcome is central to all other curricular activities of teaching and learning activities, assessment and evaluation. Both qualitative and quantitative learning construction is important in outcome design, and by using the SOLO framework (Biggs & Collis, 1982), an hierarchical explanation can be provided to define priorities for levels of understanding for stating learning objectives. Criterion referencing of objectives clearly portrays meaningful course expectations to the students and provides a step towards an aligned framework for both the design of teaching activities and assessment. Through a qualitative and student-centred approach to teaching and learning activities, students are encouraged to be in control of their own learning. Such a student-centered approach is driven by the context of the learning environment (Lindblom-Ylanne, et al., 2006).

Aligned assessment is associated with qualitative and quantitative learning outcomes. Summative assessment can encourage deep learning skills such as critical reasoning and application of problems to a real world context when aligned with criterion referenced objectives of a course (Biggs, 1999). Non-discipline specific skills can be enhanced
through evaluating student abilities of non instructional goals such as developing meta-cognitive abilities, and peer skills in the discourse and practices of academic disciplines (Leggett, et al., 2004). Such aligned assessment can be employed to improve student learning and the quality of teaching.

In the current climate of institutional accountability for learning, a workable structure is required to evaluate the development and learning of students. This requires a focus on cognitive development of the student and the impact of teaching practice on the learning experience. To integrate alignment throughout the teaching process, assessment procedures enhance a classroom culture conducive to student-centered learning (Shephard, 2000).

In a tertiary science setting, student outcomes are expected to be multi-faceted. This may embrace an understanding and application of the scientific method to a contextual framework. In multidisciplinary courses we may be imparting a mixture of declarative knowledge, expect a variety of communicative knowledge presentations, and anticipate some emancipatory feedback from students. As the complexity of contextual concepts increases so does the complexity of elements and the constituent relationships between them. To evaluate functioning knowledge in such a complex setting, assessment techniques are required that integrate many of the identified learning approaches by Biggs, (1999). Common quantitative procedures, alone are unlikely to encompass the full range of cognitive and social aspects of learning, thus qualitative models such as SOLO (Biggs & Collis, 1991) may provide a framework for aligned curriculum design with allied assessment items for the teaching and learning of complex pedagogical contexts. The next chapter discusses the development of the SOLO model and its application in science education and within a tertiary context.
Chapter 2
The Solo Model and Study Rationale - a qualitative assessment of learning outcomes

Introduction

The SOLO model of Biggs and Collis (1982) straddles the divide between quantitative and qualitative approaches to assessment of learning outcomes. The levels within SOLO are based on qualitative analysis of the students’ perceptions of various learning tasks which are used to measure the quality of learning on an ordinal scale (Marton & Svensson, 1979). The foundation of the model is a hierarchy of generic categories (modes and levels) which describe an increasingly more complex learning response. Theoretically this can be applied to any learning context. The SOLO model has developed over 30 years from origins in Piagetian research to the most recent two-learning cycle version (Pegg, 2003; Pegg & Davey, 1998).

The first part of this chapter follows the temporal pathway of the SOLO model from its inception in 1979, and its application in science education and within a tertiary context. This section concludes with an evaluation of main criticisms of the theoretical basis of the model.

Development of the SOLO model

The SOLO model originated as a reaction to criticism of Piagetian stages of children observed from school classes. In correspondence with Piagetian stages, SOLO evolved from a single unbranched hierarchy of five levels which focussed on concrete thinking (Biggs, 1989). In contrast to Piaget, the levels were logically distinct rather than a continuum on a developmental pathway. By 1982, Biggs and Collis depicted the Model with five ‘levels’ (prestructural - P, unistructural - U, multistructural - M, relational - R and extended abstract - EA) each corresponding to a modified Piagetian scale. In addition, a dual linear hierarchy was proposed showing recurring learning cycles of
different SOLO cycles within each ‘mode’ or cognitive stage (Biggs & Collis, 1991; Table 2.1). The model developed to distinguish clearly the degree of abstraction of understanding (the mode) and the structure of the response (levels) (Biggs & Collis, 1982). Here, the five modes rather than ‘level’ corresponded with the original Piagetian stages of development. By 1991, a terminology for the modes was established, and the typical age they become apparent (Biggs & Collis, 1991). Multimodal functioning was identified with at least two levels of cycles within some modes, and hypothetically two learning cycles in all modes (e.g., Pegg & Davey, 1998). The first cycle (U1, M1, R1) identified by Pegg and Davey (1998) corresponds to the original unistructural (U) category of Biggs and Collis (1991), while M2 and R2 are equivalent to the M and R of Biggs and Collis (1991; Table 2.1).

**SOLO Modes and Levels**

The two factors which discriminate between the qualities of response in SOLO are the degree of abstraction presented in the learning outcome and the structural complexity of the response. The modes represent the degree of abstractions and the structural complexity of responses within a given mode forms the second order hierarchy of SOLO Levels. The detail of this framework is described in this section.

SOLO comprises five modes (sensori-motor, ikonic, concrete symbolic, formal and postformal), which become sequentially available to individuals from birth to early adulthood. These five modes are described in Table 2.2 in order of appearance form birth to maturity based on descriptions in Biggs & Collis (1991. pp.61-67) and Collis and Biggs (1991. pp. 188-191).
Table 2.1 Major steps in the development of the SOLO model, and their relationship to Piagetian stages and forms of knowledge.

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<tbody>
<tr>
<td>Modified Piagetian stages’ 1</td>
<td>SOLO level isomorphic to Piagetian stage</td>
<td>SOLO mode isomorphic to Piagetian stage</td>
<td>SOLO levels, single learning cycle</td>
<td>SOLO mode isomorphic to Piagetian stage, two learning cycles</td>
</tr>
<tr>
<td>Formal operations (16+)</td>
<td>Extended Abstract (EA)</td>
<td>Postformal (20+)</td>
<td>Postformal (20+)</td>
<td>Theoretical</td>
</tr>
<tr>
<td>Concrete Generalisation (13-15)</td>
<td>Relational (R)</td>
<td>Formal (16+)</td>
<td></td>
<td>Theoretical</td>
</tr>
<tr>
<td>Middle Concrete (10-12)</td>
<td>Multistructural (M)</td>
<td>Concrete–symbolic (6+)</td>
<td>Concrete–symbolic (6+)</td>
<td></td>
</tr>
<tr>
<td>Early Concrete (7-9)</td>
<td>Unistructural (U)</td>
<td>Ikonic (18 months+)</td>
<td>Ikonic (18 months+)</td>
<td>Declarative</td>
</tr>
<tr>
<td>Pre-operational (4-6)</td>
<td>Prestructural (P)</td>
<td>Sensorimotor (birth+)</td>
<td>Sensorimotor (birth+)</td>
<td>Intuitive</td>
</tr>
</tbody>
</table>

1 (as per Collis 1975, cited in Biggs & Collis, 1982, pp. 24-25)
Table 2.2 Modes of SOLO and developmental emergence.

<table>
<thead>
<tr>
<th>Mode</th>
<th>Characteristics</th>
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</thead>
<tbody>
<tr>
<td>Sensori-motor</td>
<td>This mode involves tacit knowledge, the unarticulated “know-how” to perform motor skills in response to physical environmental stimuli. In infants where this is the only available mode it is associated with learning responses such as sucking, grasping and crawling. In adults, the sensorimotor mode is invoked in learning of skilled motor activities such as gymnastics or swimming, but this learning is augmented by more abstract modes.</td>
</tr>
<tr>
<td>(from birth to about 18 months of age)</td>
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<tr>
<td>Ikonic</td>
<td>This mode represents a step of abstraction from action to thought by way of mental imagery or “ikon” generation. Such ikonic thought in young children is associated with intuitive knowledge that is perceived directly, and is prerequisite for and associated with the development of language.</td>
</tr>
<tr>
<td>(from 18 months to about 6 years of age)</td>
<td></td>
</tr>
<tr>
<td>Concrete-symbolic</td>
<td>The concrete-symbolic mode represents a further progression in abstraction. In this stage oral language is supplemented by more abstract symbol systems such as written languages, signs, maps and so forth. These symbol systems follow an internal logic, and relate in a logical manner to the experienced world that they represent. Mastery of these more abstract symbol systems requires explicit instruction, in contrast to the previous modes, and this is the task of primary and secondary schooling. This leads to declarative knowledge, where symbol systems are used to describe the concrete world. Most of the cognitive tasks in day-to-day living are within this mode.</td>
</tr>
<tr>
<td>(from around 6-14 years of age)</td>
<td></td>
</tr>
<tr>
<td>Formal mode</td>
<td>Some individuals develop a more abstract system of thinking that enables manipulation of theoretical constructs that do not necessarily have any direct empirical referent. Formal thinking allows for hypothesis generation and propositional reasoning, and the theoretical knowledge associated with the formal mode is necessary for understanding abstract academic disciplines. It is therefore the target mode for undergraduate university study.</td>
</tr>
<tr>
<td>(from about 16 years of age)</td>
<td></td>
</tr>
<tr>
<td>Postformal mode</td>
<td>This mode is hypothesised to occur in a small minority of individuals. The postformal mode has not been subject to much examination or supported by empirical evidence, but is thought to be characterised by the ability to question and challenge the basic tenets and bounds of a discipline, and to make major innovations in a specific disciplinary area.</td>
</tr>
<tr>
<td>(from about 20 years of age onwards)</td>
<td></td>
</tr>
</tbody>
</table>

Diverging from Piagetian theory, the advanced SOLO modes augment rather than replace proceeding stages. Consequently multimodal function is possible with age, with adults demonstrating a wider repertoire of modes than presented by young children (Biggs & Collis, 1991. p. 62). For example the formal mode can be used to support a learning task in the sensori-motor mode; this is evident in a sensori-motor activity such as swimming by applying the theoretical aspects of water resistance to improve performance. Another example is where learning in the formal mode is frequently augmented by concrete-symbolic referents. Teaching an abstract scientific concept such as molecular structure in chemistry is commonly demonstrated by different coloured beads representing different elements and white connectors representing the bonds.
SOLO modes are context dependent and do not predetermine the level of abstraction of learning outcome related to age of an individual. Thus a student performing in the formal mode in one learning context may respond in a concrete-symbolic or even in the iconic mode in a less familiar context. Performance within the modes is thought to proceed through a cycle of five levels of structural complexity; prestructural, unistructural, multistructural, relational and extended abstract (Table 2.3; Biggs & Collis, 1991). Hence, these levels can be used to classify learning responses based on structural complexity from which the model gets its name Structure of the Observed Learning Outcome. The SOLO levels are hierarchical (Table 2.3) with each level subsuming its precursor; hence performance at any level implies consolidation of proceeding levels.

Biggs and Collis (1991) argued that the hierarchy of SOLO levels demonstrates a consistent learning sequence of any skill or cognitive task. Responses classified according to the SOLO framework should reflect a common learning sequence in gaining understanding of a particular topic, and therefore can enlighten curriculum and teaching decisions.

### Table 2.3 Hierarchical levels of SOLO

<table>
<thead>
<tr>
<th>Level</th>
<th>Characteristics</th>
</tr>
</thead>
<tbody>
<tr>
<td>Prestructural (P)</td>
<td>Responses at this level are engaged with the task, but contain only irrelevant elements, or are restatements of the question. No relevant information is provided.</td>
</tr>
<tr>
<td>Unistructural (U)</td>
<td>Unistructural responses provide one relevant element in response to a given question. Different unistructural responses can be equally correct but inconsistent with each other, reflecting focus on different aspects of the phenomenon.</td>
</tr>
<tr>
<td>Multistructural (M)</td>
<td>Responses at this level contain two or more relevant elements relevant to the question, however the elements are not linked or integrated. A range of multistructural responses could also be equally correct, depending on the focus of attention.</td>
</tr>
<tr>
<td>Relational (R)</td>
<td>These responses include most or all relevant elements and the interrelationships between them, integrating these into a coherent, meaningful conceptual scheme.</td>
</tr>
<tr>
<td>Extended Abstract (EA)</td>
<td>At this level the structure of a response is generalised, incorporating elements more removed from the given system in transition to a new more abstract mode. Thus the extended abstract level represents a link between relational responses at Mode N, and a unistructural response at Mode N+1.</td>
</tr>
</tbody>
</table>

The levels within modes are based on the number of components contained in a response and interactions between these components. The components include units of information relevant to the learning task (Biggs & Collis, 1982). Unistructural responses...
consider one component, Multistructural include more than one component and Relational responses consider interrelationships between components. Extended abstract responses indicate a transition to a new mode. A relational response in one mode becomes a new single more complex element of the next more abstract mode (Biggs & Collis, 1991). Where a relational response is not qualitatively more abstract it may also become a more complex element in the next cycle in a two-learning cycle mode (Pegg, 2003; Pegg & Davey, 1998).

In the two-learning cycle (Pegg and Tall, 2002), if the abstract nature of the outcome is the same as that identified in the previous three levels, i.e., U1 M1 R1, then the next level is a new unistructural level, U2. A new level works through a new entity formed from the integration of several learning characteristics. If the new outcome represents a qualitatively different, more abstract way of thinking, then the response can be coded within the next mode. This new level is labelled as a new unistructural level, a U1, in the next acquired mode. In the case of moving from the concrete symbolic mode into the formal mode, this new unistructural level represents the start of a new conceptual cycle. The latter has been predicted as a key learning framework for students in their late secondary and early tertiary education (Pegg and Tall, 2002).

**Transition through SOLO Modes and Levels**

According to Biggs and Collis (1991) maturation in learning is achieved as individuals advance through different levels within a mode before advancing between modes. Such cognitive development is thought to reflect both the availability of working memory, and contextual factors such as the exposure to new information and learning settings. Thus proceeding between modes requires both the physiological development, relational understanding in the previous mode and a suitable social context.

Increased capacity for information processing occurs as children mature, with older children having a greater capacity to keep a question in mind and relate their answer to a question (Pines & West, 1986). A relational (R) response requires all pieces of information to be assimilated, linked together and expressed, demonstrating an increased response of the working memory over the expression of a single concept in a unistructural (U) response.
Modal shifts occur when individuals are required to reorganise their prior knowledge in an attempt to solve a new problem (Biggs & Collis, 1991). This emanates from the importance of a conflict situation for cognitive growth to occur as outlined by Pines and West (1986). Thus, knowledge is actively built up based on an individual’s prior conceptions and experiences, and not merely transferred from one situation to another (Geelan, 1996).

Social support is also a key factor in the transition between modes, with research indicating that cognitive development of an individual is accelerated through the interactions with others (Tobin, 1990). Commonly parents initiate cognitive change in infants by providing a model and content for their children (Biggs & Moore, 1993). This supports the theory of social constructivism whereby the roles of environmental factors are recognised in the learning process. It has been argued, however, that factors other than just social interactions influence the learning process (Cobern, 1993). Context includes epistemology (Habermas, 1971) and cultural influences (Fisher & Waldrip, 1997). Factors such as religion, occupation, geographic location, education and economic levels all have implications in learning new material.

In summary, modal shifts developed within the SOLO paradigm resulted from a combination of physiological, social and cultural factors. While aspects such as physical maturation and the capacity of working memory are intrinsic to the individual, social and cultural support is required throughout the curriculum to best enhance transition between levels and modes. Application of the SOLO model has thus been used to develop curricula from primary to tertiary settings. It also provides a theoretical setting by which new ideas in educational settings; teaching methods and assessment techniques can be tested. This is facilitated by the logical and hierarchical classification of student responses.

Applications of SOLO model in science and higher education

The SOLO taxonomy facilitates insight into student cognitive development and pattern of maturity in understanding specific concepts. Several studies have investigated the use of a single learning cycle per mode of SOLO, as a measure of learning outcomes in
science especially at a secondary school level (e.g., Creedy, 1992; Levins, 1997; Panizzon & Pegg, 1997). In a tertiary context, where content-related assessment of an essay assignment for first-year physiotherapy students was inadequate, the SOLO model facilitated integrated, coherent and holistic understanding (Tang, 1998). The single cycle SOLO model has also been used together with a phenomenological approach to investigate first year biology student responses to an open ended question on photosynthesis. High correlations between both methods where found between rank ordering of student responses.

Within the two-learning cycle version of SOLO (e.g., Pegg, 2003) only two studies have used this approach at university level (Panizzon, 1999; Quinn, 2006). Panizzon (1999; 2003) identified that 71% of written responses of first year student understanding of diffusion and osmosis fell in the concrete symbolic mode with the dominant response being M2, falling short of the theoretical form of knowledge considered a target for tertiary education (Biggs & Collis, 1991, pp.61-67). A recent study by Quinn (2006) investigated the relationship between learning approaches and outcomes of on and off-campus students in a first year biology unit. Qualitative variation in responses was described in a hierarchy consistent with the two-cycle version of SOLO, with most responses coded in the second cycle multi-structural level of the concrete symbolic mode. In the latter study, deep approaches to learning correlated positively with three different measures of learning outcome.

In other undergraduate tertiary contexts, SOLO has been used in teacher education (Hattie & Purdie, 1998), and for study skills intervention (Hattie, Biggs & Purdie, 1996). In a study of learning approaches and outcomes of first year nursing students, SOLO was endorsed as a model which successfully measured qualitative differences in learning outcomes and more valid than quantitative achievement scores (Trigwell & Prosser, 1991). In postgraduate courses SOLO has been used to examine qualitative variation in short answer written statements and assessment essays (Boulton-Lewis, 1992).

A single cycle version of the SOLO taxonomy was used to describe differences in the way students and educators solved small code reading exercises for computer programming by adding two categories between M and R (Lister, Errol, Whalley, &
Responses were collected in the form of written and think-aloud reaction. The authors found that educators tended to manifest a SOLO relational response on small reading problems, whereas students tended to manifest a multistructural response being consistent with the literature on the psychology of programming.

SOLO has also been used to determine links between learning approaches and learning outcomes, with a deep approach to learning associated with higher SOLO outcomes, and surface approaches with lower level SOLO outcomes. Marton and Saljo (1976) found high correlation between learning approach and SOLO levels, with a surface approach to learning limiting the learning outcome at a mutistructural level (van Rossum & Schenk, 1984). Similarly, student explanations coded using SOLO related strongly to learning orientation, with lower SOLO levels associated with reproducing (surface) learning approaches (Watkins, 1983). In addition, results from students in a first year physics courses showed comparable patterns (Millar, Prosser, & Sefton, 1989; Prosser, Hazel, Trigwell, & Lyons, 1996), and students who used peer collaboration and deep approaches attained higher scores for an essay assignment in first year physiotherapy (Tang, 1998).

**Evaluation of SOLO**

The SOLO model has been used extensively across a range of contexts in science and tertiary education. These range from a tool in constructing and testing assessment items, a research framework, and measuring qualitative differences in learning outcome and learning orientation. Three major criticisms have been made of the SOLO approach to identifying learning outcomes including; reliability in its application, its linear structure, and its broad-spectrum application conflicting with the content specific nature of required outcomes.

In theory, SOLO categories can be applied to any content material. Despite this being an advantage of the model (Dahlgren, 1984) it may present problems when the learning outcome is tied to the specific content of the learning task. The standard SOLO model (Biggs & Collis, 1991) could not be validly applied to children’s responses to arithmetic cues and that the data fitted a bifurcated, rather than a linear sequence of hierarchical
outcome. To overcome this, content specific characteristics may need to be incorporated into the levels of the model. Likewise, Atherton (2005) was cautious of this kind of progressive model, which aspires inexorably to a final state. Without content specific characteristics, Atherton argued that a poor relational construct may cause an individual to pursue an invalid framework at the extended abstract level because of being insufficiently informed at more modest levels. However, Atherton (2005) acknowledged that it forms a good guide, especially at relational levels of understanding to student learning patterns.

Difficulty in applying SOLO to postgraduate student essays and short written responses has been found where the structure and categorisation criteria led to unstable categories leading to inter-rater disagreement (Chan, Tsui, & Chan, 1998). In this study, subcategories were added to improve their precision of the 1982 version of the SOLO model. Despite these changes, the authors did espouse the benefits of the SOLO model for measuring cognitive learning outcomes. However, finer categorisation of SOLO levels did not eradicate the problem of conceptual ambiguity of SOLO in their context.

Summary
The SOLO model is a generic tool for identifying qualitative variation in learning outcomes. The SOLO model has been used extensively across a range of contexts in science and tertiary education. These range from a tool in constructing and testing assessment items, a research framework and measuring qualitative differences in learning outcome and learning orientation. The categorisation of responses in the SOLO hierarchy is based on the degree of abstraction (the Mode) in conjunction with the level of complexity (the Level).

Unlike the Piagetian framework from which it originated, the SOLO model fundamentally departs from Stage Theory on two counts. The first is that SOLO focuses on specific responses to learning situations rather than the developmental stage of the individual and second, that context is recognised as a dominant influence on the response of an individual. Consequently, functioning across a variety of modes and levels is expected for different learning outcomes.
The SOLO model has evolved through various versions which have been used in many contexts including science and tertiary education. Critics of SOLO outline problems with reliable application due to its linear structure and its broad-spectrum application in relation to qualitative content-specific differences in some contexts. Two studies have successfully used the more recent two-learning cycle per mode version in a tertiary science context. In the latter, tertiary context SOLO was demonstrated to help construct assessment questions that elicit relational responses in biology in a natural setting.

**Study Rationale**

Assessment is a process of ongoing formative and summative evaluation that can be employed to improve student learning and the quality of teaching. In the current climate of institutional accountability for learning, a workable structure is required to evaluate the development and learning of students. This requires a focus on cognitive development of the student and the impact of teaching practice on the learning experience. The cognitive structural model, SOLO, of Biggs and Collis (1982, 1991), can provide an assessment framework which has been aligned with the aims and methods of instruction.

Limited application of the SOLO model has been achieved with actual unit-related assessment items to measure learning outcomes (Boulton-Lewis, 1992; Chan, et al., 1998; Tang, 2008). Only a single study has used the recently developed two-learning cycle SOLO model as a measure of qualitative differences in learning outcomes of a natural university setting (Quinn, 2006). The other two-cycle SOLO study by Panizzon (1999, 2003) utilised analysis of biological concepts separate from unit related assessment. These studies focused on a single concept. Furthermore, although SOLO frameworks have been used in tertiary settings to assess extended prose assignments where relational thinking is imperative for satisfactory accomplishment, to date there is limited use of SOLO for multiple concept analysis in the sciences.

Learning outcomes in science include the range of incomplete and partial understanding of single concepts to complete and integrated understandings of multiple concepts accepted by the scientific community. Assessment in the disciplines of Ecology and
Environmental Science often focuses on the progression of independence by the student, in scientific research design and report writing. Student outcomes are expected to be multi-faceted; from an understanding and application scientific method to a contextual framework of ecological setting.

This thesis examines the essence of this learning outcome and how it may be better assessed through classification by a cognitive framework. Assessing what each student knows in a broad subject area, such as ecology, is complex. Assessing students understanding in circumstances where each student can pursue different focus within a topic, where the possible topics of study include natural phenomena which are only beginning to be studied by professional scientists and managers, is even more difficult. The limited application of SOLO to learning of diverse concepts appears to be due to intellectually demanding and time consuming processes of coding broad concepts (Pegg & Tall, 2002).

In teaching ecology and environmental science, we are dealing with a mixture of facts and declarative knowledge from real world scenarios. To evaluate functioning knowledge in this setting, an assessment method that can encompass extended prose in a case study like setting is required. This task integrates many of the learning approaches identified by Biggs, (1999) including reading extensively, interrelating, organising, applying, research skills, reflection and a sense of relevance.

Extended written assessment items are often graded by an analytic method of summing marks from pre-determined components, but this does not utilise benefits of an extended prose task to the full. From such tasks we can analyse how a student can construct their response to a question or issue framework or “discourse structure”, integrated with factual and applied knowledge. Assessing the existence and quality of such a ‘discourse structure’ is a holistic judgement that can be met by through SOLO framework (Biggs, 1999). For example, a relational discourse would express causal understanding through explanations and interpretations. Because most ecology is taught within the realms of accepted paradigms and theories at an undergraduate level, a Concrete Symbolic Mode would be acceptable for learning outcomes. Following this, to be working at a level for multiple concepts and standard scientific skills to be understood and applied, it would
be hypothesised that a relational level at the concrete symbolic mode would be the rational minimum target for a student outcome.

**Research Themes and Questions**

This research project aims to develop a protocol for marking scientific written assessments using a cognitive structural perspective provided by the SOLO Model (Biggs & Collis, 1991) for second year tertiary level ecology units. A sectional based and holistic approach within the cognitive structural model will be used to compare the effective alignment of assessment by extended written assignments. The lines of inquiry are guided by the following themes and subsequent research questions.

**Theme 1:** To develop categories of written responses to a scientifically developed extended written assessment task within the SOLO model, specifically,

- **Research Question 1:** Can sections of a scientific report based assessment task be categorised by the SOLO model? (i.e., Introduction, methods, results and discussion)
- **Research Question 2:** What is the distribution of SOLO categories across different report sections?
- **Research Question 3:** How do the SOLO categories from a sectional analysis correlate with the actual quantitative grade given to the students?

**Theme 2:** To develop an holistic marking schedule for a extended written assessment task, for learning to use the scientific method in an ecological context and write a scientific report

- **Research Question 4:** How does this correlate with the quantitative grade given to the students?
Chapter 3

Research Methodology

Introduction

This chapter provides a description, justification and evaluation of the study methodology. The context of the study is outlined and includes the concepts of scientific research methodology, scientific expression, and argument used to measure the students’ learning outcomes. An account of the research design includes a description of the data collection procedure, recruitment of participants and sample sizes. The analytical process is illustrated, and the methodology critically evaluated.

Context of research

This study was designed to investigate the learning outcomes of tertiary environmental science students (research themes and questions outlined in Chapter 2). The focus is on the development of scientific method application and report writing for a cohort of second year students enrolled in Science degrees (predominantly Bachelor of Environmental Science and Bachelor of Natural Resources Management). This is achieved through the study of two written assessment tasks that aimed to develop skills in scientific review, hypothesis formulation, formulation and expression of appropriate scientific methods, and presentation of subsequent of results and synthesis in undergraduate students.

The basis of this research is a second-year core unit to students enrolled in the Bachelor of Natural Resource Management and Environmental Science in the School of Environmental and Rural Science at the regional University of New England (UNE), in Armidale NSW. The study was based on the unit ECOL202 Marine and Freshwater Ecology. Approximately 40% of students at UNE are from rural and regional areas, with about 70% of the student population studying in off campus mode.
On-campus students are required to attend two lectures and one practical session each week for 13 weeks, as well as a two-day field trip that is linked to one of their assessments. Off campus students are required to attend a four-day Intensive School at the beginning of the unit. At the Intensive School the students receive assignment information, lectures and undertake the same two day field trip as on-campus students to gather the information necessary to complete an assessment task. All students have access to lecture material (powerpoint and audio podcasts), unit outline with assessment information, study guide with lecture summaries and additional readings, and e-copies of required readings (pdf format) through the Blackboard site for this unit.

The written assessment tasks for students enrolled in on-campus and off-campus mode were the same. The first assessment item is worth 20% and the second 40% of the overall grade. The remaining 40% is from a two-hour written examination. The research focus of this unit aimed to develop comprehensive knowledge and skills of ecology in students in the context of marine and freshwater environments with the aim of helping students how to understand and manage aquatic ecosystems.

The management of marine and freshwater systems is concerned with addressing problems that arise from the stewardship, control, development and beneficial utilisation of water resources and the organisms that live in aquatic ecosystems. These issues are undoubtedly multi-disciplinary, and synthesize aspects of botany, geography, chemistry, geology, hydrology, zoology, physics and many other disciplines. Student outcomes in this unit are therefore expected to be multi-faceted; encompassing an understanding and application of scientific method to a contextual framework of aquatic systems and land-water linkages. Some outcomes directly related to the written assessment tasks include:

- a firm conceptual framework, resulting from reading and research experience, of the fundamental aspects of how physical and chemical variables in marine and freshwater ecosystems interact and influence biological features;
• be able to predict the likely outcomes of changes to land-water linkages and ecological processes in many aquatic ecosystems in Australia and overseas; and

• to understand how this knowledge can be used to wisely manage marine and freshwater environments in an ecologically sustainable manner.

To code multiple interacting variables the assessor needs to draw on knowledge of both context and experience to make informed decisions (Hammersley, 2001, p.223.). Due to the intellectually demanding of coding broad concepts there has been a lack of application of SOLO to learning of diverse concepts (c.f. Pegg & Tall, 2002). Examination of qualitative variation in learning outcomes using SOLO, to date, has focused primarily on narrow conceptual content. The most recent research into student understanding of science concepts using the SOLO model has focused on specific individual scientific concepts such as diffusion and osmosis (Panizzon and Pegg, 1997), photosynthesis (Hazel, Prosser, & Trigwell, 2002; Levins & Pegg, 1993) and natural selection (Creedy, 1992). For pragmatic reasons of the researchers’ experience in research and teaching of aquatic ecology, this discipline was chosen for the current study. The researcher is also familiar with the unit and course curriculum. Prior to this study, the researcher was employed as a marker for written assessment tasks analogous to those examined here.

**Design of study**

This study focused on the understanding in qualitative variation in learning outcomes from ecological report writing. The results pertaining to learning outcomes were analyses using a sequence of data collection. This subsection begins with a list of techniques used (Table 3.1).

A major component of the current study was the development of a qualitative assessment schedule derived from the SOLO model (Chapter 2), the remainder of this section outlines the process and rationale of development of SOLO marking schedule.
Table 3.1 Outline of sequence associated with collection and coding of learning outcomes.

<table>
<thead>
<tr>
<th>Sequence</th>
<th>Data Source</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Stage 1</strong></td>
<td></td>
</tr>
<tr>
<td>Identification of ecological topic</td>
<td>• Discussion with unit coordinator</td>
</tr>
<tr>
<td></td>
<td>• Examining unit material</td>
</tr>
<tr>
<td><strong>Stage 2</strong></td>
<td></td>
</tr>
<tr>
<td>Designing a Pilot SOLO Framework</td>
<td>• Semester 2, 2007. Assignment requests from students</td>
</tr>
<tr>
<td></td>
<td>• Collection of unmarked assessment items from students of semester 2, 2007.</td>
</tr>
<tr>
<td></td>
<td>• Pilot examination of written responses from partial report writing task: SOLO analysis of assessment task 1 (Habitats out of a Hat – HOOAH – design of an aquatic ecological project to assess an impact).</td>
</tr>
<tr>
<td></td>
<td>• Pilot examination of full report writing task: SOLO analysis of assessment task 2 (River Continuum Concept study RCC – scientific report).</td>
</tr>
<tr>
<td><strong>Stage 3</strong></td>
<td></td>
</tr>
<tr>
<td>Application of SOLO Framework</td>
<td>• Semester 2, 2008. Assignment requests from students</td>
</tr>
<tr>
<td></td>
<td>• Collection of unmarked assessment items from students of semester 2, 2008.</td>
</tr>
<tr>
<td></td>
<td>• Examination of written responses from components of a partial report writing task: SOLO analysis of assessment task 1 (Habitats out of a Hat HOOAH).</td>
</tr>
<tr>
<td></td>
<td>• Examination of components of a full report writing task: SOLO analysis of assessment task 2 (River Continuum Concept study RCC).</td>
</tr>
<tr>
<td></td>
<td>• Holistic examination of a full report writing task: SOLO analysis of assessment task 2 (River Continuum Concept study RCC).</td>
</tr>
</tbody>
</table>
Rationale and development of SOLO marking schedule

The major analysis was through determining qualitative learning outcomes based on written assessment items which reflect both skills in scientific report writing, and execution and analysis of an ecological study. The conceptual context for the investigation of qualitative differences in learning outcomes was the written expression of ecological studies as a scientific report. This entailed literature review, hypothesis formulation and testing, data collection, presentation and interpretation.

Assessment in ecology often focuses on the progression of independence, by the student, in research design and report writing. This research project seeks to examine the essence of this learning outcome and how it may be better taught through classification of responses by a cognitive framework.

Two assessment items were analysed with a systematic approach to dissecting the assignment to allocate qualitative level to separate sections of the report. The first task provided the students with experience in reviewing a hypothetical scenario of an environmental setting and an ecological disturbance. From this they were to formulate hypotheses for testing the ecological impact and design appropriate scientific methods to tackle this problem based on readings in the scientific literature. The second assignment extended the students to writing a full scientific report through a real-world problem solving task to be designed, executed during the 2-day field trip, and reviewed in the context of a well known theory of river function.

Assignment 1: The student task – Habitats out of a Hat (HOOAH)

*During a practical session students were given the opportunity to select an aquatic ecological habitat and a potential ecological disturbance that might occur in their given habitat. The student task was to review the literature about the habitat and identify possible species, population or community that would be appropriate as indicators to test the impact of their given disturbance event. The students were provided key references for their given scenario. From here they were to formulate hypothesis which could be tested to explore the effects of their disturbance on their selected indicators and habitat. Further they were to formulate appropriate methods for testing their scenario in a robust and replicated scientific study.* (Summarised from Appendix 1,
Ch. 3 Methodology

Assignment 2: The student task – The River Continuum Concept (RCC)

During the Intensive School and practical classes students explore a fundamental ecological process – the input, movement and breakdown of various forms of organic matter – in several contrasting ecosystems. Models are discussed that aquatic ecologists believe predict the passage of organic matter and resources, and their influence on the biota in river ecosystems. Predictions from these models were tested in a NSW, north coast river. Students worked in groups to develop hypotheses, methods and gather data during the 2-day field trip to test one prediction of a foundation and dominant river model ‘The River Continuum Hypothesis’ of Vannote et al. (1980). Individual assignments presenting the group data were submitted as a project report in standard scientific paper format. (Summarised from appendix 1, Course notes)

Analysis of written responses

In 2007, a small group of student reports \((n=8)\) were collected for each assessment task as a pilot study to formulate SOLO categorisation for each section of the report; i.e., Introduction, Hypothesis and Methods for assessment task 1, and Introduction (including hypothesis), Methods, Results, and Discussion for assessment task 2. Two of the 5 modes of cognition associated with the SOLO structure (Biggs and Collis, 1982) were relevant to these assessment tasks: Concrete Symbolic and Formal. Categories for a holistic approach to marking student outcomes were also formulated for assessment task 2.

To examine qualitative variation in responses to items in the written assessment task the researcher read through the entire set of reports for the sample study of the 2007 cohort. Similar responses were grouped, and emerging categories and examples of each were defined and refined. Key points were summarised into written record of SOLO categories relevant to each section within and between the two assessment tasks.

Throughout the process, consultations were held with the unit coordinator to confer patterns of scientific and ecological learning outcomes expected of the students. Discussions were also made with an authority experienced in coding SOLO responses.
that was unfamiliar with the content matter. Questions, objections and suggestions about then emerging categorisation of responses were resolved during discussions. The categorisation procedure continued through re-reading until the responses stabilised. For Assessment task 2, categorisation for assessment task one was used as a framework from which the analysis of the full report was made.

The final coding scheme for each assessment task was used to mark the 2008 cohort of students. This was tested for inter-marker reliability giving a pre-coded sample (Eight responses, 27%) from each task to the unit coordinator. The two sets of codes were compared by Spearman Rank Correlation for each section of the two assessment tasks.

Data Collection procedures

This section outlines the data collection procedures including issues relating to recruitment of participants and details of the study sample response rate.

Participants

Unit coordinators of several ecology units were approached early in the study to determine suitable assessment tasks for the investigation. Due to the restructuring of a number of units in 2007, ECOL202 Marine and Freshwater Ecology was chosen due to the continuity of assessment tasks between student cohorts for 2007 and 2008. Thus the population of interest for this study was all on-campus and off-campus students enrolled in this unit in 2007 and 2008.

Following the agreement of the unit coordinator to assist in the study, the research proposal was submitted to, and approved by the UNE Human Research Ethics Committee (HREC), approval number HEO7/150 (Appendix 3.1).

For both years of the study the unit coordinator informed the students of the project during the first practical session of the unit, and the researcher described the project face-to face with the students during a subsequent lecture session (on-campus students only). Off-campus students were informed of the project online through the Blackboard site in their subject introductions, and again during their residential school by the unit coordinator.
Project information sheets and consent forms were distributed to the students (appendices 3.2 and 3.3) during the information session by the researcher, and to maximize response rate, again during the practical session prior to the submission date of the assessment items. Again external students were presented the above forms on-line and during the residential school. Detailed response rates for the study are detailed in Table 3.1.

### Table 3.2 Response rate from students for assessment tasks.

<table>
<thead>
<tr>
<th></th>
<th>HOOAH</th>
<th></th>
<th>RCC</th>
<th></th>
<th>Total Enrolments</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Int</td>
<td>Ext</td>
<td>Int</td>
<td>Ext</td>
<td></td>
</tr>
<tr>
<td>2007</td>
<td>8/17</td>
<td>n/a</td>
<td>12/12</td>
<td>17/17</td>
<td>29</td>
</tr>
<tr>
<td>2008</td>
<td>26/30</td>
<td>8/11</td>
<td>26/30</td>
<td>8/11</td>
<td>41</td>
</tr>
</tbody>
</table>

#### Data Analysis

In this section procedures used to analyse the data are described. This section opens with a description and review of educational uses of a multi-dimensional scaling procedure which was used to analyse and graphically represent the relationships between the qualitative outcomes of the students. Details of the analytical procedure follow for each research theme of the current study.

**Patterns of distribution of SOLO categories**

A multi-dimensional scaling (MDS) procedure was used to analyse and graphically represent the relationships between the qualitative outcomes of the students among sections of the report. A non-metric MDS analysis uses interval or ratio scaled data to produce a similarity matrix that can be viewed graphically. The MDS produces maps that effectively represent similarities/dissimilarities between objects (Kruskal & Wish, 1978), the closer the objects are in a MDS ordination plot the more similar the samples are.

MDS analyses have been used previously in educational studies of teacher perceptions, curricular goal analysis, and primary and tertiary science teaching. Multi-dimensional scaling and related analytic procedures were used to estimate the accuracy of achievement of a set of goals used to pattern the design of a graduate curriculum.
(Leitzman, Rutt & Austin, 1980). Students’ conceptions about the relationships among science, technology, and society were examined for fifth grade students by exploring the relationships among 31 environmental issues using multidimensional scaling analysis (Thirunarayanan, 1998). In the tertiary sciences, MDS has been used to identify relationships among concepts related to word associations in knowledge acquisition for the conception of the chemical equilibrium (Gussarsky & Gorodetsky, 1995).

**Research Theme 1 - Sectional analysis**

A multi-dimensional scaling (MDS) procedure was used to analyse and graphically represent the relationships between the qualitative measures of outcomes of the students among sections of the report. In the current study, the learning outcome of each student is represented on the plot and the relationship between the objects represents their underlying dissimilarity (PRIMER, Clarke & Gorley, 2006). The interpretation of the plot depends on how well the representation of the plot fits the actual dissimilarities between objects. This is given by a stress value; stress values are ideally 0 - 0.2 and if greater than 0.3 indicate that the configuration of the objects in the MDS is no better than by chance. Specifically a matrix of Bray-Curtis similarities between all 34 students was calculated and subjected to non-metric MDS and 2-dimensional ordination. Following ordination, an Analysis of Similarities (ANOSIM, Clarke, 1993) was used to quantitatively test differences between the average of all rank similarities among students between report sections and the average of all rank similarities between students within report sections. ANOSIM tests the null hypothesis that average of rank dissimilarities between all possible pairs of students between all report sections is the same as the average rank dissimilarity between pairs of students within sections. The test statistic $R$ is scaled between +1 and -1. Positive $R$ values suggest that student outcomes are more dissimilar between report sections and for negative $R$ values the converse is true.

To determine which report section contributed to the separation among student outcomes a SIMPER (Similarity Percentage; Clarke, 1993) was performed. In this case SIMPER computes the percentage contribution of each student’s outcome to the dissimilarities between and within all pairs of sampling units within each quantitative grade unit (i.e., P, C, D, HD). The percentage contribution and its standard deviation is calculated showing which report sections best discriminate between quantitative grade
unit. The test results provide a list of sections and their percentage contributions to
dissimilarities between groups or similarities within groups. For the purposes of this
study the percentage contribution of each report section to within grade group
similarities is presented.

**Research Theme 2 – Holistic analysis**

A spearman rank correlation was performed on the distribution of qualitative grades
across SOLO categories to testing the validity of the SOLO model against the graded
outcomes of the students provided by the unit coordinator. A non-metric multi
dimensional scaling (MDS) procedure was used to represent the relationships between
the holistic outcomes of the model and that from the sections of the report (PRIMER,
Clarke & Gorley, 2006). Similarly, the learning outcomes for each student are
represented on the plot, and the relationship between the objects represents their
underlying dissimilarity between all 34 students and was calculated and subjected to
MDS.

To determine which report section contributed to the separation among the holistic
student outcomes a SIMPER (Clarke, 1993) was performed. In this case SIMPER
computed the percentage contribution of each student’s outcome to the dissimilarities
between and within all pairs of sampling units within each holistic grade unit condensed
into first or second cycle concrete symbolic, and first cycle formal modes.

**Evaluation of design**

In this section the methodology used in the research study is subject to critical
evaluation. The section begins with discussion of reliability and validity, with a
consequent evaluation of the overall study methodology by the highlighted principles of
each. Finally, ethical aspects of the research methods are examined.

**Reliability and validity**

The importance of validity is to ensure the accuracy of the interpretation on the
collected data (internal validity) and the extent by which concepts can be generalised to
the wider population (external validity; Wiersma, 1991). In this study the relevant issues
of internal validity are selection effects and spurious conclusions (Tuckman, 1988).
Selection effects identify the importance that the research sample is representative of the larger population. This was not an issue as the targeted population was the whole cohort to be assessed within the unit under investigation. However, for the pilot study only a small number of the cohort responded (~45%), therefore limiting the range of available student outcomes. For the main study there was > 95% student participation. The possibility of spurious conclusions through the accuracy of interpretation by the researcher was addressed by correlating the SOLO coding with the quantitative grade given by the unit coordinator.

The major issue with external validity of the study was non-response bias due to the voluntary nature of participation. This may have been an issue with the low number of respondents for the pilot studies. A response of greater than 90% of class participations rates from the second cohort of the study would have reduced this issue. There is an inherent tension between the ethical requirements for voluntary participation and the random sampling requirements of quantitative nomothetic research (Burns, 1997). Non-response bias could not be ethically prevented in this study however; efforts were made to maximize response rates, especially in 2008, by explaining the potential benefits to future students to participating students. Support from the unit coordinator to communicate this to both the on- and off-campus students during introduction to the unit and prior to assessment due dates greatly alleviated any bias. The few class members who did not participate in the 2008 study did not frequent lectures and failed the unit (grades < than 50%, D. Ryder pers comm.). Thus any bias was to be in the lack of quantitative descriptions available from reports likely to represent the first cycle concrete symbolic mode.

The consistency of the research and the degree to which it can be replicated cannot have validity without some degree of reliability (Leedy, 1993). Internal reliability is enhanced by multiple researcher assessment of subjective assessment items. Inter-judge agreement on SOLO categories was used to reduce such issues within this study (see below). External reliability is enhanced by a number of features advocated by Miles and Huberman (1994), including precise description of the context of the methods, together with and explicit statement of the perspective of the researcher. Qualitative examples are provided to substantiate sections for model development. The use of actual assessment items in the model development also promoted external validity.
Reliability and validity of the SOLO model

Reliability and inter judge agreement

The main concepts used in the SOLO taxonomy are expressed through the review of number of studies in Chapter 2. Outcomes in SOLO are categorized through the structural complexity and conceptual nature of the response. Inter-judge agreement is the determinant of reliability for SOLO outcomes, where consistency in single marker’s responses, across items and time is theoretically improbable (Biggs & Collis, 1982). In the original single learning cycle of SOLO, inter –judge agreement for three disciplinary areas was seen as adequate (Biggs & Collis, 1982; Boulton-Lewis, 1992; van Rossum & Schenk, 1984;). Inter-judge disagreement was reported when applying SOLO for marking postgraduate essays (Chan et al., 2002), thus questioning the reliability of the categorisation criteria in this context.

In the two learning cycle version of SOLO, Panizzon (1999) reported intra-rater and inter-rater reliabilities over 97% using 20 random samples coded against SOLO descriptors. Past studies of SOLO in a science context have focused on the understanding of single concepts. Similarly a study using SOLO categories in assessing first year Biology student outcomes of single concepts found high inter-judge reliability from co-researchers both familiar and un-familiar with the context (Quinn, 2006). In this study, multiple scientific and ecological skills, cognitive understanding and concepts are examined by the SOLO categorisations. Due to the extensive length of the reports only 20% of reports were analysed for inter-rater reliability between the researcher and a specialist familiar with the study context. Where inconsistencies arose in the present study between the pilot study categories and the 2008 cohort, discussions with an authority on SOLO were achieved until inter-subjective problems were resolved.

Validity and independent ratings

The criterion validity of the original version of SOLO was examined using two measures (Biggs & Collis, 1982). Correlations between SOLO ratings of high school essays were correlated against independent ratings by an experienced teacher. Factor analyses and inter-correlation of SOLO ratings and other cognitive test results demonstrated that SOLO levels were also related to “cognitively relevant processes” (Biggs & Collis, 1982). Criterion validity of SOLO was also supported with high
positive correlations with Marton and Saljo’s (1984) four hierarchically related levels of learning. The evidence above relates to the single cycle of SOLO, but the validity of the more recent two-cycle version (Pegg & Davey, 1998) has limited critical review.

This study was designed to determine the variation in students learning responses using the two cycle model of SOLO, and to examine its application to a multi-faceted assessment task common to ecology and environmental science units. To date, SOLO has been used in science curricula to examine questions of a single concept which are worded to elicit extended responses. In this study the potential of SOLO level ratings as a tool for outcome measurement for multi-faceted and multi-concept written tasks is examined for a context with a potentially comprehensive range of extended responses. Thus, part of this study is to evaluate the validity of SOLO categories against quantitative ratings by a specialist in ecology and the teaching of environmental science.

**Ethical Considerations**

All aspects of this study were presented and approved by the UNE Human Ethics committee (HREC), approval number HEO7/150. Therefore in the judgment of the committee, the study complied with standard ethical considerations such as voluntary participation, fully informed consent, the “do-no harm” principle and confidentiality. Assessment reports were collected from those students whom have given consent to participate in the study. Students submitted an unmarked copy of their assignments either in hard copy or electronically to the researcher. The assessment tasks were de-identified and student names and numbers were deleted with only a record of the participants being known to the researcher. Assessment outcomes from the research project did not influence the student quantitative grades in any way (Student information sheet and consent form, Appendix 2).

The reporting of this study poses some challenges to the ethical issue of confidentiality as the research could not be accurately reported without the identity of the institution and academic area involved in the study being revealed. Thus in theory, some readers may be able to identify individuals as a group within the cohorts of participants. However the specific SOLO outcomes of each student could not be related to individual participants. Measures were taken to avoid ethical issues by ensuring fully voluntary, informed and confidential participation and the research was conducted in the spirit of ethical responsibility.
Summary

This chapter provides a description, justification and evaluation of the study methodology used to investigate learning outcomes of tertiary Environmental Science students through development of scientific method application and report writing for a group of second year students. Included in this process were aspects of the topic, and unit organisation and content, as well as an explanation of the concepts of scientific research methodology and scientific expression and argument used to measure the students learning outcomes. The description of research design outlined the data collection procedures, including issues relating to recruitment of participants and details of the study sample response rate. The analytical process used was detailed and finally the methods were critically evaluated.

The methods outlined in this chapter yielded qualitative and quantitative results relating to the research question of investigating a qualitative approach to evaluate student outcomes of a broad scientific topic. Chapter 4 evaluates student outcomes through the sectional analysis of a partial scientific report. Chapter 5 evaluates student outcomes through the sectional analysis of a whole scientific report, and Chapter 6 considers the relationship between the qualitative sectional analysis and a potential holistic method to scientific report assessment of tertiary students.
Chapter 4: Results Part 1.

A STUDY OF SECTIONAL SOLO CATEGORISATION OF A PARTIAL SCIENTIFIC REPORT ASSIGNMENT: HABITATS OUT OF A HAT (MARINE AND FRESHWATER ECOLoGY 202, 2007)

Introduction

The research methodology outlined in the previous chapter focused on developing a protocol for marking scientific written assessments using a cognitive structural perspective provided by the Structure of the Observed Learning Outcome Model (Biggs and Collis, 1991) for a second year university ecology unit. This study aims to extend the current application of the SOLO model in a tertiary setting to assess extended prose assignments where relational thinking is imperative for satisfactory accomplishment of multiple concept learning. To evaluate functioning knowledge in the teaching of ecology and environmental science, an assessment method that can encompass extended prose in a case study like setting is required.

In this chapter, the Research Theme 1, a sectional based framework within the cognitive structural model was used to compare the effective alignment of assessment by extended written assignments. This theme is guided by the following specific line of inquiry. To develop categories of written responses to a scientifically developed extended written assessment task within the SOLO model? Specifically the following research questions where considered:

1. What are the SOLO categorises of qualitative responses to a scientific report based assessment task (i.e., Introduction, Methods, Results and Discussion).
2. What is the distribution of SOLO categories across different report sections?
3. How do the SOLO categories from a sectional analysis correlate with the actual quantitative grade given to the students?
The results pertaining to these lines of enquiry are presented in the order they are posed above. The results pertaining to question 1 will be presented from a pilot study from the 2007 cohort of students from Aquatic Ecology 202. The results pertaining to question 1 are a qualitative analysis of 8 written responses to an assessment item, *Habitats out of a Hat*. The results of this are then interpreted in terms of a two cycle SOLO model. Subsequently, the SOLO schedule developed from the pilot group is used to qualify students responses form a larger cohort of students enrolled in the equivalent unit in 2008 to cover questions 2 and 3.

**Pilot Study 2007. Student written responses to ‘Habitats out of Hat’ mini-report.**

This section presents the results of student written responses to an assessment item with the aim of each student reviewing the literature about a given aquatic habitat and identify possible ecological indicators and an appropriate experimental design to test for an ecological impact for their given disturbance event. Their task was to then formulate an hypothesis which could be tested to explore the effects of the impact on their selected indicators, clearly linking the key components of habitat, indicator, hypothesis and appropriate methods for testing their scenario in a robust and replicated scientific study.

**Categories of Response**

Eight assignments were systematically analysed to gain an overview of the qualitative elements required from the students to execute the task. This systematic approach to assessment dissects the assignment in order to allocate a qualitative assessment to individual sections of the report. The reasoning for the first phase of categorisation within each report subsection of the assessment task is outlined below.

Coding responses required thorough understanding of all the related concepts and terms, in order to detect qualitative differences in responses. In some responses terms and theoretical frameworks were used inappropriately and often ambiguously. The mere mention of a term or framework in context was categorised differently from a response in which the term or framework was given a detailed description of the appropriate
process. The final format exhibited the different groups of like responses within 3-4 categories depending on the report section.

**INTRODUCTION**

<table>
<thead>
<tr>
<th>Category A</th>
<th>is characterised by a rational/ general knowledge approach to scientific understanding.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Category B</td>
<td>takes the discussion into a scientific context.</td>
</tr>
<tr>
<td>Category C</td>
<td>illustrated deductive interpretation of the review from use of ecological theory and approaches to scientific methodology.</td>
</tr>
</tbody>
</table>

**HYPOTHESIS**

<table>
<thead>
<tr>
<th>Category A</th>
<th>describes the progression to a logical testable hypothesis.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Category B</td>
<td>describes the mechanism for the prediction would be quantified (i.e., ( x ) changed ( y ) because of and increase ( z )).</td>
</tr>
<tr>
<td>Category C</td>
<td>presents a hypothesis in relation to the introduction. A hypothesis in this section would be founded on a given scientific theory.</td>
</tr>
</tbody>
</table>

**METHODS**

<table>
<thead>
<tr>
<th>Category A</th>
<th>demonstrates a simplistic understanding for potential scientific methodology, often common sense measurements are suggested.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Category B</td>
<td>addresses issues of appropriate scientific sampling methodology. The concrete referent in the second mode is the traditional scientific sampling methods. Here methodology can relate to hypotheses from both the concrete symbolic or formal modes and utilize aspects of scientific sampling methodology appropriately.</td>
</tr>
<tr>
<td>Category C</td>
<td>challenges a standard scientific method. This was not observed in undergraduate study context but postulated as the next progressive category</td>
</tr>
</tbody>
</table>

Within the five modes of thinking associated with the SOLO structure, two most relevant modes to this assessment task are *concrete symbolic* and *formal*. The two-cycle per mode version of SOLO was used as a framework in which to fit categories of response. As described in Chapter 2, the two-learning cycles per mode version of SOLO postulates at least two-cycles of levels within each mode, such as two rounds of
unistructural, multistructural and relational responses representing increasing levels of complexity of each response.

It is predicted that responses from undergraduate students in this study will fall into categories of increasing sophistication from A – C. Categories A and B fall into the concrete symbolic mode, and C and D in the Formal mode. A key focus between these categories was on the structural complexity between A and B, and C and D and a level of abstraction between categories B and C. This relates to a two learning cycle per mode version of SOLO as outlined in Chapter 2. Essentially the broad groupings of response categories referred to as A and B are representative of a single mode in the SOLO model, and category C of the next progressive mode.

The first is the concrete symbolic mode in which the main feature is the presentation by the individual of concepts and operations applied though the symbolic systems of written language. This results in declarative knowledge as individuals describe their real world experiences. In Category A the students present a general logical and ordered understanding of a conceptual framework given to them as a concrete starting point (i.e., the habitat and the environmental impact). A hypothesis written in this category is simple and strives for a logical testable form. Often common sense measurements are suggested within this category without full use of standard scientific methodology.

Responses from students in Category B are again bounded by their ‘specified’ starting point but extend their introductory review into a scientific context, with use of scientific language and protocols for citation, and may provide a relevant ‘learnt’ scientific process for their observations. The hypothesis in this category demonstrated scientific thought through predicting a possible quantifiable mechanism for their prediction.

The formal mode is represented by the third level of responses. The responses within these categories demonstrated that individuals had an increased abstraction of thought and were able to move away from the concrete reference provided by the assessment task. The individuals here presented responses which pertained to ecological processes and theories not explicitly imparted as given knowledge with the task objectives. Subsequently these are analysed further as potential levels within the SOLO modes; unistructural (U), multistructural (M) and relational(R ).
Fit of response to the SOLO Model

The relationship between the categories of response previously outlined in this chapter (4.1.1) is assessed in this subsection with regard to the levels within each mode.

Introduction

**First Cycle Concrete Symbolic**

U1

- One concept discussed about the habitat in question, and a single concept of indicator species, with no linking elements. (nb. None of the students presented a basic unistructural response in the Concrete Symbolic mode by virtue of multiple elements being intrinsic to the task. However, multiple unistructural elements were apparent in one student’s response.)

M1

- Indicator species/community appropriate to the ecological impact and habitat in question but the relationship is not made explicit
- A list of concepts relating to the habitat and indicator species and often lacking logical flow.
- Lack of understanding of ecologically significant aspects of the habitat leading to a general explanation often presented as a list of physical attributes of the specified system.

M1 transitional

- The scale of the impact is not made explicit leading to general statements.

R1

- The indicator species/community is appropriate to the habitat and related to the impact in a logical/ common sense way.

In Assignment 5, although the majority of the introduction is in mutistructural form, a clear rational relational statement is made without a scientific context; “it (Triglochin) is also an integral part of the food web in rivers as it is a member of the producers level...,thus is a good indicator of the health of the ecosystem within the river. Triglochin has also been observed at range of salinities...having detrimental effects to individuals.”
2nd Cycle Concrete Symbolic

U2

- Clear statement of the impact at a biological or ecosystem scale.
- Explicit description of the environmental impact and logically linked to the habitat in question.

M2

- The indicator species/community is appropriate to the habitat, and discussion of the impact is presented in a logical way demonstrating an awareness of appropriate temporal and spatial scale, and the level of biological organisation is shown.
- Several unrelated issues are presented.

In Assignment 3, although simplistic language is used for the most part (e.g., As the opening sentence: “A river is defined as...”), in the introduction with a multistructural form, the introduction is concluded with an attempt at a relational statement “The river Blackfish use submerged hollow logs as breeding sites and due to this, submerged wood is a real danger for lowering breeding rates for these fish”. However to get a R1 grading, the statement would require explicit details and reference as to how the breeding cycle of The Blackfish centers around woody debris. Despite a limited introduction, the multiple hypotheses represented show relational characteristics between the Blackfish population and woody debris and implies that this impact will extend to breeding by stating “There will be no larval or juvenile fish (up to 25mm) in areas where submerged timber has been removed.”

M2 transitional

- Terms used without full explanation or relevance to the habitat or indicator species/community in question
- Some connections are made between the three elements of the introduction (habitat, impact and indicator species), however not all elements are interrelated.

R2

- The indicator species/community is appropriate to the habitat and discussion of the impact is presented in a logical way with a clear understanding of appropriate temporal and spatial scale, and level of biological organisation required for a given scenario.
A Second Cycle Concrete Symbolic relational response is demonstrated in Assignment 2: “coral species...have a narrow thermal tolerance due to the algae with which they have in symbiosis. The capacity of the zooanthellae to convert trapped light energy is lost at temperatures above their threshold...degrading and poisoning the zooanthellae which are released from the coral in a process known as bleaching.” Previous discussion in the introduction outlining global, ocean scale then coral community scale impacts of global warming demonstrate an example of an R2 response.

**Formal**

**U1**
- Discussion of a single concept of ecological disturbance theory relevant to impact and habitat in question.

**M1**
- Multiple concepts of ecological theory and management practises are discussed without logical implications to the impact and habitat in question.

**M1 Transitional**
- Some connections are made between issues of ecological theory or management practises, however, not all logical implications to impact and habitat are interrelated.

**R1**
- Multiple concepts of ecological theory are discussed with logical implications to impact and habitat at an appropriate spatial and temporal scale.
- The impact of the disturbance on the indicator species/community is explicitly examined and put in context of biological organisation (i.e., impact at species level; physiological; population level; biomass, productivity; or community level; and/or food chain dynamics).

The Introduction from Assignment 1 presents with a formal mode response demonstrating ecological and management theory relevant to the impact and habitat “Fens are not a climax community, and build up of nutrients is part of a successional process that may ultimately convert a fen into a woodland. Management involving the removal of organic matter ...can prevent this succession from going to completion...”

In summary, two student outcomes presented a non-scientific framework and their responses were multistructural (M1) and relational (R1) in the concrete symbolic mode.
A case for a U1 is alleged by suggesting a single content discussion with the non-scientific argument. Four of the pilot assessment items fell into the category of second cycle concrete symbolic, with responses within a scientific framework. Again no responses were indicative of a unistructural category. Two responses were multistructural (M2) and a single response was relational (R2). One response showed extended complexity distinguishing it from the two M2 responses, and demonstrated some relational connections between elements resulting in it being placed in a separate multistructural transitional (Mt) category.

Three student responses demonstrated abstract thinking, and reviewed potential ecological processes and theories within their introduction. Three responses presented a single aspect of ecological disturbance theory (R1F), while two students discussed ecological disturbance theory in context of other ecological processes such as nutrient succession (see example above) giving them an R1F response. Again the logic for an M1F and an MtF response was written post hoc as a logical hierarchical pathway between U1F and R1F.

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**Hypothesis Formulation**

**First Cycle Concrete Symbolic**

**U1**

- A question is posed.
- Independent disturbance within a habitat are presented with no logical reasoning implied, or direction of change given for any interaction between elements (i.e., there is a difference between element a and element b).

**M1**

- A logical hypothesis is presented, but reasoning for interaction is not explicit or vague terminology is used so that the stated hypothesis is not testable.
- Often multiple possible causes given with no clear direction of change.
- Often no reasoning behind the scale of the impact or the level of biological organisation being impacted upon, thus the hypothesis is not testable.

**R1**

- A logical testable hypothesis: (e.g., “species x does not occur at the impacted site”). Direction of change is qualified.
In Assignment 4 the hypothesis stated the cause of the interaction between seagrass and nutrient pollution but is muddled in logic and not explicit. “an increase in nutrients from pollutants settling in an urban estuarine environment will over stimulate plants growth, thus leading to processes of eutrophication creating algal blooms.” This is an unscientific statement and is unclear whether seagrass growth would be stimulated together with algal growth, rather than stating that seagrass growth would decline due the excessive algal growth, created by high nutrient levels which in turn reduce sunlight available for photosynthesis of the seagrasses.

Second Cycle Concrete Symbolic

U2
- A single testable hypothesis with statement of a single quantifiable causal parameter.

M2
- Multiple testable (i.e., relates to multiple scale of the impact, or biological organisation) hypotheses with statement of quantifiable causal parameter/s.

The hypotheses from Assignment 2 although explicit with regard to impact effects on the coral species do not give a qualitative measure of the impact: e.g., “1. Increases in sea surface temperature...” “2. persistent unfavourable conditions...” Due to these generalised statements. The hypotheses are given a M2 response.

R2
- Multiple testable hypotheses with logical/causal parameters and explicit reasoning linking and/or explaining interactions between the hypotheses.

Formal

U1
- The hypothesis tests an existing theory.

M1
- Multiple hypotheses that test an existing theory.

R1
- Multiple hypotheses with explicitly interrelated logical connections which challenge existing scientific principles/theories.
Three responses were indicative of the first level concrete symbolic pertaining to non-directional quantitative elements of hypothesis formulation. One of these was a logical testable hypothesis being a R1. Five responses demonstrated second cycle elements, one with multiple elements but without explicit quantifiable direction for the prediction. Four demonstrated Relational multiple hypotheses that were logically connected. No hypotheses were scored in the Formal mode as no explicit existing scientific theories were tested by any of the students.

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**Formulation of methods**

**First cycle Concrete Symbolic**

U1
- A single method of testing independent aspects of a general hypothesis.

M1
- Multiple methodologies for testing aspects of a general hypothesis and/or not logically connected.

R1
- Methodology is consistent with the prediction from the hypothesis.

**Second Cycle Concrete Symbolic**

U2
- A single aspect of sampling methodology is presented discussed (i.e., randomization, or experimental controls, or sample replication).

M2
- Appropriate design using many aspects of sampling methodology (randomization, and controls, and replication).

R2
- Appropriate design using many aspects of sampling methodology (randomization, and controls, and replication) with explicit explanation. For example: how a control is effective; why randomization is appropriate compared to other types of sampling procedures, and the need for an explicit number of replicates is explained.
- Multiple methodologies that clarify questions relating to temporal and spatial scale, and biological organisation through an explicit and logical approach.
Examples of clear statement of controls in methods from assignment 1
“For each method, the data set generated can be compared against a similar set obtained from a site known to be unaffected by nutrient enrichment, or against a set obtained from the same site when known to be unaffected…” And at a different scale “To control for variation between individual test plants…” Assignment 8 also demonstrates a clear R1 response in the methodology with a very good sample design that has elements of replication, randomization and appropriate controls.

Formal

U1
• A single standard methodology is challenged in the context of the investigation.

M1
• Multiple standard methodologies are challenged in the context of the investigation.

R1
• Multiple standard methodologies are challenged in the context of the investigation, and are explicitly and logically interrelated in the investigation of the stated hypothesis.

All evaluated methods fell in the second cycle of the concrete symbolic mode, with all students using some standard practice of scientific methodology. Three examples were presented in the multistructural level, where aspects of appropriate design using methods such as controls, randomisation and replication without explicit explanation why their measurable aspects are appropriate to their context. Four students fully explained their use of standard scientific methods appropriate to their context, with multiple methodologies explained that clarified measurements relating to spatial and/or temporal scales.

A summary of student responses is presented in Table 4.1, showing the mode and level attained for each report section and associated quantitative grade they were given by the subject coordinator as their grade towards the unit assessment.
A high distinction was given to the student whose qualitative SOLO outcomes fell in the relational level of the formal mode in the Introduction, and second cycle relational for the Hypothesis and Method Sections. Two other ‘distinction’ students presented Introductions’ graded in the formal mode. Student 2, however, demonstrated qualitative outcomes in the second cycle concrete symbolic mode, with a R2 for their Introduction.

<table>
<thead>
<tr>
<th>Student</th>
<th>Introduction</th>
<th>Hypothesis</th>
<th>Methods</th>
<th>Quantitative Grade</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>F/R1</td>
<td>CS/R2</td>
<td>CS/R2</td>
<td>HD</td>
</tr>
<tr>
<td>2</td>
<td>CS/R2</td>
<td>CS/M2</td>
<td>CS/R2</td>
<td>D</td>
</tr>
<tr>
<td>3</td>
<td>CS/M2t</td>
<td>CS/R2</td>
<td>CS/M2</td>
<td>C</td>
</tr>
<tr>
<td>4</td>
<td>CS/M2</td>
<td>CS/R1</td>
<td>CS/M2t</td>
<td>Low C</td>
</tr>
<tr>
<td>5</td>
<td>CS/R1</td>
<td>CS/M1</td>
<td>CS/M2</td>
<td>Low C</td>
</tr>
<tr>
<td>6</td>
<td>F/R1</td>
<td>CS/R2</td>
<td>CS/R2</td>
<td>D</td>
</tr>
<tr>
<td>7</td>
<td>CS/M1</td>
<td>CS/M1</td>
<td>CS/M2</td>
<td>High C</td>
</tr>
<tr>
<td>8</td>
<td>F/U1</td>
<td>CS/R2</td>
<td>CS/R2</td>
<td>D</td>
</tr>
</tbody>
</table>

The remaining students were given credits as their quantitative grade and demonstrated a range of multistructural second cycle concrete symbolic mode elements across sections, or first cycle concrete symbolic relational or multistructural level elements. Although numbers are too low to statistically correlate quantitative grades and qualitative outcomes in this pilot study, there is a clear related hierarchical trend between SOLO model and cyclical elements. This final coding scheme for each assessment task was used to mark this assignment from the 2008 cohort of students.

Patterns and distributions of SOLO categories for a partial scientific report

This section describes the distribution of SOLO categories for written responses to the partial scientific report from students of ECOL202 Marine and Freshwater Ecology, 2008 cohort (UNE Academic renewal process led to change in name from Aquatic Ecology in 2007) with the same aim as previously stated. In summary, their objective
was to review the literature about a given habitat, identify potential ecological indicators of a given impact, write a scientific hypothesis that links the habitat, indicator and impact, and design a scientific experiment or field survey to test the hypothesis.

Thirty-four out of 41 enrolments volunteered assignments that were systematically analysed using the SOLO framework devised from the 2007 pilot cohort. Inter-marker reliability was for 20% of reports (7 reports) between the researcher and a specialist familiar with the study context for this unit. Where inconsistencies arose in the present study between the pilot study categories and the 2008 cohort, discussions with an authority on SOLO were achieved until inter-subjective issues were resolved. For the 2008 cohort, the two sets of codes for the 20% subsample were compared by Spearman Rank Correlation for each section of the two assessment tasks ($R = 0.9$).

This subsection specifically addressed the following issues:

- Analysis and representation of the distribution of the qualitative SOLO outcomes for students among individual sections of the report.
- Examination of the relationship between qualitative SOLO categories and the quantitative grade the students were given for their unit assessment.
- To determine which report section contributed to the separation among student outcomes.

**Distribution of SOLO outcomes for report sections**

The distribution of SOLO categories for written responses to the partial scientific report is summarised in Figure 4.1 and presented in Table 4.2. Only four of the responses for the Introduction section were in the formal mode and all other responses were in the concrete symbolic mode.

Outcomes for the Introduction section ranged from first cycle concrete symbolic, relational to formal with most (38%) responses in the concrete symbolic, multistructural level. Seven student’s responses (21%) were at a transitional level above multistructural, demonstrating non fully-integrated scientific pathways in the literature review. These students got off to a sound start but tended to have inconsistencies between their hypotheses and methods (see comments for students 1, 7, 14, 15 and 24; Table 4.2).
Students with introduction section outcomes in the first cycle concrete symbolic, lacked scientific language, style and scientific references. These assignments relied on inappropriate ‘Wikipedia’, or general web-searched citations as their information sources (e.g., students 4, 9). Peer reviewed scientific articles are expected in a literature review for this type of assignment at a tertiary level, and examples were given to each student at the onset of the task by the unit coordinator. Those students with Introduction outcomes in the formal mode either demonstrated a context of community ecology (students 2 and 19), or integrated ecological process with management issues (students 27, 31).

The Hypothesis section outcomes were distributed throughout all SOLO levels of the first and second cycle concrete symbolic mode (Table 4.2). There was a 48%, 52% split between first and second cycles respectively demonstrating that many students could formulate a logical testable hypothesis but failed to predict or quantify the direction of change in their indicator species or community for their given disturbance. Further, 27% of outcomes demonstrated a quantified prediction for a single line of enquiry (e.g., students 22 and 23) and 10% of outcomes demonstrated logical and integrated predictions between multiple testable hypotheses (e.g., student 8, 13).

Outcomes from the Methods section exhibit a broken distribution between SOLO categories, with 25% of responses in the first cycle multistructural level, and the remainder in the multistructural and relational levels of the second cycle concrete symbolic mode. Of the latter, 65% were M2 or transitional (Table 4.2). Those methods that were in the 1st cycle were often inconsistent with their stated general hypotheses (e.g., students 1, 15 and 30).

The majority of student responses demonstrated some knowledge of scientific protocol, but either lacked a link with their stated hypotheses (e.g., student 24), lacked details to make the study repeatable (students 22 and 23), or did not present a method that reflected the field reality of their scenario (e.g., student 33). Three students (25, 26 and 29) demonstrated methods that were detailed and repeatable with explicit scientific research protocols for a number of lines of enquiry relevant to their scenario.
Figure 4.1 Distribution of SOLO categories for written responses to the partial scientific report from students of ECOL202, 2008 cohort.
Table 4.2 SOLO categories and quantitative grades for written responses to the partial scientific report from students of ECOL202, 2008 cohort.

<table>
<thead>
<tr>
<th>Student</th>
<th>Status</th>
<th>Grade</th>
<th>Introduction</th>
<th>Hypothesis</th>
<th>Methods</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>I</td>
<td>57</td>
<td>M2t</td>
<td>U2</td>
<td>M1</td>
<td>Promising beginning but methods inconsistent with hypothesis</td>
</tr>
<tr>
<td>2</td>
<td>I</td>
<td>52</td>
<td>M2</td>
<td>M2t</td>
<td>M1</td>
<td>No mention of theory, or ecological processes</td>
</tr>
<tr>
<td>3</td>
<td>I</td>
<td>80</td>
<td>R2</td>
<td>U2</td>
<td>R2</td>
<td>Good but could have extended method with a field experimental trial</td>
</tr>
<tr>
<td>4</td>
<td>I</td>
<td>50</td>
<td>R1</td>
<td>R1</td>
<td>M2</td>
<td>Poorly referenced, methods not all appropriate</td>
</tr>
<tr>
<td>5</td>
<td>I</td>
<td>61</td>
<td>R2</td>
<td>R2</td>
<td>M2t</td>
<td>Methods don't logically flow from all aims</td>
</tr>
<tr>
<td>6</td>
<td>I</td>
<td>73</td>
<td>R2</td>
<td>U2</td>
<td>M2</td>
<td>No explicit hypothesis</td>
</tr>
<tr>
<td>7</td>
<td>E</td>
<td>69</td>
<td>M2t</td>
<td>R1</td>
<td>M2</td>
<td>Very general, not logically written in parts</td>
</tr>
<tr>
<td>8</td>
<td>E</td>
<td>96</td>
<td>FM1t</td>
<td>R2</td>
<td>R2</td>
<td>Well integrated discussion with ecological processes</td>
</tr>
<tr>
<td>9</td>
<td>I</td>
<td>70</td>
<td>R1</td>
<td>M1</td>
<td>M1T</td>
<td>Wikipedia referenced – simplistic</td>
</tr>
<tr>
<td>10</td>
<td>I</td>
<td>65</td>
<td>M2</td>
<td>U2</td>
<td>M2</td>
<td>Lacking references</td>
</tr>
<tr>
<td>11</td>
<td>E</td>
<td>77</td>
<td>R1</td>
<td>M1</td>
<td>M2</td>
<td>Causality expressed b/w impact and indicator but not integrated into H or methods</td>
</tr>
<tr>
<td>12</td>
<td>E</td>
<td>78</td>
<td>R2</td>
<td>R1</td>
<td>M2</td>
<td>Single element put into scientific context. Hypothesis left general</td>
</tr>
<tr>
<td>13</td>
<td>I</td>
<td>53</td>
<td>U1</td>
<td>R2</td>
<td>M2</td>
<td>Follows many lines to assess problem</td>
</tr>
<tr>
<td>14</td>
<td>I</td>
<td>77</td>
<td>M2t</td>
<td>R1</td>
<td>M2</td>
<td>Logical flow b/w sections but not detailed hypothesis, methods lacking</td>
</tr>
<tr>
<td>15</td>
<td>I</td>
<td>67</td>
<td>M2t</td>
<td>M2t</td>
<td>M1</td>
<td>No follow up from good introduction, muddled methods</td>
</tr>
<tr>
<td>16</td>
<td>I</td>
<td>64</td>
<td>R1</td>
<td>R1</td>
<td>M2</td>
<td>Hypothesis not quantifiable</td>
</tr>
<tr>
<td>Student</td>
<td>Status</td>
<td>Grade</td>
<td>Introduction</td>
<td>Hypothesis</td>
<td>Methods</td>
<td>Comments</td>
</tr>
<tr>
<td>---------</td>
<td>--------</td>
<td>-------</td>
<td>--------------</td>
<td>------------</td>
<td>---------</td>
<td>----------</td>
</tr>
<tr>
<td>17</td>
<td>E</td>
<td>80</td>
<td>R2</td>
<td>R1</td>
<td>R2</td>
<td>General hypothesis</td>
</tr>
<tr>
<td>18</td>
<td>I</td>
<td>65</td>
<td>R1</td>
<td>U2</td>
<td>M2</td>
<td>Simplistic style - web references only</td>
</tr>
<tr>
<td>19</td>
<td>E</td>
<td>96</td>
<td>FU1</td>
<td>R2</td>
<td>R2+</td>
<td>Context of community ecology, full methodology touches on analysis</td>
</tr>
<tr>
<td>20</td>
<td>I</td>
<td>75</td>
<td>M2t</td>
<td>M2</td>
<td></td>
<td>Good design, two independent lines of experimental trials not integrated. No hypothesis</td>
</tr>
<tr>
<td>21</td>
<td>I</td>
<td>85</td>
<td>R2</td>
<td>R2</td>
<td>R2</td>
<td>Full, detailed and relevant but doesn't bring in theory</td>
</tr>
<tr>
<td>22</td>
<td>I</td>
<td>68</td>
<td>M2</td>
<td>U2</td>
<td>M2</td>
<td>Logical but limited detail</td>
</tr>
<tr>
<td>23</td>
<td>I</td>
<td>50</td>
<td>M2</td>
<td>U2</td>
<td>M2</td>
<td>Logical but limited detail</td>
</tr>
<tr>
<td>24</td>
<td>I</td>
<td>56</td>
<td>M2t</td>
<td>R2</td>
<td>M2</td>
<td>Brings in irrelevant info, methodology not fully linked with H</td>
</tr>
<tr>
<td>25</td>
<td>I</td>
<td></td>
<td>R2</td>
<td>R2</td>
<td>R2+</td>
<td>Full survey and experimental methods</td>
</tr>
<tr>
<td>26</td>
<td>E</td>
<td>88</td>
<td>M2t</td>
<td>R1</td>
<td>R2+</td>
<td>General hypothesis but methods cover all scales and analysis</td>
</tr>
<tr>
<td>27</td>
<td>I</td>
<td>80</td>
<td>F R1</td>
<td>M2t</td>
<td>R2</td>
<td>Good holistic understanding of management role in system</td>
</tr>
<tr>
<td>28</td>
<td>I</td>
<td>85</td>
<td>R2</td>
<td>R2+</td>
<td>R2</td>
<td>Hypothesis shows clear logical progression of all aspects</td>
</tr>
<tr>
<td>29</td>
<td>I</td>
<td>91</td>
<td>M2</td>
<td>R2</td>
<td>R2++</td>
<td>Full, detailed and relevant but doesn't bring in theory</td>
</tr>
<tr>
<td>30</td>
<td>I</td>
<td>50</td>
<td>U2</td>
<td>R1</td>
<td>M1</td>
<td>No logical flow or ecological understanding. List of multiple ideas</td>
</tr>
<tr>
<td>31</td>
<td>E</td>
<td>78</td>
<td>FM1</td>
<td></td>
<td>R2</td>
<td>Well integrated discussion with management relevance but no explicit hypothesis</td>
</tr>
<tr>
<td>32</td>
<td>I</td>
<td>53</td>
<td>R1</td>
<td>U2t</td>
<td>M1</td>
<td>Essence OK but badly written, not written scientifically</td>
</tr>
<tr>
<td>33</td>
<td>I</td>
<td>83</td>
<td>R2</td>
<td>U1</td>
<td>M2</td>
<td>No explicit hypothesis and no relation to field reality</td>
</tr>
<tr>
<td>34</td>
<td>I</td>
<td>71</td>
<td>R2</td>
<td>U2</td>
<td>R2</td>
<td>No detail in single aspect hypothesis</td>
</tr>
</tbody>
</table>
**Integrated patterns of distribution of SOLO categories between qualitative SOLO categories and the qualitative grade**

A multi-dimensional scaling (MDS) procedure was used to analyse and graphically represent the relationships between the qualitative outcomes of the students among sections of the report. The axes on the MDS map are in themselves, meaningless and the second is that the orientation of the picture is arbitrary. The key issue is that is which point is close to which others. The MDS map represents the similarities/dissimilarities between objects, the closer the objects are in a MDS ordination plot the more similar the samples (Figure 4.2). The stress value of 0.13 demonstrates that the plot represents a good configuration of the actual dissimilarities between objects (ideally 0 - 0.2). When looking at a map that has non-zero stress, the distances among items are imperfect, distorted, representations of the relationships given by your data. The greater the stress, the greater the distortion but larger distances, however are more accurate because the stress function accentuates discrepancies in the larger distances (Kruskal and Wish, 1978).

The SOLO outcomes show a gradient of response from pass to high distinction grade on both axes of the ordination space (Figure 4.2). Pass and Credit grades cannot be differentiated by the distribution of the SOLO outcomes but these separate on both axes from the Distinction and HD outcomes.
Following the ordination, an Analysis of Similarities (ANOSIM, Clarke and Warwick, 2004) was used to quantitatively test differences between the average of all rank similarities among students between report sections and the average of all rank similarities between students within report sections (Table 4.3). ANOSIM tests the null hypothesis that the average of rank dissimilarities between all possible pairs of students between all report sections is the same as the average rank dissimilarity between pairs of students within sections. The test statistic $R$ is scaled between +1 and -1. Positive $R$ values suggest that student outcomes are more dissimilar between report sections and for negative $R$ values the converse is true. The ANOSIM analysis (Table 4.3) demonstrated no significant discrimination between pass and credit level students by the SOLO analysis but it demonstrates significant discrimination between pass and distinction and HD students, and between Credit and Distinction and HD students. There is also significant discrimination between Distinction and HD students from the ranked SOLO sectional analysis.

**Figure 4.2** MDS ordination plot of Assessment task 1: Ranked SOLO section analysis. Groupings by quantitative grade.
Table 4.3 ANOSIM (Analysis of Similarities): Ranked SOLO section analysis. Groupings by quantitative grade.

Sample statistic (Global R): 0.291

Significance level of sample statistic: 0.2% (* = significant differences)

<table>
<thead>
<tr>
<th>Groups</th>
<th>R Statistic</th>
<th>Significance Level %</th>
</tr>
</thead>
<tbody>
<tr>
<td>HD, D</td>
<td>0.456</td>
<td>0.2</td>
</tr>
<tr>
<td>HD, C</td>
<td>0.554</td>
<td>0.1</td>
</tr>
<tr>
<td>HD, P</td>
<td>0.444</td>
<td>0.4</td>
</tr>
<tr>
<td>D, C</td>
<td>0.191</td>
<td>1.6</td>
</tr>
<tr>
<td>C, P</td>
<td>0.047</td>
<td>0.6</td>
</tr>
</tbody>
</table>

Contribution of report sections to separation among student outcomes

To determine which report section contributed to the separation among student outcomes a SIMPER (Similarity Percentage, Clarke & Warwick, 1994) was performed. In this case SIMPER computes the percentage contribution of each student’s outcome to the dissimilarities between and within all pairs of sampling units within each quantitative grade unit (i.e., P, C, D, HD). The percentage contribution and its standard deviation is calculated showing which report sections best discriminate between quantitative grades. The test results provide a list of sections and their percentage contributions to dissimilarities between groups or similarities within groups. For the purposes of this study the percentage contribution of each report section to within grade group similarities is presented (Table 4.4).

Overall the average similarity between outcomes for the HD, Distinction and Credit level students were greater than 85%, demonstrating a good grouping between SOLO outcomes in each of these categories. The grouping of the Pass level student outcomes falls short of 80% indicating a greater spread of SOLO outcomes in this category than for the other qualitative grades (see MDS ordination Figure 4.2).

In the HD category there is an even distribution of contributions from each of the Introduction, Hypothesis and Methods sections (30 – 37%). Contrary, the Hypothesis section of the Distinction graded student outcomes only contributes 13.6% to this outcome, with a dominance of the Introduction section explaining at 46.9% of the
similarity among this section of assignments. Similarly, the Hypothesis section shows lesser contribution for the Credit level student outcomes at 29% (c.f. 36 and 34% for Introduction and Methods respectively). Conversely, the Hypothesis section shows the greatest degree of contribution for the Pass level student outcomes (35.6%).

Table 4.4 SIMPER (Similarity Percentages) - section contributions to SOLO outcomes between analysis of qualitative grades. Int = Introduction, Hyp = Hypothesis, Met = Method.

*High distinction (HD)*, Average similarity: 91.65

<table>
<thead>
<tr>
<th>SECTION</th>
<th>Int</th>
<th>Hyp</th>
<th>Met</th>
</tr>
</thead>
<tbody>
<tr>
<td>Av.Rank</td>
<td>8.29</td>
<td>7.57</td>
<td>8.57</td>
</tr>
<tr>
<td>Av.Sim</td>
<td>29.77</td>
<td>27.80</td>
<td>34.08</td>
</tr>
<tr>
<td>Sim/SD</td>
<td>8.88</td>
<td>4.20</td>
<td>10.34</td>
</tr>
<tr>
<td><strong>Contrib%</strong></td>
<td><strong>32.48</strong></td>
<td><strong>30.34</strong></td>
<td><strong>37.18</strong></td>
</tr>
</tbody>
</table>

*Distinction (D)*, Average similarity: 85.82

<table>
<thead>
<tr>
<th>SECTION</th>
<th>Int</th>
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<th>Met</th>
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<tbody>
<tr>
<td>Av.Rank</td>
<td>8.63</td>
<td>3.50</td>
<td>7.00</td>
</tr>
<tr>
<td>Av.Sim</td>
<td>40.30</td>
<td>11.70</td>
<td>33.82</td>
</tr>
<tr>
<td>Sim/SD</td>
<td>9.58</td>
<td>1.73</td>
<td>9.24</td>
</tr>
<tr>
<td><strong>Contrib%</strong></td>
<td><strong>46.95</strong></td>
<td><strong>13.63</strong></td>
<td><strong>39.41</strong></td>
</tr>
</tbody>
</table>

*Credit (C)*, Average similarity: 85.44

<table>
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<td>Av.Rank</td>
<td>6.00</td>
<td>4.67</td>
<td>5.56</td>
</tr>
<tr>
<td>Av.Sim</td>
<td>0.75</td>
<td>24.50</td>
<td>29.18</td>
</tr>
<tr>
<td>Sim/SD</td>
<td>5.78</td>
<td>6.23</td>
<td>3.51</td>
</tr>
<tr>
<td><strong>Contrib%</strong></td>
<td><strong>36.42</strong></td>
<td><strong>29.02</strong></td>
<td><strong>34.56</strong></td>
</tr>
</tbody>
</table>

*Pass (P)*, Average similarity: 79.61

<table>
<thead>
<tr>
<th>SECTION</th>
<th>Int</th>
<th>Hyp</th>
<th>Met</th>
</tr>
</thead>
<tbody>
<tr>
<td>Av.Abund</td>
<td>5.20</td>
<td>5.60</td>
<td>4.90</td>
</tr>
<tr>
<td>Av.Sim</td>
<td>25.86</td>
<td>28.34</td>
<td>25.41</td>
</tr>
<tr>
<td>Sim/SD</td>
<td>2.90</td>
<td>4.42</td>
<td>3.25</td>
</tr>
<tr>
<td><strong>Contrib%</strong></td>
<td><strong>32.48</strong></td>
<td><strong>35.60</strong></td>
<td><strong>31.92</strong></td>
</tr>
</tbody>
</table>
Overview and Discussion

This chapter has outlined the results pertaining to developing a protocol for marking scientific written assessments using a cognitive structural perspective provided by the SOLO (Biggs & Collis, 1991). An analytical framework within the cognitive structural model was used and compared with quantitative grades to determine for effective alignment of assessment by written assignments. The following specific lines of inquiry were addressed for a partial scientific report. The measure of outcome used was written responses to a question about presenting a scientific review, from which a hypothesis was developed relating to measurements of disturbance in a given ecosystem. Further the students were required to formulate appropriate methods for testing their scenario in a scientifically appropriate manner.

A small subsample of the 2007 cohort was used to design a pilot framework to qualitatively assess this assessment task for the following year’s students. The student reports were written and hence analysed in three sections; Introduction, Hypothesis and Methods. From four potential categories, the SOLO framework was used to place the two relevant categories in two-cycles of each the concrete symbolic mode due to separation on structural complexity of scientific expression, and two cycles showed extended abstract cognition resulting in their placement in the formal mode. The pilot assessments were further analysed for SOLO levels (U, M and R) within each cycle and mode.

The SOLO framework from the pilot cohort was subsequently tested on student written outcomes for the same task in the following years’. The distribution of the SOLO outcomes of these students among sections of the report demonstrated that the majority of responses were in the second cycle concrete symbolic mode for all report sections.

Outcomes from the Introduction ranged at a higher hierarchical level from first cycle concrete symbolic, relational to formal level responses. Hypotheses and Methods were constrained within first and second cycles of the CS mode, with little use of ecological theory in the development of hypotheses. The Methods were unlikely to be presented in
the formal mode, as the uses of specified, standard scientific practices were part of the outcomes for the task.

Multiple dimensional scaling analytical techniques were used to determine the relationship between qualitative SOLO categories and the qualitative grade the students were given for their unit assessment. There was no significant discrimination between pass and credit level students by the current SOLO analysis, but significant discrimination between all other quantitative groupings.

Finally, the report section which contributed to the separation among student outcomes was determined. The grouping of the pass level students had a greater spread of SOLO outcomes in this category than for the other higher qualitative grades. The Hypothesis section showed the greatest contribution to determining the pass level student outcomes. Pass level students with outcomes in the first cycle had predominantly reviewed non-scientific literature and did not express their hypothesis/es within the explicit context of their scenario.

The variability in lower grades may also be influenced by general observations of student learning behaviour by the unit coordinator, including group and field work participation. Outcomes from the current categorisation in the first cycle concrete symbolic mode may be inappropriate (i.e., not writing within a scientific framework) for a pass at second year university level. Thus, contextual factors may need to be considered within a comprehensive qualitative assessment of the student’s full learning experience (c.f. Elton & Johnston, 2002). However, only written outcomes presented for grading could be assessed. In contrast a HD is an unambiguous achievement of top level expectations of all task objectives, where consistency throughout a whole assignment would be expected. The assessment objectives need to be clarified for which forms of procedural ideas are important for this learning outcome (c.f. Ramsden, 2003). Making an objective judgment about the extent to which each criterion has been achieved has been more difficult than expected despite the use of a criterion referenced marking framework for report sections.

In general, the results presented in this chapter provide a theoretically grounded description of an hierarchy of levels for responses to the scientific report presentation of understanding of ecological management of typical human disturbance events. The
results of analysis of the learning outcomes suggest that the majority of students could present a scientifically written review, formulate testable questions, and design robust replicable studies in a scientific framework. A few students demonstrated greater abstract cognition and application by presenting ideas beyond those directly instructed for the task.

The SOLO framework is applied and extended in the next chapter to encompass a full scientific report (i.e., with results and discussion sections) format for student outcomes of an ecological investigation.
Chapter 5: Results Part 2


Introduction

The qualitative marking framework outlined in the previous chapter presented a protocol for marking scientific written assessments using a cognitive structural perspective, namely the Structure of the Observed Learning Outcome Model (SOLO; Biggs and Collis, 1991) for a partial scientific report. Continuing in Research Theme 1, the analytical framework is extended in this chapter and applied to a full scientific report assessment item.

A sectional based framework within the cognitive structural model is used to compare the effective alignment of assessment by extended written assignments. This theme is guided by the following specific lines of inquiry:

To develop categories of written responses to a scientifically developed extended written assessment task within the SOLO model. Specifically the following research questions will be investigated:

1. To develop SOLO categories of qualitative responses to a scientific report based (i.e. Introduction, methods, results and discussion)
2. What is the distribution of SOLO categories across different report sections?
3. How do the SOLO categories from a sectional analysis correlate with the actual quantitative grade given to the students?

The results pertaining to these lines of inquiry are presented in the order they are posed above. The results pertaining to question 1 are presented from a pilot study from
the 2007 cohort of students from Marine and Freshwater Ecology 202. These results form a qualitative analysis of 12 written responses to an assessment item, the testing of the River Continuum Concept, and interpreted in terms of a two cycle SOLO model (Chapter 2). Subsequently, the SOLO schedule developed from the pilot group is used to evaluate student responses from a larger cohort of students enrolled in the equivalent unit in 2008 to cover questions 2 and 3.


This section presents the results of student written responses to an assessment item with the aim of the students during the intensive school (off-campus students) and practical classes (on-campus students) to explore a fundamental ecological concept. The students were asked to investigate the input, movement and breakdown of various forms of organic matter by invertebrates in two contrasting river ecosystems. Student objectives were to work in groups to develop hypotheses, methods and then gather data during the 2-day field trip to test their specific predictions to the ‘The River Continuum Hypothesis’ of Vannote et al. (1980). Individual assignments presenting the group data were submitted as a project report in standard scientific paper format (i.e., with 4 sections, Introduction, Methods, Results, Discussion).

Categories of response
Twelve assignments were systematically analysed to gain a general picture of the qualitative elements required from the students to execute the task. A systematic approach to assessment dissects the assignment to allocate a qualitative assessment to individual sections of the report. The reasoning for the first phase of categorisation within each subsection of the assessment task is outlined below. The Introduction in this assignment integrated elements of both the Introduction and Hypothesis sections from Chapter 4, the Methods are similar but more detailed than in the previous chapter, and the Results and Discussion were analysed as new components.

Similar to Chapter 4, coding responses required thorough understanding of all the related concepts and terms, in order to detect qualitative differences in responses. The
final format exhibited the different groups of like responses within 3 categories depending on the report section.

INTRODUCTION

<table>
<thead>
<tr>
<th>Category</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Category A</td>
<td>Characterised by a rational/ general knowledge approach to scientific understanding. A logical testable hypothesis is developed.</td>
</tr>
<tr>
<td>Category B</td>
<td>Takes the discussion into a scientific context. The mechanism for any prediction/ hypotheses is quantified.</td>
</tr>
<tr>
<td>Category C</td>
<td>Illustrated deductive interpretation of the review from use of ecological theory and approaches to scientific methodology. The hypothesis reflects integration of ecological principles and/or theory from the review (i.e., the RCC). More than one hypothesis is presented to examine fully aspects of the theory under investigation.</td>
</tr>
</tbody>
</table>

METHODS

<table>
<thead>
<tr>
<th>Category</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Category A</td>
<td>Demonstrates a simplistic understanding potential scientific methodology; often common sense measurements are suggested.</td>
</tr>
<tr>
<td>Category B</td>
<td>Addresses issues of appropriate scientific sampling methodology. Here methodology can relate to hypotheses from all categories and utilize aspects of scientific sampling methodology appropriately.</td>
</tr>
<tr>
<td>Category C</td>
<td><em>A standard scientific method is challenged. Not observed in this undergraduate context but postulated as the next progressive category.</em></td>
</tr>
</tbody>
</table>

RESULTS

<table>
<thead>
<tr>
<th>Category</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Category A</td>
<td>The first cycle of the results demonstrated a simplistic use of scientific methodology; graphical presentation absent; often common sense measurements demonstrated without statistical summary (ie means, variance etc). Data are consistent with methods and thus the prediction from the hypothesis.</td>
</tr>
</tbody>
</table>
Category B The second cycle addresses issues of appropriate scientific data presentation and basic statistical data summaries (i.e., means, variance, correlation analysis, etc).

Category C Examines aspects of the test system that may cause variation from the RCC model (e.g., differences in riffles vs pools).

DISCUSSION

Category A The first cycle is characterised by a rational/ general knowledge approach to scientific understanding. Appropriate reference to the scientific source of the information is not made.

Category B The discussion is in a scientific context. The River Continuum Concept (RCC) is discussed in relation to the data set presented in the results. Appropriate reference to the original source of the theory is made (Vannote et al., 1980) and the summary is written in a scientific style. A statement of refuting or supporting the original hypothesis is made.

Category C This category illustrates deductive interpretation of the results which are synthesised in the framework of ecological theory and approaches to scientific methodology. Aspects of the theory under investigation are considered as processes in themselves, each in turn are examined within the Australian context of the study.

It is made apparent that the River Continuum Concept (RCC) is the theory under investigation. All aspects of the RCC are discussed. The relationships between biotic, physical, and chemical processes along the river continuum are made explicit by discussion in logical progression in a scientific writing style. Appropriate reference to the original source of the theory is made (Vannote et al., 1980). There is examination of context (temporal, spatial, methodological) specific variables which affected the results.

As in Chapter 4, within the five modes of thinking associated with the SOLO structure, the two learning cycles most relevant to this assessment task are concrete symbolic and formal. The two-cycle per mode version of SOLO was used as a framework in which to fit categories of response. As described in Chapter 2, the two-learning cycles per mode version of SOLO postulates at least two-cycles of levels
within each mode, such as two rounds of unistructural, multistructural and relational responses representing increasing levels of complexity of each response. It is evident from the discussion, above, those responses from the report section by undergraduate students in this study fall into three categories of sophistication from A – C. Categories A and B fall into the concrete symbolic mode, and C in the formal mode. Once more, a key focus between these categories was on the structural complexity between A and B, and C and D and a level of abstraction between categories B and C. This relates to a two learning–cycle per-mode version of SOLO as outlined in Chapter 2. Essentially the broad groupings of response categories referred to as A and B are representative of a single mode in the SOLO model, and category C of the next progressive mode.

The first category corresponds with the concrete symbolic mode in which the main feature is the presentation by the individual of concepts and operations applied through the symbolic systems of written language. In Category A the students present a general logical and ordered understanding of a conceptual framework of the River Continuum Concept (RCC) given to them in the Introduction. This is incorporated in the Introduction and captures a general simple aspect of the RCC and strives for a logical testable form. Often common-sense measurements are suggested within this category without full use of standard scientific methodology.

Results reflect the common sense measurement and lack scientific presentation with ‘list-like’ non-condensed data set. The Discussion in Category A does not acknowledge the original conceptual framework, with broad conclusions are drawn from only a subset of supporting data. The relationship between biotic, physical and chemical changes along the river continuum may not be made explicit or lacking in logical progression.

In Category B the students’ responses are again bounded by the given reference to the RCC but extend their introductory review into a scientific context, with use of scientific language and protocols. The hypothesis forms a statement of refuting or supporting the original ideas presented in the RCC, thus demonstrating scientific thought through predicting a possible mechanism for their prediction. A logical progression of refuting or supporting the original hypothesis/es is made. Thus the
relationships between biotic, physical and/or chemical factors are made explicit by discussion in logical progression with reference to the original source of the theory.

In the Discussion section, the data are synthesised in relation to other studies which examine similar aspects of the RCC. Multiple aspects of the data are logically presented in a scientific format and the data are consistent with methods, and thus the prediction from the hypothesis.

In the Results, aspects of the data may be shown in a relational fashion by clear representation in graphical form distinguishing dependent and independent variables of the hypothesis (e.g., correlations between FFG abundance and organic matter biomass). Aspects of variance are presented graphically as error bars where appropriate or as standard deviations or percentiles in tabulated data. Standard scientific presentation is adhered to with figures and summary tables are discussed in the body of text of the ‘results’ section. Data sets may be examined in different ways (e.g., compare absolute differences vs proportional differences in data sets). Appropriate reference to the original source of the theory is made (Vannote et al., 1980) and the summary is written in a scientific style.

A statement of refuting or supporting the original hypothesis is made in the Discussion. Appropriate reference to the original source of the theory is made (Vannote et al., 1980) and a summary of the presented results is written in a scientific style. The relationship between biotic, physical and chemical results is acknowledged by discussion in logical progression with reference to the original source of the theory. Finally, the presented data are discussed in the context of other studies which observe similar aspects of the RCC.

The formal mode is represented by the third level (C) of responses. The responses within these categories demonstrated that individuals had an increased abstraction of their thought processes and were able to extend their ideas from the RCC. The individuals here presented responses which pertained to other ecological processes and theories not explicitly imparted as given knowledge within the RCC. All aspects of the RCC are discussed such as physical changes, changes in invertebrate species structure or changes in organic matter fractions from an upland to a lowland stream. Aspect/s
within the RCC is discussed in a context of ecological processes implicit in the RCC, such as:

- Discussion of energy sources and production in streams are introduced and prefaced to the RCC (i.e., allochthonous vs autochthonous sources of primary production).
- The biota are put in the context of types of consumers and explained as Functional Feeding Groups as outlined in the RCC.
- The geographical context of the RCC is made clear in that it was written for northern hemisphere streams where deciduous trees contribute the dominant source of organic material in upland streams. Hypotheses may explicitly examine aspects of the system that may cause variation from the RCC. A single aspect within the RCC is supported by the data presented in the Results.

The Discussion is the key section to demonstrate understanding within the formal mode. This is synthesised within a context of ecological processes, data are summarised in support of the multiple ecological processes involved in the RCC and are all integrated in a logical fashion. The presented data are examined within a context of other principles of ecological function (e.g., productivity models and algal biomass; food web dynamics).

Importantly, the RCC is discussed in an historical context and as a model created to explain the function of northern hemisphere streams. This issue is synthesised within the Australian context of the study and the non-deciduous nature of Australia’s dominant endemic flora. Further challenges to the RCC in an Australian/southern hemisphere context are made with supporting literature. Consequently, existing alternative theories of river function are introduced.

To acquire a higher cycle of the formal mode the RCC and other existing theories of river function are challenged by presenting a new hypothesis of river function. Subsequently the division of modes above are analysed further as potential SOLO levels; unistructural (U), multistructural (M) and relational (R ).
Fit of response categories to the two-learning cycle SOLO model

The relationship between the categories of response previously outlined is assessed in this subsection with regard to the levels within each mode.

Introduction

First Cycle Concrete Symbolic

U1

- One aspect of the River Continuum Concept (RCC) is discussed; such as either physical changes, or changes in invertebrate species structure or changes in organic matter fractions between upland and lowland streams. Appropriate reference to the scientific source of the information is not made.
- The hypothesis is presented as independent elements with no logical reasoning implied, or direction of change given for any interaction between elements (i.e., there is a difference between the upstream and downstream sites).
- Writing style is imprecise with unclear aims, may be difficult to follow and/or subjective, without facts.

M1

- Multiple aspects of the River Continuum Concept (RCC) are discussed such as physical changes, changes in invertebrate species structure or changes in organic matter fractions from a upland to a lowland stream. The relationships between biotic, physical and chemical changes along the river continuum are not made explicit or lacking in logical progression.
- A logical hypothesis is presented, but reasoning of the difference between sites is not explicit or vague terminology used so that the hypothesis is not testable.

R1

- All aspects of the River Continuum Concept (RCC) are discussed such as physical changes, changes in invertebrate species structure or changes in organic matter fractions from a upland to a lowland stream. The relationships between biotic, physical and chemical changes along the river continuum are made explicit by discussion in logical progression in a non scientific writing style. A logical testable hypothesis is presented (e.g., the course organic matter is less at the downstream than upstream site). Direction of change is qualified.
Second Cycle Concrete Symbolic

U2

- One aspect of the River Continuum Concept (RCC) is discussed, either physical changes, or changes in invertebrate species structure, or changes in organic matter fractions between upland and lowland streams. Appropriate reference to the original source of the theory is made (Vannote et al., 1980) and the summary is written in a scientific style.
- Several key elements allow scientific writing:
  - **Precision**: ambiguities in writing cause confusion in the aim.
  - **Clarity**: writing that is difficult to follow greatly amplifies any confusion on the part of the reader
  - **Objectivity**: any claims need to be based on facts, not intuition or emotion
- A single testable hypothesis with statement of a single quantifiable causal parameter (e.g., the dry weight of coarse organic matter (>1mm) is less at the downstream than upstream site).

M2

- Multiple aspects of the River Continuum Concept (RCC) are discussed such as physical changes, changes in invertebrate species structure or changes in organic matter fractions from an upland to a lowland stream. The relationships between biotic, physical and chemical changes along the river continuum are not made explicit or lacking in logical progression. Appropriate reference to the original source of the theory is made (Vannote et al., 1980) and the summary is written in a scientific style.
- Multiple testable (i.e., relates to multiple aspects of the RCC) hypotheses with statement of quantifiable causal parameter/s.

M2 transitional

- Terms used without full explanation or relevance
- Some connections are made between elements of the RCC but not all elements are interrelated.

R2

- All aspects of the River Continuum Concept (RCC) are discussed including physical changes, changes in invertebrate species structure or changes in organic matter fractions from a upland to a lowland stream.
- The relationships between biotic, physical, and chemical changes along the river continuum are made explicit by discussion in logical progression in a scientific writing style. Appropriate reference to the original source of the theory is made (Vannote et al., 1980) and the summary is written in a scientific style.
• It is made clear that the RCC was written in the context of northern hemisphere streams and explained that the deciduous nature of most northern hemisphere trees creates the dominant source of organic material in upland streams.

• Multiple testable hypotheses with logical/causal parameters and explicit reasoning linking and/or explaining interactions between the hypotheses.

**Formal Mode**

**U1**

• It is clear that the River Continuum Concept (RCC) is the theory is under investigation. All aspects of the River Continuum Concept (RCC) are discussed such as physical changes, changes in invertebrate species structure or changes in organic matter fractions from a upland to a lowland stream. The relationships between biotic, physical, and chemical changes along the river continuum are made explicit by discussion in logical progression in a scientific writing style. Appropriate reference to the original source of the theory is made (Vannote et al., 1980).

• A single aspect within the RCC is discussed in a context of ecological processes, examples are:
  - Discussion of energy sources and production in streams are introduced and prefaced to the RCC (i.e., allochthonous vs autochthonous sources of primary production).
  - The biota are put in the context of consumers and explained as Functional Feeding Groups as outlined in the RCC.
  - A single testable hypothesis with statement of a single quantifiable causal parameter (e.g., the dry weight of course organic matter (>1mm) is less at the downstream than upstream site).

**M1**

• Multiple ecological processes within the RCC are discussed in a context of ecological theory.

• Multiple testable (i.e., relates to multiple aspects of the RCC) hypotheses with statement of quantifiable causal parameter/s.

**M1 transitional**

• Some connections are made between processes above, however, not all elements are interrelated.

**R1**

• The multiple processes of the RCC are discussed in a context of ecological theory and all integrated in a logical fashion.

• It is made clear that the RCC was written in the context of northern hemisphere streams and explained that the deciduous nature of most northern hemisphere trees creates the dominant source of organic material in upland streams.
• Multiple testable hypotheses with logical/causal parameters and explicit reasoning linking and/or explaining interactions between the hypotheses.

• Challenges to the RCC in an Australian/southern hemisphere context are made with supporting literature.
• The dominance of non deciduous trees in natural upland Australian river systems.
• Possible effects of land management practices on organic matter inputs into river systems (e.g., tree clearance, agricultural pastures adjacent to river banks, changes to natural river flow patterns).
• Existing alternative theories of river function are introduced.

U2

• The RCC and other existing theories of river function are challenged by presenting a new hypothesis of river function.

Most student responses (10/12) gave detailed descriptions of the given theory and students explained the relationships between all aspects of the River Continuum Concept (RCC). The students made clear that the RCC was written in the context of northern hemisphere streams and explained that the deciduous nature of most northern hemisphere trees creates the dominant source of organic material in upland streams. They extended this knowledge to multiple testable hypotheses acknowledging that the test scenario would likely differ from the theory due to dominant vegetation types and current catchment management. Two students failed to write in a scientific style and remained in the first cycle concrete symbolic due to a lack of appropriate referencing in this section.

Over half (7/12) of the students had outcomes in the Formal Mode for their Introductions. These students presented outcomes which discussed ecological processes key to the RCC theory. This included discussion of energy sources and they discussed biota in the context of consumers and explained as Functional Feeding Groups.
Methods

First Cycle Concrete Symbolic

U1

- A single method of testing independent aspects of a general hypothesis.

M1

- Multiple methodologies for testing aspects of a general hypothesis.
- Hypotheses not logically connected.

R1

- Methodology/s are consistent with the prediction from the hypothesis.

Second Cycle Concrete Symbolic

U2

- A single aspect of sampling methodology is presented discussed (i.e., controls, or, randomisation, or replication). The reader should be able to easily follow the methods used to generate the data.

M2

- Appropriate design using many aspects of sampling methodology (i.e., controls, and randomisation and replication).

R2

- Appropriate design using many aspects of sampling methodology (controls, and randomisation and replication) with explicit explanation. For example, how a control is affective; why randomisation is appropriate against other types of sampling procedures, the need for an explicit number of replicates is explained.
- Multiple methodologies that clarify questions relating to temporal and spatial scale, and biological organisation through an explicit and logical approach.

Formal

U1

- A single standard methodology is challenged in the context of the investigation.

M1

- Multiple standard methodologies are challenged in the context of the investigation.
R1

- Multiple standard methodologies are challenged in the context of the investigation are explicitly and logically interrelated in the investigation of an hypothesis.

Most methods were written in the concrete symbolic mode due to the standard scientific framework of the student expectations. A single student failed to use standard methods, presenting ideas in a list like fashion. One quarter of outcomes followed standard scientific methods but did not logically integrate their progression of methods or omitted their planned data analysis, (M2). Three quarters of outcomes were well presented following standard scientific protocol and logical development from their given hypotheses.

---

**Results**

**First Cycle Concrete Symbolic**

**U1**
- Only one aspect of the data represented in a non-scientific format. (i.e., data maybe presented in prose with no graphical representation or statistical summary).
- The results logically correspond with the methods.

**M1**
- Multiple aspects of the data represented in non-scientific format.
- Not logically connected and/or not consistent with methods.

**R1**
- Multiple aspects of the data are logically presented in a non-scientific format.
- Data are consistent with methods and thus the prediction from the hypothesis.

**Second Cycle Concrete Symbolic**

**U2**
- Only one aspect of the data represented in scientific format (i.e., graphical representation or statistical summary).

**M2**
- Multiple aspects of the data represented in a scientific format (e.g., Functional Feeding Groups and Organic Matter abundance).
• Not logically connected and/or not consistent with methods
• Data maybe presented graphically but not summarised appropriately in the body of text of the 'results’ section.
• Often no figure captions or figure captions are too verbose instead of dialogue in the body of the text.
• Data maybe missing aspects of variance/ percentiles in representation of means/medians, etc.

R2

• Multiple aspects of the data are logically presented in a scientific format and the data are consistent with methods and thus the prediction from the hypothesis.
• Multiple aspects of data maybe shown in a relational fashion by clear representation in graphical form distinguishing dependent and independent variables from the hypothesis (e.g., Correlations between FFG abundance and organic matter biomass).
• Aspects of variance are presented graphically as error bars where appropriate, or as standard deviations or percentiles in tabulated data.
• All figures and summary tables are discussed in the body of text of the ‘results’ section.
• Examination of data in different ways (e.g., compare absolute differences vs proportional differences in data sets).

Formal

U1

• Examining aspects of the system that may cause variation from the RCC model (e.g., within site variation such as differences in riffles vs pools).

All but a single outcome for the results section were presented in the second cycle of the concrete symbolic mode. Half were multistructural, with some aspects of the hypothesis and methods not being fully investigated and presented as new data in this section. The remainder demonstrated a relational presentation of their data.

Multiple aspects of the data were logically presented in a scientific format and were consistent with methods and thus the prediction from the hypothesis. These students used appropriate tools of graphical representation and displayed variance appropriately. Many of these students presented data in different ways, for example they compared absolute differences to proportional differences in data sets to express fully patterns of their research outcomes. The single student that showed outcomes for
their Results section in the formal mode used statistical analysis beyond the expectations for the assessment outcomes.

Discussion

**First Cycle Concrete Symbolic**

**U1**
- One aspect of the River Continuum Concept (RCC) is discussed through limited data presented in the Results.
- Appropriate reference to the scientific source of the information is not made.
- Present broad conclusions with only a subset of supporting data.
- Draw conclusions not explicitly presented in the Results.

**M1**
- Multiple aspects of the RCC are discussed as presented in the results. The relationships between biotic, physical and chemical changes along the river continuum are not made explicit or lacking in logical progression.
- Appropriate reference to the scientific source of the information is not made.
- Draw conclusions not explicitly presented in the Results.
- Jump to broad conclusions with only a subset of supporting data.

**R1**
- All aspects of the RCC are discussed such as physical changes, changes in invertebrate species structure or changes in organic matter fractions from an upland to a lowland stream.
- The relationships between biotic, physical and chemical changes along the river continuum are presented data made explicit by discussion in logical progression in a non-scientific writing style.
- Appropriate reference to the scientific source of the information is not made.

**Second Cycle Concrete Symbolic**

**U2**
- One aspect of the River Continuum Concept (RCC) is discussed in relation to the data set presented in the results. For example, either physical changes, or changes in invertebrate species structure or changes in organic matter fractions between upland and lowland streams.
- Appropriate reference to the original source of the theory is made (Vannote et al., 1980) and the summary is written in a scientific style.
• The reader should be able to easily follow both the methods used to generate the data and the chain of logic used to draw conclusions from the data.
• A statement of refuting or supporting the original hypothesis is made.

M2

• Multiple aspects of the RCC are discussed in relation to the data set presented, such as physical changes, changes in invertebrate species structure or changes in organic matter fractions from a upland to a lowland stream.
• A relationship between biotic, physical and chemical results is not made explicit or lacking in logical progression. A statement of refuting or supporting the original hypothesis is made as a list and not synthesised with the literature.
• Appropriate reference to the original source of the theory is made (Vannote et al., 1980) and the summary is written in a scientific style.

M2 transitional

• Some connections are made between elements of the RCC but they are not interrelated. Some synthesis of data with literature is made which support the RCC.

R2

• All aspects of the RCC are discussed and supported by relevant summary of the data set.
• A logical progression of refuting or supporting the original hypothesis/es is made.
• The relationship between biotic, physical and chemical results is made explicit by discussion in logical progression with reference to the original source of the theory.
• The data are synthesised in relation to other studies which examine similar aspects of the RCC.
• The RCC is discussed in an historical context of northern hemisphere streams. The deciduous nature of most northern hemisphere trees creates the dominant source of organic material in upland streams is indicated but not fully synthesised within the Australian context of the study.

U1

• A single aspect within the RCC is supported by the data presented in the Results.
• This is synthesised within a context of ecological processes
• These data are synthesised in relation to other studies which examine similar aspects of the RCC.
Ch. 5 Results

M1

- Multiple data sets from the results are summarised and synthesised as ecological processes within the RCC.
- This data is synthesised in relation to other studies which examine similar aspects of the RCC.
- A relationship between results about different ecological processes results are not made explicit or lacking in logical progression or not synthesised with appropriate literature.

M1 transitional

- Some connections are made between processes above, however, not all elements are interrelated.

R1

- Data are summarised in support of the multiple ecological processes involved RCC all integrated in a logical fashion.
- The data are synthesised in relation to other studies which examine similar ecological processes both within and without the perspective of the RCC.
- Results may be synthesised in relation to other principles of ecological function (e.g., productivity models and algal biomass; food web dynamics)
- The RCC is discussed in an historical context in that of northern hemisphere streams. This issue is synthesised within the Australian context of the study and the non deciduous nature of Australia’s dominant endemic fauna.
- Challenges to the RCC in an Australian/southern hemisphere context are made with supporting literature.
- Possible effects of land management practices on organic matter inputs into river systems (tree clearance, agricultural pastures adjacent to river banks, changes to natural river flow patterns).
- Existing alternative theories of river function are introduced.

Second Cycle Formal

U2

- The RCC and other existing theories of river function are challenged by presenting a new hypothesis of river function.

Those students with an outcome for their Introduction in the formal mode also had an outcome for their Discussion in the formal mode, albeit some were at a different level for each section. All students’ outcomes demonstrated a level higher than M2 in the concrete symbolic mode, regardless of their outcome in the Introduction section. For example, students 5 and 6 presented a greater comprehension of the concepts behind
the study after synthesis of their own research procedure. Students 1 and 8 demonstrated exceptional comprehension of the significance of their study, by introducing other theories of river function as possible explanations for their study results, together with land, river management repercussions from theories derived from differing geographic regions, to those under investigation (Table 5.1).

Table 5.1 Summary of systematic and holistic SOLO categories from Assessment task 2 (Mode/Level). Methods and Results in the Concrete Symbolic mode unless indicated.

<table>
<thead>
<tr>
<th>Student</th>
<th>Introduction</th>
<th>Methods</th>
<th>Results</th>
<th>Discussion</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>R1 (F)</td>
<td>R2</td>
<td>R2</td>
<td>R1(F)</td>
</tr>
<tr>
<td>2</td>
<td>U1 (F)</td>
<td>M2</td>
<td>M2</td>
<td>M1(F)</td>
</tr>
<tr>
<td>3</td>
<td>R2 (CS)</td>
<td>M1</td>
<td>M2</td>
<td>M2 (CS)</td>
</tr>
<tr>
<td>4</td>
<td>M1(F)</td>
<td>R2</td>
<td>R1(F)</td>
<td>M1 (F)</td>
</tr>
<tr>
<td>5</td>
<td>R1(CS)</td>
<td>R2</td>
<td>R2</td>
<td>M2 (CS)</td>
</tr>
<tr>
<td>6</td>
<td>R1 (CS)</td>
<td>R2</td>
<td>M2t</td>
<td>M2t (CS)</td>
</tr>
<tr>
<td>7</td>
<td>R1(CS)</td>
<td>R2</td>
<td>R2</td>
<td>R1 (F)</td>
</tr>
<tr>
<td>8</td>
<td>R2 (CS)</td>
<td>R2</td>
<td>R2</td>
<td>R2 (CS)</td>
</tr>
<tr>
<td>9</td>
<td>R2 (CS)</td>
<td>M2</td>
<td>M2</td>
<td>R2 (CS)</td>
</tr>
<tr>
<td>10</td>
<td>U1 (F)</td>
<td>R2</td>
<td>M2</td>
<td>U1(F)</td>
</tr>
<tr>
<td>11</td>
<td>M1(F)</td>
<td>R2</td>
<td>R2</td>
<td>M1(F)</td>
</tr>
</tbody>
</table>

A summary of student responses is presented in Table 5.1, showing the mode and level attained for each report section and associated quantitative grade they were given by the subject coordinator as their score towards the unit assessment. Those who received an HD consistently got the highest qualitative outcome for each section of the report. Those with a distinction also demonstrated outcomes in the Introduction and Discussion in the formal mode, or relational level of the second cycle concrete symbolic mode. These students could integrate some but not all theoretical aspects of the study.

Students who gained a credit grade had section outcomes in both the first and second cycle of the concrete symbolic mode, although all had Discussion outcomes in the second cycle. These students could work within a scientific framework but not extend past the explicit theoretical framework given by direct instruction. These students
displayed a wide functional understanding of scientific method and a range of practical application of the scientific method from M1 to R2.

Due to the small sample size for this pilot study there were no students with lower quantitative grades at a pass or fail level, or the envisaged comparable qualitative outcomes across all levels of the concrete symbolic cycles. Sample bias may have been caused by only confident students offering their assessment tasks for this study.

Similar to outcomes from the partial scientific report (Chapter 4), numbers are too low to statistically relate quantitative grades and qualitative outcomes in the pilot study. Again there is a related hierarchical trend between SOLO model and cyclical elements. This final coding scheme for each assessment task was used to mark the 2008 cohort of students.

Patterns and distributions of SOLO categories for a full scientific report

Distribution of SOLO outcomes for report sections
This section describes the distribution of SOLO categories for written responses to the full scientific report from students of ECOL202 Marine and Freshwater Ecology, 2008 cohort with the same aim as part 5.1. In summary, their objective was a written response to an assessment item with the aim to explore a fundamental ecological process through testing one prediction of a foundation and dominant river model ‘The River Continuum Concept’ of Vannote et al. (1980). Individual assignments presenting the group data were submitted as a project report in standard scientific paper format (i.e., with 4 sections, Introduction, Methods, Results, Discussion).

Thirty-four out of 41 enrolled students volunteered their assignment that were each systematically analysed using the SOLO framework devised form the 2007 pilot cohort above. Inter-marker reliability was for 30% (10 reports) of reports between the researcher and a specialist familiar with the study context. Where inconsistencies arose in the present study between the pilot study categories and the 2008 cohort, discussions with an authority on SOLO were achieved until inter-subjective problems were resolved. For the 2008 cohort, the two sets of codes were compared by Spearman
Rank Correlation for each section of the two assessment tasks (R > 0.96 for all report sections, Table 5.2).

The questions addressed for inquiry were

- To analyse and graphically represent the distribution of the qualitative SOLO outcomes of each student among sections of the report.
- To examine the relationship between qualitative SOLO categories and the quantitative grade the students were given for their unit assessment.
- To determine which report section contributed to the separation among student outcomes.

<table>
<thead>
<tr>
<th>Table 5.2 Inter Marker Reliability (n=10).</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
</tr>
<tr>
<td>Intro  Marker 1</td>
</tr>
<tr>
<td>Marker2</td>
</tr>
<tr>
<td>Methods Marker 1</td>
</tr>
<tr>
<td>Marker2</td>
</tr>
<tr>
<td>Results Marker 1</td>
</tr>
<tr>
<td>Marker2</td>
</tr>
<tr>
<td>Discussion Marker 1</td>
</tr>
<tr>
<td>Marker2</td>
</tr>
</tbody>
</table>

The distribution of SOLO categories for written responses to the full scientific report is presented in Table 5.3 and summarised in Figure 5.1. Six (17.6%) of the responses for the Introduction section were in the formal mode, all other responses were in the concrete symbolic mode. Outcomes for the Introduction section ranged from first cycle concrete symbolic, Relational; to formal, relational, with most (35%) responses in the concrete symbolic multistructural level. Seven student’s responses (20.5%) were at a transitional level above multistructural, demonstrating non fully-integrated scientific pathways in the literature review. The students, whose introductory section outcomes were in the first cycle concrete symbolic, were lacking scientific language
style and either omitted a direct reference to the RCC, or wrote a very simplistic summary.

Those students with Introduction outcomes in the formal mode either demonstrated a context of community ecology and extended principles in the RCC (e.g., students 8, 21 & 29) or integrated ecological process with management issues (e.g., student 19).

The outcomes from the Methods section range from U1 – R2, with 44% of responses in the second cycle multistructural level, and 32% and in the second cycle relational level. Those methods in the first cycle often had methods inconsistent with their stated general hypotheses, and used non-scientific language and no standard scientific practices (e.g., students 3, 4, 18). The majority of student responses (83%) demonstrated good knowledge of scientific protocol with 11 students presenting full detailed, repeatable methods with explicit scientific research protocols for a number of lines of enquiry relevant to their scenario. Student 19 showed exceptional method by addressing numerous factors from the RCC as clear testable hypotheses, with explicit methods proceeded by potential statistical analyses.

Similar to the Methods, a small percentage (15%) had outcomes in the Results section in the first cycle concrete symbolic mode. However, only two students had both the Methods and Results outcomes in the first cycle (students 5, 18). The majority of outcomes for Results (76.4%) were in the second cycle, and two students (students 19 & 21) had results in the formal mode. The latter had a thorough analysis of the aspects of the RCC addressed by their hypotheses, with student 21 displaying multiple lines of enquiry into a dual factor relationship of variables.

Many students presented multiple aspects of the data in a scientific format and presented them graphically but failed to summarise them adequately in the body of text of the ‘results’ section. Often the body of text in the results section lacked clarity, or did not relate to the presented data (e.g., student 7, 34) or lacked demonstration of variance in their figures (e.g., students 2, 7).

Despite the variety of outcomes between cycles and modes in the preceding section, only a single student (2) had an outcome for their Discussion section in the first cycle mode. The written results for this student did not reflect the data that they had
presented and thus their conclusions misrepresented the precise nature of their results. The remainder of students had outcomes in the second cycle concrete symbolic (76%) or in the formal mode (15%).

Notably, seven students had unistructural second cycle outcomes; these students pursued a single factor throughout the whole report (e.g., students 4, 16, 24, 32). Student 14, followed a single aspect of the RCC throughout the report but followed numerous lines of enquiry in their Methods and Results, but left each ‘open ended’ in the discussion, thus was given an outcome of multiple unistructural elements.

Those students with outcomes in the formal mode revisited ecological processes and/or management issues form their introduction, and integrated these ideas with their data in the Discussion section (e.g., students 8, 11, 19). Student 21 followed a single aspect of the RCC but placed it in a context of a full understanding of ecological principles surrounding the given theoretical context. Multiple issues surrounding this factor were addressed in the Discussion including why aspects of the RCC were not met in their study and finally alternative theories, from the literature, were offered as a possible explanation.

Conspicuously, the students which followed a single factor throughout their investigation (Students 9, 15, 16, 21, & 24) worked within the same group for study design and data collection for a particular aspect of the RCC. They chose predator invertebrates as their line of investigation. Simply, the RCC states that the relative proportion of stream invertebrate predators changes along the river continuum and is indicative of the changing food resources. Although this particular hypothesis can lend its investigation to the predators alone (i.e., a single factor analysis), by which most of the students tackled the problem, student 21 extended the data set to represent other invertebrate groups. This student thus presented the collected data of the group in the broader context of the RCC, and with discussion of short falls of the theory, had outcomes for the assessment task in the formal mode.

Overall, the majority of student responses demonstrated good review of the given theory; good knowledge and application of scientific protocol, and could discuss their results in the context of the theory. Of the five students who had outcomes for their introduction in the formal mode, four also has outcomes for their discussion in the
formal mode. Once a student has grasped abstract constructs of the investigation it appears that they may be better conceptually equipped to apply personal discoveries within this cognitive framework. Comparing those students outcomes with a relational level of the second cycle concrete symbolic (11 students) with that of their outcome in the Discussion, you find that seven have the same outcome, and four remaining have a Discussion outcome at a transitional level between M2 and R2.

The single student (28) who had a lower outcome in the introduction and concluded with an R2 outcome in the Discussion had a M2 transitional outcome in the Introduction. It is possible that this student ‘wrote’ him/her self into a greater understanding during the report writing process. Similarly, all of the five students who had an outcome for their Introduction in the first cycle concrete symbolic increased their outcome to the second cycle concrete symbolic for the Discussion section.

![Figure 5.1 Distribution of SOLO categories for written responses to the full scientific report from students of ECOL202, 2008 cohort.](image-url)
Table 5.3 SOLO categories, and quantitative grades for written responses to the full scientific report from students of ECOL202, 2008 cohort.

<table>
<thead>
<tr>
<th>Student</th>
<th>Intro</th>
<th>Methods</th>
<th>Results</th>
<th>Discussion</th>
<th>GRADE</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>M2t</td>
<td>M2</td>
<td>M2 (basic)</td>
<td>M2t</td>
<td>72</td>
<td>States ideas but doesn't follow through, Non-directional Hypothesis. Poor data presentation.</td>
</tr>
<tr>
<td>2</td>
<td>M2t</td>
<td>M2</td>
<td>M1</td>
<td>U1</td>
<td>67</td>
<td>Relates study location to RCC, site differences unclear. Illogical Presentation of Results. Written results do not reflect data. Conclusion misrepresents patterns.</td>
</tr>
<tr>
<td>3</td>
<td>R2</td>
<td>R1</td>
<td>M2</td>
<td>R2</td>
<td>76</td>
<td>Methods simple, Data could be better presented. Relates results to theory &amp; anomalous data well explained.</td>
</tr>
<tr>
<td>4</td>
<td>U1</td>
<td>R1</td>
<td>U2</td>
<td>U2</td>
<td>50</td>
<td>Simple Statement of RCC, General Hypothesis. Inappropriate language in Methods, and basic data presentation. No integration of results with theory.</td>
</tr>
<tr>
<td>5</td>
<td>M2t</td>
<td>M1</td>
<td>R1</td>
<td>M2t</td>
<td>74</td>
<td>Good description of RCC but no clear Hypothesis. Lacked scientific prose in parts. Simple data representation. Integrated data and RCC but no further references.</td>
</tr>
<tr>
<td>6</td>
<td>R2</td>
<td>M2t</td>
<td>R2</td>
<td>R2</td>
<td>74</td>
<td>Good directional and relational Hypothesis. Methods not clear. Data presentation appropriate to Hypothesis.</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Score</td>
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<td></td>
</tr>
<tr>
<td>7</td>
<td>R2</td>
<td>M2</td>
<td>M2</td>
<td>M2t</td>
<td>72</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Good application of RCC and spatial scale.</td>
<td></td>
<td></td>
<td></td>
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</tr>
<tr>
<td>8</td>
<td>F</td>
<td>M1</td>
<td>R2</td>
<td>R2</td>
<td>F</td>
<td>M1</td>
</tr>
<tr>
<td></td>
<td>Explanation brings in detailed ecological processes in Introduction and Discussion.</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>9</td>
<td>M2t</td>
<td>M1</td>
<td>M2</td>
<td>U2</td>
<td>71</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Not fully integrated RCC into context. Non scientific language in parts. Data not shown in correlative manner, No variance shown or explained. Some attempt to relate to other literature.</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>10</td>
<td>M2</td>
<td>M2</td>
<td>M2t</td>
<td>M2t</td>
<td>70</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Hypothesis not well formulated. Introduction good. Details of methods lacking. No variance shown in data.</td>
<td></td>
<td></td>
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</tr>
<tr>
<td>11</td>
<td>F</td>
<td>M1</td>
<td>R2</td>
<td>R2</td>
<td>F</td>
<td>M1</td>
</tr>
<tr>
<td></td>
<td>Text brings in detailed ecological processes in Introduction and Discussion.</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>12</td>
<td>R2</td>
<td>M2</td>
<td>M2</td>
<td>M2t</td>
<td>71</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Brings in human disturbance as influencing project outcomes. Non-scientific presentation of results. Theory sound but application to results inconsistent.</td>
<td></td>
<td></td>
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<td></td>
</tr>
<tr>
<td>13</td>
<td>U1</td>
<td>M2</td>
<td>R2</td>
<td>M2t</td>
<td>68</td>
<td></td>
</tr>
<tr>
<td></td>
<td>No direct reference to RCC. List like methods despite good presentation and coverage of results. RCC brought into the discussion but data not integrated with theory.</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>14</td>
<td>F</td>
<td>M1</td>
<td>R2</td>
<td>M2</td>
<td>M2t</td>
<td>74</td>
</tr>
<tr>
<td></td>
<td>Did not link Introduction review of RCC in Discussion.</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>M2t</td>
<td>R2</td>
<td>M2</td>
<td>U2 multi</td>
<td>Score</td>
<td></td>
</tr>
<tr>
<td>---</td>
<td>-----</td>
<td>-----</td>
<td>-----</td>
<td>----------</td>
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<td></td>
</tr>
<tr>
<td>15</td>
<td>M2t</td>
<td>R2</td>
<td>M2</td>
<td>U2 multi</td>
<td>68</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>List like presentation with little integration of ideas and data. Single aspect followed through report.</td>
<td></td>
</tr>
<tr>
<td>16</td>
<td>R1</td>
<td>M2</td>
<td>R1</td>
<td>U2</td>
<td>70</td>
<td></td>
</tr>
<tr>
<td></td>
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<td></td>
<td></td>
<td>No peer-reviewed references, no explicit hypothesis. Limited data presentation. Follows only single factor.</td>
<td></td>
</tr>
<tr>
<td>17</td>
<td>R2</td>
<td>M2</td>
<td>M2</td>
<td>R2</td>
<td>70</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Good review and multi factor Hypothesis. Methods list like, and results difficult to decipher. Brought in relevant studies in Discussion.</td>
<td></td>
</tr>
<tr>
<td>18</td>
<td>M1</td>
<td>M1</td>
<td>R1</td>
<td>U2</td>
<td>53</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>No details of RCC, posed as a list of facts. Methods and data presentation simplistic. Brings in context of RCC in Discussion.</td>
<td></td>
</tr>
<tr>
<td>19</td>
<td>F</td>
<td>R1</td>
<td>R2 ++</td>
<td>M1</td>
<td>F R1</td>
<td>96</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Good review of RCC and related ecological principles and management issues. Other possible theories addressed. All factors addressed by Hypothesis. Thorough data analysis and discussion.</td>
<td></td>
</tr>
<tr>
<td>20</td>
<td>M2</td>
<td>M2</td>
<td>M2</td>
<td>M2t</td>
<td>70</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Some irrelevant material in review. Dual factors treated separately throughout.</td>
<td></td>
</tr>
<tr>
<td>21</td>
<td>F</td>
<td>M1</td>
<td>R2</td>
<td>M1</td>
<td>F U1</td>
<td>86</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Good review of RCC and related ecological principles. Other possible theories addressed. Multiple lines of single factor addressed thoroughly in Discussion.</td>
<td></td>
</tr>
<tr>
<td>22</td>
<td>M2</td>
<td>M2</td>
<td>M2</td>
<td>M2</td>
<td>72</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Dual Factor directional Hypothesis. Ideas used without definition.</td>
<td></td>
</tr>
<tr>
<td>23</td>
<td>M2t</td>
<td>M2</td>
<td>M2</td>
<td>M2</td>
<td>72</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Sound assignment structure but details are off on tangent with limited references.</td>
<td></td>
</tr>
<tr>
<td></td>
<td>R1</td>
<td>U2</td>
<td>U2 multi</td>
<td>U2</td>
<td></td>
<td></td>
</tr>
<tr>
<td>---</td>
<td>----</td>
<td>----</td>
<td>----------</td>
<td>----</td>
<td>---</td>
<td>---</td>
</tr>
<tr>
<td>24</td>
<td>R1</td>
<td>U2</td>
<td>U2 multi</td>
<td>U2</td>
<td>58</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Single line of investigation. Simple Introduction.</td>
</tr>
<tr>
<td>25</td>
<td>R2</td>
<td>M2t</td>
<td>M2</td>
<td>M2</td>
<td>65</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Good description of RCC, but language 'difficult' Too many quotes. Good Hypothesis. Scientific idea there but details lacking in Methods and Results.</td>
</tr>
<tr>
<td>26</td>
<td>R2</td>
<td>M2t</td>
<td>R2</td>
<td>R2</td>
<td>78</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Great Review with discussion of other theories. Understanding of underlying ecological processes.</td>
</tr>
<tr>
<td>27</td>
<td>R2+</td>
<td>R2</td>
<td>R2+</td>
<td>R2+</td>
<td>95</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Good review of RCC and related ecological principles. Australian relevance in context. All factors addressed by Hypothesis. Thorough analysis and discussion.</td>
</tr>
<tr>
<td>28</td>
<td>M2t</td>
<td>R2</td>
<td>M2t</td>
<td>R2</td>
<td>79</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Good review of RCC but follows only single factor throughout.</td>
</tr>
<tr>
<td>29</td>
<td>F U2</td>
<td>R2</td>
<td>U2 multi</td>
<td>F U1</td>
<td>88</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Good review of RCC and related ecological principles. Other possible theories addressed. All factors addressed but not posed as explicit hypothesis,</td>
</tr>
<tr>
<td>30</td>
<td>M2</td>
<td>M1</td>
<td>U2 multi</td>
<td>M2</td>
<td>72</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Study context lacking, and few details in Methods and Results. Few ideas posed but not integrated.</td>
</tr>
<tr>
<td>31</td>
<td>R2</td>
<td>U2</td>
<td>U2</td>
<td>R2</td>
<td>83</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Good review of RCC and Australian relevance in context. All factors addressed through general question. Basic analysis and good discussion.</td>
</tr>
<tr>
<td>Ch. 5 Results</td>
<td>States ideas but doesn't follow through, Single factor Hypothesis. Basic data presentation.</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>--------------</td>
<td>---------------------------------------------------------------------------------------------</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>32</td>
<td>U2 M2 M1 U2 67</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>33</td>
<td>R2 R2 M2t R2 85</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>34</td>
<td>R2 R2 M2t M2t 78</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Concise explanation brings in detailed ecological processes in Introduction and Discussion.</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Good review of RCC and understanding of local scale issues. Results muddled.</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Didn't make most of extensive results in interpretation.</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Integrated patterns of distribution of SOLO categories between qualitative SOLO categories and the qualitative grade

A multi-dimensional scaling (MDS) procedure was used to analyse and graphically represent the relationships between the qualitative outcomes of the students among sections of the report. The MDS figure represents the similarities/dissimilarities between objects (Kruskal & Wish, 1978), the closer the objects are in a MDS ordination space the more similar the composition of the samples (Figure 5.2). The stress value of 0.1 demonstrates that the plot represents a good configuration of the actual dissimilarities between objects (ideally 0 - 0.2). The SOLO outcomes show a gradient response from pass to HD grade on both axes of the ordination space. Due to the low number of pass graded students (3) it is difficult to determine a clear differentiation between pass and credit grades in this analysis. Again there is some overlap between credit and distinction grade student outcomes between the axes. Students with HD outcomes show a clear separation from the other groups.

Figure 5.2 MDS ordination plot of Assessment task 2: Ranked SOLO section analysis. Groupings by quantitative grade.

Following ordination, an Analysis of Similarities (ANOSIM, Clarke & Warwick, 2004) was used to quantitatively test differences between the average of all rank similarities among students and report sections, and the average of all rank similarities between students within report sections (Table 5.4). ANOSIM tests the null hypothesis that
average of rank dissimilarities between all possible pairs of students between all report sections is the same as the average rank dissimilarity between pairs of students within sections. The test statistic $R$ is scaled between +1 and -1. Positive $R$ values suggest that student outcomes are more dissimilar between report sections and for negative $R$ values the converse is true. The ANOSIM analysis (Table 5.4) demonstrated a significant discrimination between pass and credit level students, pass and distinction, and pass and HD graded students. No significant discrimination was determined between credit and distinction graded students. There was also significant discrimination between Distinction and HD students from the ranked SOLO sectional analysis.

Table 5.4 ANOSIM (Analysis of Similarities): Ranked SOLO section analysis. Groupings by quantitative grade.

<table>
<thead>
<tr>
<th>Groups</th>
<th>R Statistic</th>
<th>Significance Level</th>
<th>%</th>
</tr>
</thead>
<tbody>
<tr>
<td>HD, D</td>
<td>0.558</td>
<td>0.5</td>
<td>sig</td>
</tr>
<tr>
<td>HD, C</td>
<td>0.595</td>
<td>0.1</td>
<td>sig</td>
</tr>
<tr>
<td>HD, P</td>
<td>1.00</td>
<td>0.8</td>
<td>sig</td>
</tr>
<tr>
<td>D, C</td>
<td>0.013</td>
<td>41.9</td>
<td>ns</td>
</tr>
<tr>
<td>D, P</td>
<td>1.00</td>
<td>1.6</td>
<td>sig</td>
</tr>
<tr>
<td>C, P</td>
<td>-0.583</td>
<td>1.2</td>
<td>sig</td>
</tr>
</tbody>
</table>

Contribution of report sections to separation among student outcomes

To determine which report section contributed to the separation among student outcomes a SIMPER (Similarity Percentage, Clarke & Warwick, 1994) was performed. In this case SIMPER computes the percentage contribution of each student’s outcome to the dissimilarities between and within all pairs of sampling units within each quantitative grade unit (P, C, D, HD). The percentage contribution and its standard deviation is calculated showing which report sections best discriminate between quantitative grade unit. The test results provide a list of sections and their percentage contributions to dissimilarities between groups or similarities within groups. For the purposes of this study the percentage contribution of each report section to within grade group similarities is presented (Table 5.5).

The average similarity between outcomes for the HD, Distinction and Pass level students was $> 90.65 \%$, Credit level students were 86%, demonstrating a good
grouping between SOLO outcomes in each of these categories. In the HD category a greater contribution (27.9%) is attributed to the Introduction and Discussion sections than the Methods and Results (20.8 -23.72%). Similarly, the Distinction category showed a similar pattern with 28.9% attributed to both the Introduction and Discussion sections. Conversely, the Introduction section of the Pass category has the lowest contribution of all sections at 15.55%. This category has the greatest contribution from the Discussion section at 33% followed by the Results at (28.86%). The Credit category has an even spread of contribution of the report sections (23.16-24.86).

### Table 5.5 SIMPER (Similarity Percentages ) section contributions to SOLO outcomes between analysis of qualitative grades.

**SIMPER (Similarity Percentages - section contributions)**

**High distinction (HD), Average similarity: 91.95**

<table>
<thead>
<tr>
<th>Section</th>
<th>Intro</th>
<th>Methods</th>
<th>Results</th>
<th>Discussion</th>
</tr>
</thead>
<tbody>
<tr>
<td>Av.Rank</td>
<td>10.29</td>
<td>8.14</td>
<td>8.92</td>
<td>10.14</td>
</tr>
<tr>
<td>Av.Sim</td>
<td>25.67</td>
<td>21.81</td>
<td>19.17</td>
<td>25.67</td>
</tr>
<tr>
<td>Sim/SD</td>
<td>11.35</td>
<td>13.99</td>
<td>5.47</td>
<td>11.35</td>
</tr>
<tr>
<td>Contrib%</td>
<td><strong>27.91</strong></td>
<td><strong>23.72</strong></td>
<td><strong>20.84</strong></td>
<td><strong>27.91</strong></td>
</tr>
</tbody>
</table>

**Distinction (D), Average similarity: 91.64**

<table>
<thead>
<tr>
<th>Section</th>
<th>Intro</th>
<th>Methods</th>
<th>Results</th>
<th>Discussion</th>
</tr>
</thead>
<tbody>
<tr>
<td>Av.Rank</td>
<td>8.0</td>
<td>6.4</td>
<td>6.6</td>
<td>7.9</td>
</tr>
<tr>
<td>Av.Sim</td>
<td>26.48</td>
<td>18.25</td>
<td>20.42</td>
<td>26.48</td>
</tr>
<tr>
<td>Sim/SD</td>
<td>10.3</td>
<td>4.21</td>
<td>9.18</td>
<td>10.3</td>
</tr>
<tr>
<td>Contrib%</td>
<td><strong>28.9</strong></td>
<td><strong>19.92</strong></td>
<td><strong>22.29</strong></td>
<td><strong>28.9</strong></td>
</tr>
</tbody>
</table>

**Credit (C),Average similarity: 86.59**

<table>
<thead>
<tr>
<th>Section</th>
<th>Intro</th>
<th>Methods</th>
<th>Results</th>
<th>Discussion</th>
</tr>
</thead>
<tbody>
<tr>
<td>Av.Rank</td>
<td>6.21</td>
<td>5.84</td>
<td>5.63</td>
<td>6.21</td>
</tr>
<tr>
<td>Av.Sim</td>
<td>22.23</td>
<td>21.52</td>
<td>20.06</td>
<td>22.78</td>
</tr>
<tr>
<td>Sim/SD</td>
<td>3.17</td>
<td>3.76</td>
<td>3.98</td>
<td>4.33</td>
</tr>
<tr>
<td>Contrib%</td>
<td><strong>25.68</strong></td>
<td><strong>24.86</strong></td>
<td><strong>23.16</strong></td>
<td><strong>26.31</strong></td>
</tr>
</tbody>
</table>

**Pass (P),Average similarity: 90.0**

<table>
<thead>
<tr>
<th>Section</th>
<th>Intro</th>
<th>Methods</th>
<th>Results</th>
<th>Discussion</th>
</tr>
</thead>
<tbody>
<tr>
<td>Av.Abund</td>
<td>3.00</td>
<td>4.00</td>
<td>4.67</td>
<td>5.00</td>
</tr>
<tr>
<td>Av.Sim</td>
<td>13.99</td>
<td>19.95</td>
<td>25.97</td>
<td>30.08</td>
</tr>
<tr>
<td>Sim/SD</td>
<td>4.31</td>
<td>7.51</td>
<td>10.29</td>
<td>15.57</td>
</tr>
<tr>
<td>Contrib%</td>
<td><strong>15.55</strong></td>
<td><strong>22.17</strong></td>
<td><strong>28.86</strong></td>
<td><strong>33.42</strong></td>
</tr>
</tbody>
</table>
Overview and Discussion

This chapter has outlined the results for developing and applying a protocol for marking scientific written assessments using a cognitive structural perspective provided by SOLO (Biggs & Collis, 1991). An analytical framework within the cognitive structural model was used and compared with qualitative grades to determine for effective alignment of assessment by written assignments. The measure of outcome used was written responses to an investigation of an ecological process to be presented in a scientific report format. The students were required to formulate appropriate hypotheses from a given theoretical framework and devise methods for testing their scenario in a field situation. Results were to be presented in a standard scientific manner and the Discussion was to evaluate their results within the given theoretical framework.

A subsample of the 2007 cohort was used to design a pilot framework by which to qualitatively assess the similar assessment task for the following years’ students. The student reports were written and hence analysed in four sections; Introduction, Methods, Results and Discussion. From three categories the SOLO framework was used to place the two categories in two-cycles of the concrete symbolic mode due to separation on structural complexity of scientific expression, and one category showed extended abstract cognition so was placed in the formal mode. The pilot assessments were effectively further analysed, for SOLO levels (U, M and R) within each cycle and mode.

The SOLO framework from the pilot cohort was then tested on the following year’s student written outcomes for the same task. The distribution of the SOLO outcomes of the students among sections of the report demonstrated that the majority of responses were in the second cycle concrete symbolic mode for all report sections. Outcomes from the Introduction ranged at a Relational hierarchical level from first cycle concrete symbolic, relational to formal level responses. Methods were constrained within first and second cycles of the concrete symbolic mode, as the uses of specified, standard scientific practices were part of the outcomes for the task.

The majority of Results outcomes were in the concrete symbolic mode with a single student displaying outcome in the Formal mode, as they extended the expected specified, standard scientific presentation by using statistical analyses not essential to
the assessment task. Discussion outcomes were presented at all levels of the second cycle concrete symbolic and formal modes.

Multiple dimensional scaling techniques were used to determine the relationship between qualitative SOLO categories and the quantitative grade the students were given for their unit assessment. There was no significant discrimination between credit and distinction level students by the current SOLO analysis, but significant discrimination between all other quantitative groupings.

Finally, the report section which contributed to the separation among student outcomes was determined. The grouping of the HD and Distinction level students was dominated by the contribution of Introduction and Discussion sections, while the Credit category had an even spread of SOLO outcomes among sections. The HD and D level students with Formal mode outcomes were consistent for both Introduction and Discussion sections. Similar to findings from Chapter 4, the HD outcome grouping showed a high level of group integrity. This is a clear cut achievement of top level expectations of all task objectives, where consistency throughout a whole assignment would be expected. In contrast the Pass level student’s outcomes were dominated by the Results and Discussion sections, with the Introduction contributing only 15%. There were only three Pass level students, and this limited sample size may have contributed to this outcome.

All students with Introduction, Methods and Results outcomes in the first cycle concrete symbolic mode had outcomes for their Discussion in the second cycle concrete symbolic mode. It is thus reasoned that the abstract nature (mode) of understanding a theoretical framework is maintained throughout such a discovery based investigation. In contrast it is proposed that within a mode (i.e., concrete symbolic mode) the cycle level is likely to increase with a discovery based learning activity. To test this, student theoretical understanding would need to be evaluated before they completed their practical field component and again after completion of the report.

In summary, the results presented in this chapter provide a theoretically grounded description of a hierarchy of levels for responses to the scientific report presentation of testing and contesting a given of ecological theory of river function. The results of analyses of the learning outcomes suggest that the majority of students could present a
scientifically written review, formulate testable questions and design and carry out robust replicable studies in a scientific framework. All students within this cohort could synthesise their results in the given ecological framework, and some students demonstrated greater abstract cognition and application by presenting ideas beyond those directly instructed for the task.

Although this extended assessment task was analysed as separate sections, the qualitative framework blended both positivist and interpretivist approaches to assessment. The lucidity and trail of presented evidence leading to the student outcomes of each section, however, were not independent. For example, the clarity of Methods was dependent on the Hypothesis formulation and justification from the Introduction; the Results were presented with clarity and interpreted astutely when aligned with the Methods; and overall, the Discussion related the previous three sections together. Multiple outcomes were expected from the assessment task and this may be better tackled to give a holistic integrated impression of a student’s work. The process of investigating a logical scientific argument may itself have provided some students with a better understanding of the ecological theory, on completion of the task, than from reviewing the topic in isolation.

To benefit learning of complex issues, which involve critical and abstract thinking, incorporating outcomes which encompass an understanding of empirical and interpretive knowledge may be of value in such diverse conceptual disciplines as ecology. Consequently, the next chapter investigates the application of the SOLO model as the basis for a framework for a holistic analysis of student outcomes.
Chapter 6: Results Part 3

A study of Holistic SOLO categorisation of a full scientific report assignment

Introduction

The qualitative marking framework outlined in the previous two chapters offered a protocol for marking scientific written assessments using a cognitive structural perspective for scientific reports provided by SOLO (Biggs & Collis, 1991). In these chapters an analytical framework was tested with each section of each report given independent outcomes. The lucidity and trail of evidence from Chapter 5, leading to the student outcomes of each section, however, were not independent. Multiple outcomes were expected from the assessment task and may be better tackled to give a holistic integrated impression of students’ work. To benefit learning of complex issues, which involve critical and abstract thinking, incorporating outcomes which encompass an understanding of empirical and interpretive knowledge may be of value in such diverse conceptual disciplines as ecology. This chapter investigates Research Theme 2, the application of the SOLO model as the basis for a framework for a holistic analysis of student outcomes.

Both an analytical/deterministic and holistic/communicative approach to the learning and assessment of the scientific inquiry is proposed in this chapter. A framework which incorporates 3 themes as a starting point is proposed: Theoretical, Practical and Functional. The theoretical concurs with the theoretical domain of Yager and McCormack (1989) and contains instrumental knowledge. The Practical theme concurs with the processes of the science domain of Yager and McCormack (1989), but also incorporate ideas of their creativity domain. This theme encompasses scientific research methodology and integrates possibilities for new exploratory procedures. The Functional theme incorporates ideas from both the Attitudinal and Application and
Connections Domains of Yager and McCormack (1989). An awareness of environmental issues for appropriate for management of requires respect for persons, biota and physical environs from different perspectives to provide balanced multifaceted debate for the moral application of scientific outcomes. The latter is an implicit goal for report writing for students in Environmental Science and Natural Resource management courses.

The following specific research questions are addressed for this scientific report.

1. To formulate a holistic qualitative framework for categories of written response to a scientific report structured question that corresponds to the SOLO model?
2. To determine the distribution of holistic SOLO categories across a cohort of ecology students.
3. Do demonstrate if the holistic SOLO categories correlate with the actual quantitative grade given to the students?
4. To consider issues of reliability and validity of such an holistic framework.

The results for a holistic qualitative framework of written response to a scientific report will again be presented from a pilot study from the 2007 cohort of students from Marine and Freshwater Ecology 202. The results for question 1 are a qualitative analysis of 12 written responses to an assessment item, The River Continuum Concept and interpreted in terms of a two cycle SOLO model. Subsequently, the SOLO schedule developed from the pilot group will be used to qualify students’ responses from a larger cohort of students enrolled in the equivalent unit in 2008 to cover questions 2 to 4.

**Pilot Study 2007. Student written responses to River Continuum Concept full-report.**

This section presents the results of student written responses to an assessment item with the aim of exploring a fundamental ecological process by students during the intensive school (off-campus students) and practical classes (on-campus students). The students were asked to investigate the input, movement and breakdown of various forms of organic matter – in several contrasting ecosystems. Student objectives were to work in
groups to develop hypotheses, methods and gather data during a 2-day field trip to test one prediction of a established river model ‘The River Continuum Hypothesis’ of Vannote et al. (1980). Individual assignments presenting the group data were submitted as a project report in standard scientific paper format (i.e., with 4 sections, Introduction, Methods, Results, Discussion).

Twelve assignments were systematically analysed to gain a general picture of the qualitative elements required of the students to execute the task. A holistic approach to assessment melds aspects of the forms of knowledge expected as outcomes from the assessment task. The reasoning for the first phase of categorisation for the reports as a whole is outlined below.

Three interelated elements are incorporated into the first phase of categorisation.

- A **Theoretical understanding** – integrating ecological theory into the context of the report
- A **Functional understanding** of scientific method and aspects of the discipline through hypothesis formulation and
- A **Practical understanding** of the scientific method though application in an ecological context.

**Categories of response**

The final format exhibited the different groups of like responses within 3 categories. The following two were revealed from the presented assignments (Categories X and Y),

**CATEGORY X**

Outcomes utilise a scientific writing style, appropriate scientific citations and use of standard scientific methodologies. A logical testable hypothesis is developed with a mechanism to explain causal change. Methodology addresses issues of appropriate scientific sampling. The logical progression addresses issues of appropriate scientific data presentation and basic statistical data summaries (i.e., means, variance, correlation analysis). The discussion is written in a scientific context. The River Continuum Concept (RCC) is discussed in relation to the data set presented in the results. In the conclusion, a statement refuting or supporting the original hypothesis is made. Appropriate reference to the original source of the theory is made (Vannote et al., 1980), and the summary is written in a scientific style. Overall an ecological and scientific context is presented and the report demonstrates consistency and/or validity in logical argument, protocol, and data analysis.
**CATEGORY Y**

An understanding in this category is characterised by the use of relevant theoretical knowledge which is established in the Introduction and through a synthesis rather than a summary in the Discussion. The outcomes here, illustrate deductive interpretation of the review from use of ecological theory and approaches to scientific methodology. The hypothesis integrates ecological principles and/or theory from the review. Methodology addresses issues of appropriate scientific sampling. The logical progression addresses issues of appropriate scientific data presentation and basic statistical data summaries. Functionally, the report investigates aspects of the test system that may cause variation from the given (RCC) model. This category illustrates deductive interpretation of the results which are synthesised in the framework of ecological theory and approaches to scientific methodology. Aspects of the theory under investigation are considered as processes in themselves. The relationships between biotic, physical, and chemical processes are made explicit by investigation and discussion in a logical manner. There is a critique of context (temporal, spatial, methodological) specific variables which affected the results.

Those holistic outcomes by undergraduate students in the pilot study fell into two categories of sophistication. Category X fell into the concrete symbolic mode, and Y in the formal mode. The key focus between these categories was on the level of abstraction between categories B and C. To align with the previous argument for a two-learning cycle per mode version of SOLO (Chapters 4 and 5), Category W is suggested as an outcome structure to represent the first cycle in a structural hierarchy representative of the concrete symbolic mode, for which Category X, above, is representative of the second cycle concrete symbolic mode.

**CATEGORY W**

Outcomes are written from a common sense point of view, with limited use of scientific language. A logical testable hypothesis is developed though simplistic use of scientific methodology. Often common sense measurements are suggested and the data are presented in a simplistic way through either tabular form or inappropriate graphs. However, the data are consistent with methods and thus the prediction from the hypothesis. Despite a logical progression of argument throughout the report, the conclusion and discussion are a summary of the report to date, and no attempt is made to relate findings to the theory in question or other relevant studies. Overall an ecological and scientific context is lacking and the report is deficient in either consistency and/or validity in logical argument, protocol, and data analysis.
The written presentation of a theoretical understanding throughout the report would classify a student response in the *concrete symbolic* versus the *formal* mode. This may be expressed within the Introduction section but may not be explicit by a systematic analysis of other sections of the report in isolation. From a holistic perspective, the SOLO Levels are key to determining logical progression of argument between sections of the report. Here inconsistencies in reasoning may be revealed more effectively than from sectional analysis alone. Any reoccurring deficiencies in student approach in tackling the three aspects of knowledge can be then used as a tool for strengthening teaching approach in these areas for the remainder of semester for the current students, and for future cohorts.

A qualitative assessment at an holistic scale is suggested whereby the division of modes above are analysed further as potential SOLO levels; unistructural (U), multistructural (M) and relational(R).

**First Cycle Concrete Symbolic**

**U1**
- Unistructural elements presented without logical relationships between the elements across the report as a whole. Many inconsistencies and non-scientific language.

**M1**
- Description of aspects of the RCC.
- Formulation of a logical hypothesis from the introductory review.
- Methods are logical but Results not presented in a scientific format.
- No flow between aspects of the report.

**M1 transitional**
- Some consistency shown between introduction, hypothesis and methodology but not fully integrated in a logical fashion.

**R1**
- The Introduction, Methods, Results and Discussion are logically connected
- Reasoning for Methods is explicit, and Results relate to Methods.
- Non-scientific language.
- Non-appropriate citations and referencing.
Second Cycle Concrete Symbolic

U2
- Unistructural elements presented without logical relationships between the elements across the report as a whole. Use of scientific citations and scientific language.

M2
- Multiple logical elements shown throughout the review, hypothesis formulation and Methods.
- The hypothesis is testable and use of elements of scientific methods.
- Results are consistent with methods.
- Discussion is a summary of the results with limited synthesis.
- Use of scientific citations and scientific language.

M2 transitional
- Aspects of causality expressed between independent sections (ie, introduction to hypothesis, or hypothesis to methods,) however, the logical progression is not consistent across the whole report.

R2
- There is a logical progression within and between sections of the report. This may be presented as an understanding of multiple aspects and relationships between elements of the RCC.
- Key results are summarised and related to the bigger picture (RCC). Through a synthesis of the literature with use of appropriate scientific citations.
- A functional understanding of scientific method and aspects of the discipline through appropriate hypothesis formulation, and the logical progression of testing through a practical understanding of the scientific method appropriately executed in the context of the study.

Formal

U1
- The formal mode illustrates deductive interpretation of the results which are synthesised in an ecological framework.
- Single aspects of the theory under investigation are considered as processes in themselves and may be the focus of testable hypotheses.
- There is examination of context (temporal, spatial, methodological) specific variables which affected the results.
M1

- Multiple logical elements shown throughout the review, hypothesis formulation and Methods.
- A number of processes are investigated through multiple testable hypotheses.
- There is partial examination of context (temporal, spatial, methodological) specific variables which affected the results.

R1

- Multiple logical elements are related throughout the review, hypothesis formulation and Methods.
- A number of processes are integrated into the theoretical framework and investigated through multiple testable hypotheses.
- There is extensive examination of context (temporal, spatial, methodological) specific variables which affected the results.

<table>
<thead>
<tr>
<th>Student</th>
<th>Holistic Outcome</th>
<th>Quantitative Grade %</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>R1 (F)</td>
<td>HD</td>
</tr>
<tr>
<td>2</td>
<td>M1(F)</td>
<td>D</td>
</tr>
<tr>
<td>3</td>
<td>R2 t (CS)</td>
<td>C</td>
</tr>
<tr>
<td>4</td>
<td>M1 (F)</td>
<td>D</td>
</tr>
<tr>
<td>5</td>
<td>M1 (F)</td>
<td>C</td>
</tr>
<tr>
<td>6</td>
<td>M2 (CS)</td>
<td>C</td>
</tr>
<tr>
<td>7</td>
<td>M2t (CS)</td>
<td>C</td>
</tr>
<tr>
<td>8</td>
<td>R1 (F)</td>
<td>HD</td>
</tr>
<tr>
<td>9</td>
<td>R2 (CS)</td>
<td>D (75%)</td>
</tr>
<tr>
<td>10</td>
<td>R2 (CS)</td>
<td>D (75%)</td>
</tr>
<tr>
<td>11</td>
<td>U1 (F)</td>
<td>D</td>
</tr>
<tr>
<td>12</td>
<td>M1(F)</td>
<td>D</td>
</tr>
</tbody>
</table>

A summary of student responses is presented in Table 6.1, showing the SOLO mode and level attained for the overall report and associated quantitative grade they were given by the subject coordinator as their score towards the unit evaluation. Those who received a HD grade consistently got the highest qualitative outcome (R1 formal). Four of the six students graded a D, demonstrated outcomes in the formal mode, and two in the R2 concrete symbolic mode. The latter students were graded between 75 – 80%. These two students could integrate some but not all theoretical aspects of the study. Those who gained a C grade had holistic outcomes in the second cycle of the concrete
symbolic mode. These students could work within a scientific framework but not extend past the explicit theoretical framework given by direct instruction. Due to the small sample size for this pilot study there were no students with lower quantitative grades at a pass or fail level, or the envisaged comparable qualitative outcomes across all levels of the concrete symbolic cycles. Sample bias may have been caused by only confident students offering their assessment tasks for this study.

Similar to outcomes from the sectional analysis (Chapters 4 and 5), numbers are too low to statistically relate quantitative grades and qualitative outcomes in the pilot study. Again there is a related hierarchical trend between SOLO model and cyclical elements. This final coding scheme for each assessment task was used to mark the 2008 cohort of students.

Patterns and distributions of SOLO categories for a holistic analysis

This section describes the distribution of SOLO categories for written responses to the full scientific report from students of ECOL202 Marine and Freshwater Ecology, 2008 cohort with the same aim as part 6.1.

Distribution of holistic SOLO outcomes

Thirty-four out of 41 enrolments volunteered assignments that were holistically analysed using the SOLO framework devised form the 2007 pilot cohort above. Inter-marker reliability was for 30% of reports between the researcher and a specialist familiar with the study context. Where inconsistencies arose in the present study between the pilot study categories and the 2008 cohort, discussions with an authority on SOLO were achieved until inter-subjective problems were resolved. For the 2008 cohort, the two sets of codes were compared by Spearman Rank Correlation for each section of the assessment task ($R > 0.94$, median $= 0.7$).
The questions addressed for inquiry were

- To analyse and graphically represent the distribution of the holistic qualitative SOLO outcomes of the students.
- To examine the relationship between qualitative SOLO categories and the qualitative grade the students were given for their unit assessment.

The distribution of SOLO categories for written responses to the full scientific report is presented in Table 6.2 and summarised in Figure 6.1.

![Figure 6.1 Distribution of proportion of SOLO categories for holistic responses to the full scientific report from students of ECOL202, 2008 cohort.](image)

Only a single student demonstrated a holistic outcome in the first cycle concrete symbolic mode (student 34, table 6.2. The majority of students (77%) had outcomes in the second cycle concrete symbolic mode. The remaining 22% had a formal mode outcome. The student with outcomes in the first cycle concrete symbolic mode restated the given theory, with no expression of understanding within a broader scientific context or the framework of their study. The study included a basic investigation of two concepts but there was no conception of their integration in a scientific sense. The data and study concepts were not integrated in the Discussion.
Those students with a unistructural level response in the 2nd cycle followed a single factor throughout the report (e.g., students 25, 26). These students attempted scientific methods and often did not use the data they collected to its full potential (e.g., 19). Students 2 and 31 are of note as they displayed a multiple factor unistructural outcome. They displayed a sound scientific context for their study but despite collecting and displaying extra data from that expected of their hypothesis, their analysis failed to explain its relevance in the study context.

Of those students with a multistructural outcome in the 2nd cycle, half were at a transitional level. These students integrated two or more issues in their hypothesis but did not relate the significance of the concepts through their data presentation of discussion. A multistructural outcome was often indicative of inappropriate or incomplete data set presentation (see students 11, 12, 32 & 33.). Those students with a transitional outcome (e.g., students 6, 7) had sound Introductions and Methods which corresponded well with the Hypotheses, but results which were not integrated well to the logic of the overall design (e.g., students 6, 7, & 15). Student 16 had inconsistencies throughout the whole report, although the general logic was adequate; student 17 showed great promise in his/her review, bringing in alternative theories, but did not follow this up in the Discussion, or relate to their results. Relational responses in the second cycle demonstrated understanding of underlying ecological processes with a sound discussion of the Australian context (e.g., student 5), scientific methodology and results presented in this category were sound and logically related to the report argument as a whole. Student 9’s outcomes were also of note as it was the best rigorous scientific study of the cohort. This student showed full and relational coverage of all multiple factors outlined in their hypothesis and displayed a thorough analysis thorough appropriate statistical methods. This report did not extend discussion into other theoretical possibilities to back their results, thus confining it in the concrete symbolic mode.

Formal mode outcomes ranged from unistructural (e.g., students 22, 29) to relational (e.g., student 8). These students explained physical features related to RCC in context of their study and related their data to other studies. Those at the unistructural level displayed full coverage of all multiple issues within a single factor hypothesis (students 22, 20). Those at a mutistructural level display clear argument against the applicability
of the RCC to the Australian context through investigation of multiple factors and spatial scales (i.e., along a river (students 1, 4). Multiple level outcomes were lengthy in discussion and could have been condensed for clarity of their argument. The single student who displayed a relational level formal outcome (student 8), showed full understanding of all processes related to the RCC and other possible theories, and argued their significance with the results. Their study displayed explicit methods, all multiple factors with correlations, and argued through appropriate scientific and statistical analysis.
Table 6.2 SOLO categories and quantitative grades for holistic responses to the full scientific report from students of ECOL202, 2008 cohort.

<table>
<thead>
<tr>
<th>Student</th>
<th>HOLISTIC outcome</th>
<th>Theoretical</th>
<th>Functional</th>
<th>Practical</th>
<th>Quantitative Grade</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>F M1</td>
<td>Fully explained scale. Physical features related to RCC in context of study. Data related well to other studies. A few irrelevant details and lengthy.</td>
<td>Clear multiple relational Hypothesis.</td>
<td>Correlation analysis in Results.</td>
<td>HD</td>
</tr>
<tr>
<td>2</td>
<td>U2 multi</td>
<td>Sound scientific basis.</td>
<td>Single factor investigation.</td>
<td>Basic, confined to single factor investigation.</td>
<td>D</td>
</tr>
<tr>
<td>3</td>
<td>M2t</td>
<td>Good understanding of RCC and related processes.</td>
<td>Multiple lines of investigation carried throughout.</td>
<td>Lacking details.</td>
<td>C</td>
</tr>
<tr>
<td>4</td>
<td>F M1</td>
<td>Context is conceptual challenges to the RCC. Full analysis, comparison with literature attempted.</td>
<td>Clear logic from theory to Hypothesis.</td>
<td>Sound and scientific, could have been condensed.</td>
<td>D</td>
</tr>
<tr>
<td>5</td>
<td>R2</td>
<td>Discussion of other theories and demonstrated understanding of underlying ecological processes. Good discussion of the Australian context.</td>
<td>Sound scientific method but some inconsistencies between Methods and Results.</td>
<td>Sound and scientific. Figures backed by statistics.</td>
<td>D</td>
</tr>
<tr>
<td>6</td>
<td>M2t</td>
<td>Sound but not extended.</td>
<td>Good logical hypothesis for context.</td>
<td>Method description and results presentation need work.</td>
<td>C</td>
</tr>
<tr>
<td>7</td>
<td>M2t</td>
<td>Sound</td>
<td>Dual issues with directional Hypothesis, followed up through Methods.</td>
<td>Results not well integrated into logic of design and context</td>
<td>C</td>
</tr>
<tr>
<td>8</td>
<td>F R1</td>
<td>Thorough understanding of RCC, ecology and other possible theories integrated with results.</td>
<td>Full coverage of all multiple factors with correlations.</td>
<td>Concise and explicit methods. Thorough scientific and statistical analysis.</td>
<td>HD</td>
</tr>
<tr>
<td>9</td>
<td>R2</td>
<td>The best rigorous scientific study. Data well backed by local references but doesn’t extend into other theories.</td>
<td>Full coverage of all multiple factors with correlations integrated through text.</td>
<td>Concise and explicit methods. Thorough scientific and statistical analysis.</td>
<td>HD</td>
</tr>
<tr>
<td>10</td>
<td>M2</td>
<td>Relevant material but no direct reference to RCC.</td>
<td>No specific Hypothesis but dual line of investigated followed through report.</td>
<td>Simplistic methods hard to reconcile with limited Review, although well presented results.</td>
<td>C</td>
</tr>
<tr>
<td>11</td>
<td>M2</td>
<td>Sound but not extended.</td>
<td>Application not extensive - two factors but no correlation attempted.</td>
<td>Multiple factors not integrated. Scientific style patchy</td>
<td>C</td>
</tr>
<tr>
<td>12</td>
<td>M2</td>
<td>Attempt to relate RCC to results but some inaccurate language.</td>
<td>Covers ideas but no integration between dual factors.</td>
<td>Basic scientific description of methods and data presentation lacking.</td>
<td>C</td>
</tr>
<tr>
<td>13</td>
<td>U2</td>
<td>Simple understanding presented.</td>
<td>Single factor followed throughout.</td>
<td>Basic expression although indicates problems with methods.</td>
<td>C</td>
</tr>
<tr>
<td>14</td>
<td>multi U2</td>
<td>Sound but not extended.</td>
<td>One aspect investigated and discussed in relation to RCC.</td>
<td>Good application of single factor investigation.</td>
<td>C</td>
</tr>
<tr>
<td>15</td>
<td>M2t</td>
<td>Sound.</td>
<td>Good multiple hypotheses linked within and between sections.</td>
<td>Field work sound, problem in presentation and interpretation.</td>
<td>D</td>
</tr>
<tr>
<td>16</td>
<td>M2t</td>
<td>Inconsistent.</td>
<td>Key results not related to bigger picture.</td>
<td>Sound method/poor presentation.</td>
<td>C</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>---</td>
<td>---</td>
<td>---</td>
<td>---</td>
<td></td>
<td></td>
</tr>
<tr>
<td>17</td>
<td>M2t</td>
<td>Great review including other related theories.</td>
<td>Hypothesis not explicitly tested, but dual factors logically followed through into results. Review not used to back up results.</td>
<td>Simplistic presentation of data. Some statistics.</td>
<td></td>
</tr>
<tr>
<td>19</td>
<td>U2</td>
<td>Simple reiteration of RCC.</td>
<td>General Hypothesis, single line of investigation.</td>
<td>Poor method description and results presentation.</td>
<td></td>
</tr>
<tr>
<td>20</td>
<td>R2</td>
<td>Integrates results with RCC and mentions other theories, but not integrated well.</td>
<td>Single line of investigation without bringing in other ecological factors.</td>
<td>Methods sound, results good and include additional factors.</td>
<td></td>
</tr>
<tr>
<td>21</td>
<td>M2</td>
<td>Data related just to RCC no other refs.</td>
<td>Dual line of argument followed through but poor links b/w sections.</td>
<td>Details lacking in Methods. Difficulty interpreting graphs and results not interpreted well in text. Used ANOVA without understanding outcome.</td>
<td></td>
</tr>
<tr>
<td>22</td>
<td>F U1</td>
<td>Thorough understanding of RCC, ecology and other possible theories integrated with results.</td>
<td>Full coverage of all multiple issues within a single factor.</td>
<td>Concise and explicit methods. Thorough scientific and statistical analysis related to Hypothesis.</td>
<td></td>
</tr>
<tr>
<td>23</td>
<td>M2t</td>
<td>Sound but not extended.</td>
<td>Poor links between sections.</td>
<td>Poor method description and results presentation.</td>
<td></td>
</tr>
<tr>
<td>24</td>
<td>M2t</td>
<td>Good understanding but didn't take discussion further than RCC.</td>
<td>Good multi faceted and directional hypotheses.</td>
<td>Poor method description and results presentation.</td>
<td></td>
</tr>
<tr>
<td>25</td>
<td>U2</td>
<td>Poor review limited references in discussion.</td>
<td>Logical single factor investigation followed through.</td>
<td>Basic scientific study poor data presentation.</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>---</td>
<td>---</td>
<td>---</td>
<td>---</td>
<td></td>
<td></td>
</tr>
<tr>
<td>26</td>
<td><em>U2</em></td>
<td>One aspect of the RCC discussed and studied.</td>
<td>Single theme followed through report.</td>
<td>Methods simplistic and data not used to full potential.</td>
<td>C</td>
</tr>
<tr>
<td>27</td>
<td><em>R2+</em></td>
<td>Good RCC and mentions other theories but not elaborated fully in context.</td>
<td>Good logical hypothesis formation.</td>
<td>Data presentation and analysis thorough and logical.</td>
<td>C</td>
</tr>
<tr>
<td>28</td>
<td><em>U2</em></td>
<td>Basic review. Use of RCC unclear.</td>
<td>Single factor investigation.</td>
<td>Some scientific presentation.</td>
<td>P</td>
</tr>
<tr>
<td>29</td>
<td><em>F U1</em></td>
<td>Displays perception of alternatives to RCC from onset as context for study.</td>
<td>Single line of investigation but context of scientific study sound.</td>
<td>Single factor investigation limits results.</td>
<td>HD</td>
</tr>
<tr>
<td>30</td>
<td><em>R2</em></td>
<td>Data related well to RCC and good selection of local references.</td>
<td>Dual issues integrated by directional hypotheses. Hypotheses followed up in investigation.</td>
<td>Sound and scientific. Figures backed by statistics.</td>
<td>HD</td>
</tr>
<tr>
<td>31</td>
<td><em>U2 multi</em></td>
<td>Patchy review in extending the RCC but does acknowledge problems with the theory.</td>
<td>Single factor investigation could be extended. Not a cohesive report</td>
<td>Not expressed well. Single factor investigation.</td>
<td>C</td>
</tr>
<tr>
<td>32</td>
<td><em>M2</em></td>
<td>Sound but not extended.</td>
<td>Dual issues integrated by directional hypotheses. Followed up in investigation.</td>
<td>Methods sound but presented as a list. Inappropriate data presentation.</td>
<td>C</td>
</tr>
<tr>
<td>33</td>
<td><em>M2</em></td>
<td>Sound with limited extra references.</td>
<td>Dual issues integrated by directional hypotheses. Followed through in investigation.</td>
<td>Data not summarised in results</td>
<td>C</td>
</tr>
<tr>
<td>34</td>
<td><em>R1</em></td>
<td>References reiterated rather than integrated in Discussion.</td>
<td>Simple dual concept investigation.</td>
<td>Very basic.</td>
<td>P</td>
</tr>
</tbody>
</table>
Integrated patterns of distribution of holistic SOLO categories and the qualitative grade

A spearman rank correlation was performed on the distribution of qualitative grades across SOLO categories to testing the validity of this model against the graded outcomes of the students. Holistic outcomes through SOLO analysis showed strong correlation with the quantitative grade allocated for assessment (Spearman $r = 0.89$, Figure 6.2). These data are corroborated by a multi-dimensional scaling (MDS) procedure from the previous chapter which analysed and graphically represents the relationships between the qualitative and quantitative outcomes of the students (Figure 6.2). The SOLO outcomes show a gradient response from pass to HD grade on both axes of the ordination space.

Figure 6.2 Correlation of SOLO Ranks from Chapter 3 and quantitative grade.
A non-metric multi dimensional scaling (MDS) procedure was used to represent the relationships between the holistic outcomes of the model and that from the sections of the report. The learning outcome for each student is represented on the plot, and the relationship between the objects represents their underlying dissimilarity between all 34 students. The validity of the holistic assessment was corroborated with the sectional analysis by an MDS ordination analysis (Figure 6.3). Each independent point represents each student outcomes condensed over the 4 report sections, with groupings (1-3) from holistic analysis overlaid on top. There is clear separation between holistic outcomes between cycles of the concrete symbolic mode and between the concrete symbolic and formal modes (Figure 6.3). The ANOSIM analysis demonstrated that there is a significant difference between the three groupings (P > 0.001, Table 6.3). Unfortunately a SIMPER analysis to obtain relative proportion of report section contributing to each group could not be performed due to low replication.

![MDS Plot of Holistic SOLO data for Assessment task 2 (full scientific report).](image)

1 = CS 1\textsuperscript{st} Cycle, 2 = CS 2\textsuperscript{nd} cycle, 3 = Formal 1\textsuperscript{st} cycle. Each independent point represents each student condensed over the 4 report sections, with groupings (1-3) from holistic analysis overlaid.
Table 6.3 ANOSIM (Analysis of Similarities): Ranked SOLO holistic analysis. Groupings by quantitative grade. CS 1st = 1, CS 2nd = 2, F 1st = 3

Sample statistic (Global $R$): 0.523
Significance level of sample statistic: 0.1% significant

<table>
<thead>
<tr>
<th>Groups</th>
<th>Statistic $R$</th>
<th>Significance %</th>
</tr>
</thead>
<tbody>
<tr>
<td>3, 2</td>
<td>0.424</td>
<td>0.2 sig</td>
</tr>
<tr>
<td>3, 1</td>
<td>0.968</td>
<td>2.2 sig</td>
</tr>
<tr>
<td>2, 1</td>
<td>0.774</td>
<td>0.3 sig</td>
</tr>
</tbody>
</table>

Overview and Discussion

This chapter has outlined the results from the development of a protocol for marking scientific written assessments using a cognitive structural perspective provided by SOLO (Biggs & Collis, 1991). A holistic framework within the cognitive structural model was used and compared with qualitative grades to determine effective alignment of assessment by written assignments. The measure of outcome used was written responses to an investigation of an ecological process presented in a scientific report format.

A subsample of the 2007 cohort was used to design a pilot framework by which to qualitatively assess the similar assessment task for the following years’ students. The student reports were analysed in a holistic manner using three interrelated elements for categorisation: Theoretical, Functional and a Practical understanding. From three categories, the SOLO framework was used to place the two categories in two-cycles of the concrete symbolic mode due to separation on structural complexity of scientific expression, and one category showed extended abstract cognition so was placed in the formal mode. The pilot assessments were effectively further analysed, for SOLO levels (U, M and R) within each cycle and mode.

The SOLO framework from the pilot cohort was then tested on student written outcomes for the same task the following year. The distribution of the SOLO outcomes for the students among sections of the report demonstrated that the majority of responses were in the second cycle concrete symbolic mode. A correlation technique was used to determine the relationship between qualitative SOLO categories and the
qualitative grade the students were given for their unit assessment. This displayed a high positive relationship between ranked qualitative categories and quantitative grade. Multiple dimensional scaling techniques were used to determine the relationship between sectional and holistic SOLO categories. There was a significant and clear separation between holistic outcomes between cycles of the concrete symbolic mode, and between the concrete symbolic and formal modes. The categorisation was consistent across two judges and the holistic model validity was supported by strong correlations with independently assigned quantitative marks for the student outcomes. The strength of a holistic approach is that it integrates all aspects of validity within the single model. Whereas the content validity is definitive in the sectional approach, construct and criterion related issues are strengthened by the holistic approach. The content is covered in both the theoretical and practical understanding whereby application of set information is assessed.

A major part of the assessment task under investigation was to uncover a measure of an individual’s reasoning process (i.e., construct validity). Further, construct application of the scientific process and a scientific writing style was required from the task. Creativity through experimental design was valued as an outcome and attitudes to the geographical significance of the given theoretical framework were issues targeted by the task. These constructs of reasoning, creativity and attitudes are all facets of the functional understanding integrated in the holistic SOLO framework.

Finally, the task was criterion referenced by being directly related to practices in the field of environmental science and management. The students were expected to take their results from a local geographical context and relate to the broader spatial context of the given theoretical structure and interpret its validity in a broader Australian context. All three aspects of the holistic SOLO framework addressed this. Only students with a formal mode outcome would have scores that reflect an integrated performance adequate for successful application in a broader context (i.e., through the examination of temporal, spatial, or methodological variables which affected the results).

Management application is also framework by which construct validity can be assessed. As a study in application of a scientific theory, management issues were not implicit for the outcomes of this assessment task, although were acknowledged by some students.
To further evaluate the student outcomes by adding a management criterion may require a third cycle to be integrated into the SOLO model. This issue is investigated in the final chapter.

This chapter has established a hierarchy of qualitatively different student understandings using holistic criteria. It has supported the criterion and between construct validity of the two-cycle per mode version of SOLO. This concurs with two comparable investigations both from a tertiary science context (Panizzon, 1999, 2003; Quinn, 2006) in supporting the validity of the model. The initial modal categorisations were time consuming but once fundamental characteristics were uncovered the next stage of defining structural levels was straightforward, and further analysis of student outcomes was more rapidly accomplished.

The following and final chapter evaluates the sectional and holistic approaches and discusses their application for development of future assessment tasks, planning teaching outcomes and teaching methods for complex multi-faceted learning contexts especially in the sciences.
Chapter 7: Discussion and Conclusion

Introduction

This chapter provides a general discussion of the overall findings of this study in which multi-faceted outcomes from assessment tasks in a tertiary Environmental Science unit are evaluated through classification by a qualitative cognitive framework. Assessment in the disciplines of Ecology and Environmental Science often focuses on the progression of independence by the student, in scientific research design and report writing. This study is unique in that there has been limited use of SOLO for assessment of diverse and multiple concept analysis in the sciences. Specifically this thesis has examined student outcomes which are multi-faceted; from an understanding and application of scientific method to a contextual framework of ecological setting. The approach was also unique in that it considered a comparative analysis of sectional, analytical and holistic qualitative approaches to assessment, in the study context.

Initially the possible limitations to the research are discussed as context for subsequent discussion. Syntheses of major outcomes follows in light of the study aims as posed in Chapter 2, and are discussed in relation to the literature in Chapters 1 and 2. Implications of the study for teaching practice and related higher education theory are discussed. Finally, a number of research initiatives generated as a consequence of the outcomes from this study are identified.

Study limitations

This section describes potential limitations and issues which arose in the course of the investigation. These issues include the non-response bias from students and researcher bias in categorising students written responses to the report questions. The limitations inherent in the design of this study and in the qualitative methods used were discussed in Chapter 3.

The breadth of categorisation of outcomes in this study may have contained some bias caused by the self-selected non-participation by some subgroups of students. These
include students who did not attend relevant practical sessions or those who may have been anxious about providing their assignment for the study assessment. For transparency in the response from each cohort, all response rates have been disclosed and the samples of each year of the study were described in detail. In particular, low participation was experienced in the 2007 cohort from whom the pilot SOLO categorisations were made. Where examples of levels within SOLO modes were not represented by the student responses, a logical categorisation for this outcome was proposed. The validity of this was tested with the larger second cohort in 2008, in which a greater range of hierarchical responses was identified.

The issue of researcher bias in the categorisation of written responses was addressed, in part, to test the validity of a recent revision of the SOLO model (Pegg, 2003). The analytical process described in chapters 4 and 5, was that responses were prepared into categories of ‘like’ responses, for later comparison with the hierarchy of categories within the SOLO theoretical framework.

During the initial categorisation of the 2007 cohort (Chapters 4-6), the researcher attempted to disregard her pre-existing knowledge of the SOLO framework and any bias towards it. By devising both between modal- and within modal-cyclical separation of categories on context specific elements of scientific understanding, further bias was minimized. However, hierarchical categorisation within cycles and modes was intentionally implemented in Chapters 5 and 6, from the knowledge that this process appeared appropriate from similar concept progression established from Chapter 4.

Although different categorisation of responses was doubtlessly possible, a coherent categorisation was established by two researchers; one for a theoretical background and one with a contextual background. This categorisation was compatible with the theoretical framework of the two–learning cycle per mode version of the SOLO model, but also unique in that there has been no precedent, for diverse and multiple concept analysis by SOLO in environmental sciences.
Overview of results

Learning outcomes in science encompasses the range of incomplete and partial understanding of single concepts to complete and integrated understandings of multiple concepts accepted by the scientific community. Assessment in the disciplines of Ecology and the Environmental Sciences often focus on the progression of independence by the student in scientific research, experimental design, interpretation of findings and report writing. Student outcomes are expected to be multi-faceted; from an understanding and application of scientific method to a contextual framework of ecological setting. This thesis has examined the essence of this learning outcome process through classification by a cognitive framework.

The research was driven by the development of a protocol for marking written scientific assessments using a cognitive structural perspective provided by the Structure of the Observed Learning Outcome Model (SOLO; Biggs & Collis, 1991) for second year university ecology units. Both an analytical and holistic approach within the cognitive structural model were compared for the effective alignment of the assessment of written assignments. The lines of inquiry were guided by the following themes and subsequent research questions.

**Theme 1**: To develop categories of written responses to a scientifically developed extended written assessment task within the SOLO model. Specifically,

*Research Question 1*: Can sections of a scientific report-based assessment task be categorised by the SOLO model? (i.e., Introduction, Methods, Results and Discussion).

*Research Question 2*: What is the distribution of SOLO categories across different report sections?

*Research Question 3*: How do the SOLO categories from a sectional analysis correlate with the actual quantitative grade given to the students?

**Theme 2**: To develop an holistic marking schedule for a extended written assessment task, for learning to use the scientific method in an ecological context and write a scientific report.
Research Question 4: How does the outcome from the holistic marking schedule correlate with the quantitative grade given to the students?

This premise was explored in the research setting of a second year unit core to students enrolled in the Bachelor of Natural Resource Management and Bachelor of Environmental Science in the School of Environmental and Rural Science at the University of New England (UNE), Armidale NSW. The study was based on the unit ECOL202 Marine and Freshwater Ecology. Students experienced the same practical classes and assessment structure whether enrolled in internal or external mode.

The conceptual content for the exploration of learning outcomes was a unit aimed to develop comprehensive knowledge and practical skills of ecology in students in the context of marine and freshwater environments, with the aim of helping students to understand how aquatic systems work to better manage these ecosystems. The teaching context was typical for a core ecology/environmental science unit with a hands-on learning approach to the development of scientific method application and report writing. Included in this process were aspects of the specific discipline content, as well as an explanation of the general concepts of scientific research methodology, and scientific expression and argument. This entailed literature review, hypothesis formulation and testing, data collection, presentation and interpretation. Two assessment items were analysed with a systematic approach to dissecting the assignment to allocate a qualitative level to separate sections of the report.

The first task provided the students with experience in reviewing a hypothetical scenario of an environmental setting from which they were to formulate hypotheses for testing an ecological impact, and design appropriate scientific methods to tackle the problem. The second assignment extended the students to writing a full scientific report through a real-world problem solving task to be designed, executed in a field setting and reviewed in the context of a well known theory.

Theme 1: Sectional analysis

The results presented in Chapters 4 and 5 provide a theoretically grounded description of a hierarchy of levels for responses to the scientific report presentation of understanding both hypothetical and natural aquatic systems. The results of analyses of the learning outcomes suggest that the majority of students could present a scientifically
written review, formulate testable questions, and design and carry out robust replicable studies in a scientific framework. All students within this cohort could synthesize their results in the given ecological framework, and some students demonstrated greater abstract cognition and application by presenting ideas beyond those directly instructed for the task.

A subsample of the 2007 cohort was used to design a pilot framework to qualitatively assess both scientific report assessment tasks for the following years’ students. The student reports were written and hence analysed in this study in clearly defined sections (introduction, hypothesis, results and discussion). From initial qualitative grouping of the assignments, the SOLO framework was used to place the relevant categories in two cycles of the concrete symbolic mode. Placement of the remaining assignments was in the formal mode, due to separation of assignments on structural complexity of scientific expression, and extended abstract cognition.

The pilot assessments were further analysed for SOLO levels (Unistructural, Multistructural and Relational) within each cycle and mode. The SOLO framework from the pilot cohort was then applied to the written outcomes of students for the same task from the following years. The distribution of the SOLO outcomes of these students among sections of the report demonstrated that the majority of responses were in the 2nd cycle concrete symbolic mode over all report sections and similarly for both assessment tasks.

It was notable that those students with higher outcomes in the qualitative hierarchy of SOLO, showed greater consistency in modes and levels across report sections. It appears that the abstract nature or mode of understanding of the theoretical framework was maintained by these students throughout the assessment task. In contrast, outcomes from the Discussion section were at a higher hierarchical level than those from the Introduction section for the majority of students. This suggests that within a mode (i.e., concrete symbolic), the cycle level is likely to increase. To test this, the theoretical understanding of students would need to be evaluated before they completed their practical field component and again after completion of their written scientific report.

The majority of students who complete the group-based field practical component and submit an assessment task for this research gain a quantitative grade of Pass or above
(Pers. Comm. D Ryder. 2008). Within these constraints, it would seem acceptable to consider outcomes in this version of the first cycle concrete symbolic mode inappropriate (i.e., not writing within a scientific framework) for a pass within a second year ecology unit at a tertiary level. The learning objectives for this assessment need to be clarified to identify which concepts and forms of procedural ideas (report structure) are important learning outcomes (c.f. Ramsden, 2003). Making an objective judgment about the extent to which each assignment criterion has been achieved has been more difficult than expected despite the use of a criterion referenced marking framework for report sections. The multiple outcomes which were expected to encompass an understanding of empirical and interpretive knowledge may have been better tackled by a holistic assessment method. Consequently, the SOLO model was used as the basis for a framework for a holistic analysis of student outcomes as follows.

**Theme 2: Holistic analysis**

In Chapter 6 a qualitative hierarchy of student understandings was established using holistic criteria. The analysis supported both criterion and construct validity of the 2-cycle per mode version of SOLO. This concurs with two comparable investigations both from a tertiary science context (Panizzon, 1999, 2003; Quinn, 2006) in supporting the validity of the SOLO model in this context.

In this section, student reports were analysed in a holistic manner using three interrelated elements for categorisation: Theoretical, Functional and a Practical understanding. By integrating these three elements, the SOLO framework was used to place two preliminary qualitative groupings of both assessment tasks in two-cycles of the concrete symbolic mode. This resulted from separation of assignments by structural complexity based on the level of scientific writing style. Extended abstract cognition was displayed by a single grouping of student outcomes placing them in the formal mode.

Similar to the sectional analysis, the assessments from the pilot study were further analysed for SOLO levels (U, M and R) within each cycle and mode. The SOLO framework from the initial cohort was then tested on the same assessment tasks from student in the subsequent year. The distribution of the SOLO outcomes for the students among sections of the report demonstrated that the majority of responses were in the second cycle, concrete symbolic mode. Further, there was a significant and clear
separation for holistic outcomes between cycles of the concrete symbolic mode, and between the concrete symbolic and formal modes. A highly positive relationship between the hierarchy of qualitative categories and quantitative grade was also apparent.

A major part of the assessment task under investigation was to expose a measure of an individual’s reasoning process (i.e., construct validity) through construct application of the scientific process and by demonstrating appropriate scientific writing style. Issues targeted in the assessment of the task included experimental design as a creative outcome, and attitudes to the geographical significance of the given theoretical framework. These constructs of reasoning, creativity and attitudes are all facets of the functional understanding integrated in the holistic SOLO framework.

A holistic approach facilitates the assessment of a student’s functional understanding that would be difficult to assess when determining qualitative outcomes using sectional approach. The strength of a holistic approach (as opposed to assessing individual sections of the written reports) is that it integrates all aspects of validity within the single model. Whereas the content validity is definitive in the sectional approach, construct and criterion related issues are strengthened by the holistic approach.

Finally the task was criterion referenced by being directly related to practices in the field of environmental science and management. All three aspects of the holistic SOLO framework addressed this. Students with a formal mode outcome had higher scores that reflected their performance in integrating concepts for successful application in a broader context.

**Evaluation of holistic vs sectional assessment approaches**

Although this extended assessment task was analysed as separate sections, the qualitative framework combined both positivist and interpretivist approaches to assessment. The lucidity and trail of presented evidence leading to the student outcomes of each section, however, were not independent. For example, the clarity of Methods was dependent on the successful formulation of a Hypothesis, which was further linked
to a justification from the Introduction. The Results could then be presented with clarity and interpreted astutely when aligned with the Methods; and overall, the Discussion related the previous three sections together. Multiple outcomes were expected from the assessment task and this may be better tackled to give a holistic integrated impression of a students’ work. The process of investigating a logical scientific argument may itself have provided some students with a better understanding of the ecological theory, on completion of the task, than from reviewing the topic in isolation. To benefit learning of complex issues which involve critical and abstract thinking, incorporating outcomes which encompass an understanding of empirical and interpretive knowledge may be of value in such diverse conceptual disciplines as ecology.

Implications for Theory

This section outlines the contribution of this study to theoretical issues related to identifying student outcomes in higher education using a hierarchy of understanding and application of ecological processes and theories. Finally, the implications of the development of a holistic framework using the SOLO model are discussed.

A valuable outcome from this study is the establishment of a hierarchy of understanding and application of ecological processes and theories, based on an explicitly articulated theoretical model. A qualitative understanding of the different ways theoretical, practical and functional knowledge is understood and applied by second year environmental science students is of both theoretical and practical value. It is also one of the few studies that has used a quantitative measure of tertiary science students responses in an extended muti-faceted written assessment task.

Together with the successful application of the two-learning cycle per mode version of the SOLO model, this study applies the SOLO framework from an interpretivist and holistic perspective. The issue of whether there is a point at which the complexity of the subject matter limits the utility of the two-cycle version of SOLO was identified by Quinn (2006). It appears that within a specific context (such as this study) a valid account of a qualitative model in a genuine complex learning setting can be achieved. The correlation between SOLO levels and modes and quantitative grade for the
assignment tasks supports the criterion validity of the model. Using the holistic schema for formulating outcomes expands the potential for the SOLO model for multi-faceted outcomes in other disciplines.

Implications for curriculum design and teaching practice

In higher education, one of the most important issues is the choice of assessment methods. It is important in the sense that students come to universities to achieve desirable learning outcomes, and understanding the effectiveness of teaching and assessment practices is important for both students and teachers.

The SOLO model has previously been used to explore assessed outcomes of learning of single, scientific concepts and had not been applied to a written multi-faceted scientific report. Establishing SOLO categories for report sections (introduction, hypothesis, results and discussion) and for a holistic assessment of whole structured written scientific assignments provides a framework that can more rapidly evaluate meaningful qualitative differences in response for other extended written scientific tasks within multi-faceted disciplines such as ecology. This section outlines the implications from the findings of this study for various aspects of the teaching and learning practice; specifically, curriculum design, evaluation of teaching methods, and professional development.

Curriculum design

The application of the latest two-cycle per learning mode model of SOLO was found to proficiently reflect student outcomes across a full cohort. The process of categorising extended written responses in a scientific format, and coding according to SOLO has implications for the understanding of a specific student cohort to target teaching assessment and outcomes. Within a unit, the SOLO framework can be used as a formative assessment tool to guide individual student progress as well as the cohort of students in the class. The models developed in this study can provide direction to aspects of course development (whether theoretical, practical or functional), that require an evidence-based change in teaching approach. Specifically, SOLO may also facilitate the re-evaluation of current assessment tasks that elicit relational responses.
The process of developing the SOLO framework has identified issues in the levels of outcomes being achieved. A Faculty-wide focus (rather than individual units) may be used to enhance relational outcomes and further formal mode outcomes for those students identified as not reaching relational outcomes. At a course level, SOLO can assist in aligning such relational outcomes, to the construction of new assessment procedures during curricular review of established units, and provide a structure for curriculum design for course restructure.

A SOLO framework such as the one developed in this study could contribute to the identification of students or cohorts that have less-developed fundamental skills and/or concept acquisition from previous units. Flawed cognition at more modest levels may cause the formation of invalid relational constructs, perhaps at a concrete symbolic level, preventing progression to appropriate abstract learning. The holistic approach provides a focus of the interpretive nature of evaluation, and may enlighten issues of prior knowledge. The progression of course/degree outcomes could be given clarity by exploiting an interpretive framework incorporating theoretical, practical and functional aspects of the sciences, in a contextual framework, and the concurrent analytical/deterministic and holistic/communicative approach to an aligned curriculum.

An emphasis on an analytical framework to encourage consolidation of empirical theoretical knowledge and practical skills may be of most benefit in early years of a degree. This could be integrated with an awareness of interpretive perspectives to demonstrate that theoretical scientific knowledge is not only deterministic. The employment of holistic frameworks for outcomes development which emphasise functional knowledge and practical applications could be increased progressively throughout a degree syllabus. A preference for interpretive and even emancipatory knowledge outcomes development for postgraduate courses would thus be a logical progression.

**Evaluating Teaching Strategies**

The finding that the majority of students responded to the scientific report assessment tasks at the 2nd cycle concrete symbolic mode and the likelihood of the cycle level increasing between and throughout the two discovery based learning activities,
demonstrates the benefits of the current teaching methods used in the unit. The current restructure of many university courses to reduce costs by eliminating field activities because of financial and logistical course constraints may diminish key pedagogical benefits of exploring scientific theory through field-based learning-by-doing activities (Conway et al., 1992). Thus, effective use of the SOLO model can demonstrate inherent values in current teaching methods which may affect institutional decisions. In summary, aligning teaching methods with a validated model of assessment assists the process of course evaluation through corroborating desirable student outcomes with selection of appropriate teaching methods.

Professional Development
In terms of assessment, this study supports the conclusions of Boulton-Lewis (1995) and Quinn (2006) that SOLO has potential for application in teaching and assessment at a tertiary level. The current SOLO assessment of learning outcomes for extended prose report tasks correlated well with quantitative grades presented from a discipline expert. This validation provides a basis to endorse the SOLO framework to other lecturers with similar unit outcomes and assessment tasks to that in the current study. The full benefits of an extended prose task include how a student can construct their response to a question or issue framework or ‘discourse structure’, integrated with factual and applied knowledge. Course designers can utilise SOLO to form targets for students’ outcomes such as a relational discourse that would express causal understanding through explanations and interpretations.

Implications for Future Research

The SOLO model has not been applied to multi-faceted, extended written scientific reports. The framework in the present study was developed using self-selected participants from two assessment tasks in a single ecology-based unit over two years. Similarly, the range of qualitative hierarchical outcomes did not cover the full spectrum of potential grades (fail through to high distinction) or the range of potential assessment tasks used in these types of units. Further research is required to explore and validate the application of the framework developed in this study (particularly the categorisation
of responses) to a range of assessment tasks and learning outcomes in other environmental science- and ecology-based units.

An evaluation of the framework developed in this study to a variety of scientific disciplines that utilise scientific knowledge for decision making will provide information on the relative importance of issues such as understanding the nature of science, science content knowledge, attitudes toward science, and the impact of science and technology on society in each unit.

The implementation of a holistic framework for assessment of tertiary science students requires improved evidence for the correlation between existing practice for assigning quantitative/analytical grades and the qualitative outcomes generated by the holistic SOLO framework.

Further research to identify links between learning outcomes for assessment tasks sought by teaching staff and outcomes from the holistic framework will promote improved curriculum alignment and increased transparency in the expectations of both students and teachers. The continued evaluation of SOLO as tool for understanding these links between how students engage in learning scientific concepts and the process of scientific assessment will provide further validation of holistic and existing analytical assessment frameworks.

Overview

A range of implications for teaching in this and other tertiary science contexts have emerged from this study. This study is unique in that there has been limited use of SOLO for assessment of diverse and multiple concept analyses in the sciences. The approach was also exclusive in that it considered a comparative analysis of sectional, analytical and holistic qualitative approaches to assessment.

Study limitations included the breadth of categorisation but were minimised by verifying the framework with a larger student cohort in which a greater range of hierarchical responses was identified. The issue of researcher bias in the categorisation of written responses was also addressed. Although different categorisation of responses was doubtlessly possible, and although the final categorisation model was influenced by
the perspective of the researcher, a coherent categorisation was established by researchers for theoretical and contextual background validity.

This thesis examined student learning of scientific research protocols, experimental design, interpretation of findings and report writing, through classification by a cognitive framework. The conceptual content for the exploration of learning outcomes was a unit aimed to develop comprehensive knowledge and practical skills of ecology in students in the context of marine and freshwater environments. The categorisation of student outcomes was compatible with the theoretical framework of the two–cycle per mode version of the SOLO model, and was unique in that there has been no precedent, for diverse and multiple concept analysis by SOLO in environmental sciences. Two themes followed the lines of inquiry

1. To develop categories of written responses to a scientifically developed extended written assessment task within the SOLO model, and
2. To develop an holistic marking schedule for a extended written assessment task, for learning to use the scientific method in an ecological context and write a scientific report.

This study has established a hierarchy of understanding and application of ecological processes and theories based on an explicitly articulated theoretical model. Together with the successful application of the two–cycle per mode version of the SOLO model, this study applies the SOLO framework from an interpretivist and holistic perspective. It was found that the mode of understanding of the theoretical framework was maintained by students throughout the assessment task and that within a mode (i.e., concrete symbolic), the cycle level is likely to increase.

There was a significant and clear separation of holistic outcomes between cycles of the concrete symbolic mode, and between the concrete symbolic and formal modes. A highly positive relationship between qualitative outcomes and quantitative grades was also apparent and were best interpreted by a holistic impression of a student’s work. To benefit learning of complex issues which involve critical and abstract thinking, incorporating outcomes which encompass an understanding of empirical and interpretive knowledge may be of value in such diverse conceptual disciplines as ecology.
Establishing SOLO categories for scientific reports and for a holistic assessment of whole, structured written scientific assignments provides a framework that can more rapidly evaluate meaningful qualitative differences in response when applied to other extended written scientific tasks within multi-faceted disciplines. The findings of this study have relevant implications for research and development aspects of tertiary teaching and learning; specifically, curriculum design, evaluation of teaching methods, and professional development.
References


Chan, C., Tsui, M. & Chan, M. (2002). Applying the structure of the observed learning outcome (SOLO) taxonomy on student’s learning outcomes: an
empirical study. *Assessment and Evaluation in Higher Education* 27(6), 511-527.


Appendices


Appendices

Appendix 1.

Ecology 202/402

Marine and Freshwater Ecology

2008

Unit Outline

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The University of New England
Armidale, NSW, 2351, Australia.
<table>
<thead>
<tr>
<th>Week</th>
<th>Topic</th>
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<tbody>
<tr>
<td>1</td>
<td>Introduction: parallels and contrasts in aquatic ecology</td>
</tr>
<tr>
<td>2</td>
<td>Inland aquatic ecosystems and habitats</td>
</tr>
<tr>
<td>3</td>
<td>Marine and estuarine ecosystems and habitats</td>
</tr>
<tr>
<td>4</td>
<td>Organic matter processes</td>
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<tr>
<td>5</td>
<td>Photosynthesis and respiration</td>
</tr>
<tr>
<td>6</td>
<td>Nutrient cycling and trophic state</td>
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<tr>
<td>7</td>
<td>Physical processes of water circulation: lakes and oceans</td>
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<tr>
<td>8</td>
<td>Temporary systems: changes in water availability over time</td>
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<tr>
<td>9</td>
<td>Groundwater Ecosystems: hydrological, chemical and ecological processes</td>
</tr>
<tr>
<td>10</td>
<td>Freshwater management and river rehabilitation</td>
</tr>
<tr>
<td>11</td>
<td>Estuarine Management</td>
</tr>
<tr>
<td>12</td>
<td>Marine management: marine parks in Australia</td>
</tr>
<tr>
<td>13</td>
<td>Synthesis and overview: relating ecological processes to effective management</td>
</tr>
<tr>
<td>Assignment Number</td>
<td>Deadline (postmarked)</td>
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<tr>
<td>1</td>
<td>5th Sept.</td>
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<td>2</td>
<td>10th Oct.</td>
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<tr>
<td>3</td>
<td>26th Sept.</td>
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<td>4</td>
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</table>
## 2008 Marine and Freshwater Ecology (Ecol 202-402) Lecture timetable

Lecture: Monday 10-11, Tutorial: Tuesday 10-11, Prac Thursday 2-5. All in Aquatic Ecol Lab

<table>
<thead>
<tr>
<th>Week</th>
<th>Starting</th>
<th>Topic (lecture and tutorial)</th>
<th>Prac</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>28 July</td>
<td>Introduction</td>
<td>No prac</td>
</tr>
<tr>
<td>2</td>
<td>4 Aug</td>
<td>Inland aquatic ecosystems: Habitats, biota and processes</td>
<td>Video, Habitats out of a Hat (HOOAH)</td>
</tr>
<tr>
<td>3</td>
<td>11 Aug</td>
<td>Marine and estuarine ecosystems: Habitats, biota and processes</td>
<td>Sampling at Lake Zot</td>
</tr>
<tr>
<td>4</td>
<td>18 Aug</td>
<td>Ecosystem Energetics: Organic matter processing and the RCC</td>
<td>Developing hypotheses</td>
</tr>
<tr>
<td>5</td>
<td>25 Aug</td>
<td>Ecosystem Energetics: Photosynthesis and respiration</td>
<td>Preparing equipment for fieldwork, seminars</td>
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<tr>
<td></td>
<td></td>
<td><strong>Weekend field trip – 30-31 August</strong></td>
<td></td>
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<tr>
<td>6</td>
<td>1 Sept</td>
<td>Ecosystem Energetics: Nutrient cycling</td>
<td>Processing field samples</td>
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<tr>
<td></td>
<td></td>
<td><strong>HOOAH due 5th September</strong></td>
<td></td>
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<tr>
<td>7</td>
<td>8 Sept</td>
<td>Stratification and physical processes</td>
<td>Analysing data and seminars</td>
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<td></td>
<td></td>
<td><strong>Mid-semester break</strong></td>
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<tr>
<td>8</td>
<td>29 Sept</td>
<td>Temporary aquatic ecosystems: Changes in water availability over time</td>
<td></td>
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<tr>
<td>9</td>
<td>6 Oct</td>
<td>Groundwater ecosystems: Hydrology, chemistry and ecology</td>
<td>No prac</td>
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<tr>
<td></td>
<td></td>
<td><strong>Prac report due 10th Oct</strong></td>
<td></td>
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<tr>
<td>10</td>
<td>13 Oct</td>
<td>Freshwater management and river rehabilitation</td>
<td>No prac</td>
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<tr>
<td>11</td>
<td>20 Oct</td>
<td>Estuarine management</td>
<td>No prac</td>
</tr>
<tr>
<td>12</td>
<td>27 Oct</td>
<td>Marine management</td>
<td>No prac</td>
</tr>
<tr>
<td>13</td>
<td>2 Nov</td>
<td>Synthesis</td>
<td>No prac</td>
</tr>
</tbody>
</table>

Textbook
As the unit spans a range of general marine and aquatic issues, **there is NO recommended textbook for this year**. However, if you are going on to do freshwater studies and Freshwater Ecology and Management (RSNR402/502), you will need to get:


This is available from the bookshop or from Bec Wood in Ecosystem Management (rwood@une.edu.au, 02 6773 2539)

However, if you are going on to do marine studies consider:


**Unit Co-ordinator:**

Dr Darren Ryder

Room 311 (top floor in the Natural Resources Bldg)

Phone: (02) 6773 5226

Fax: (02) 6773 2769

email dryder2@une.edu.au

Please use e-mail as your primary means of contact whenever possible
Ecol 202 Marine and Freshwater Ecology

The big picture

Aquatic ecology is a huge topic, spanning freshwater, estuarine and marine environments, and synthesizing aspects of botany, geography, chemistry, geology, hydrology, zoology, physics and many other disciplines. Ultimately we aim to learn how to understand and manage aquatic ecosystems. Issues relating to aquatic ecology appear daily in the media, often focussing on destruction of aquatic habitats and the need to protect threatened species or communities. The need for a robust scientific basis for managing the globe’s waters has never been stronger. Hence, one theme in this unit is how rigorous, well-planned science and an understanding of ecological processes underpin effective aquatic management.

A second theme focuses on how physical, chemical, and biological components of aquatic ecosystems function and interact. With this understanding comes a better appreciation of how human activities alter these components, and how we can manage to reduce our impacts on our oceans, estuaries and wetlands. Each of you brings different perspectives and experiences to this unit, and we hope you will constantly evaluate the information, skills, and attitudes that we explore as the unit unfolds.

A third theme is linkages and the role of the hydrological cycle at a range of scales in linking a wide diversity of aquatic habitats together - ‘from swamp to sea’ in many cases. Swamps drain to the groundwater or small creeks that fuse to form large rivers that enter estuaries, and hence to the sea. Evaporation and rainfall complete the cycle.

Unit focus

This unit will focus on:

- the special properties of water as a medium in which to live
- ecological features of freshwater and marine habitats of Australia
- types of plants and animals in these habitats
- the roles they play in important ecological processes such as organic matter breakdown
- measuring water quality and sampling aquatic biota
• parallels and contrasts between inland and marine aquatic ecosystems
• what linkages and processes occur in aquatic and adjacent terrestrial ecosystems
• managing human uses of aquatic ecosystems in an ecologically sustainable manner

Resources

In tackling these themes, you may find the following resources useful:

• the notes in the aquatic ecology study guide
• a video of a range of aquatic habitats, their biota, and how to sample them (we shall loan you this video during the Residential School but wish you to return it after the unit)
• the field trip to some of the aquatic habitats featured in the video
• the web site containing the Study Guide of lecture notes, and resource book of some key papers to get started and some supplementary readings for interest.
• newspapers and media coverage of aquatic issues
• library and world-wide web resources

Who are we?

In keeping with the multidisciplinary aim of this unit, you will find that we come from a range of different backgrounds and with different interests.

_Darren Ryder_ is a freshwater ecologist who has worked on water quality, invertebrates, organic matter and nutrient cycling in south-west Australian swamps and wetlands as well as inland and coastal rivers of New South Wales and Victoria such as the Murray, Murrumbidgee, and Hunter Rivers. My interests lie in the development of bioindicators for assessing river rehabilitation, impacts of river regulation stream ecosystems and the interactions between organic matter cycles and aquatic food webs.

_Steve Smith_ is a benthic ecologist with an interest in human impacts in marine and estuarine ecosystems. His research involves assessing the impact of pollutants, as well as documenting patterns and causes of natural variation, in invertebrate communities in subtropical, subantarctic, and Antarctic coastal environments. Steve has been involved with the Solitary Islands Marine Park since its inception and continues to advise the NSW Marine Parks Authority through the Solitary Islands Marine Park Advisory Committee.
Unit aims and learning outcomes

In this unit, we depart from the traditional 'discipline-based approach' that emphasises content (you can get much of that from the sources listed above). Instead, we prefer a more 'cognitive' approach that provides opportunities for you to use and strengthen your intellectual faculties, applying skills and knowledge to tackle aquatic issues and questions. Therefore, the unit and fieldwork at the Residential School focuses on a process (organic matter dynamics) in several contrasting aquatic habitats, and integrates physical, chemical and biological attributes of these habitats. We want you to be able to 'do' aquatic ecology as well as 'know' about it!

By the end of this unit, we would expect that you:

• have a firm conceptual framework, resulting from your reading and research experience, of how physical and chemical features in marine and freshwater ecosystems interact and influence the biota and some ecological processes such as organic matter dynamics,

• know the necessary equipment and methods, and have the technical skills to sample water quality and biota from a range of aquatic ecosystems.

• be able to predict the likely outcomes of changes to land-water linkages and ecological processes in many aquatic ecosystems in Australia, and,

• understand how this knowledge can be used to wisely manage marine and freshwater environments in an ecologically sustainable manner.

Matching learning outcomes with assessment

Given our expectations above, we have tried to ensure the assessment tasks maximise your opportunity to develop your skills and demonstrate these learning outcomes. The weighting of these tasks (see below) reflects our perception of their importance and the time we expect you to need to devote to them (from a unit total of 150 hours).

Assessment provides more than just a number for us to put in a box to estimate your success in learning. We hope that our feedback that accompanies your returned work provides a valuable guide for you, and we shall be searching for evidence that you have acted on our suggestions and feedback. If you have any questions about how to tackle an assignment, please ask. Most external students feel a bit lonely and isolated and it is very wise to send a quick email
or phone us to clarify the expectations of an assessment task or to confirm that you are on the right track. Contact Darren Ryder as a first step.

Assignments and Assessment

Assessment weightings

Assessment for ECOL202 is based on:
1. 1000 word Habitat Assessment 20%
2. 2,500 word Practical Report 40%
3. Examination (2 hr) on 40%

Assessment for ECOL502 is based on:
1. 1000 word Habitat Assessment 15%
2. 2,500 word Practical Report 30%
3. 1,000 word thematic review 20%
3. Examination (2 hr) 35%

e-Submission: All assignments must be submitted through Turnitin and the e-submission process available to all students through the unit Blackboard site. Assignments are not to be posted or emailed to the unit coordinator

Assessment tasks

Assignment 1. Habitats out of a Hat (due September 5th)

One of the first problems an ecologist faces is a practical one: how to sample organisms of interest in an aquatic habitat. There’s not much point in agonising over a possible threat to that habitat unless we can give some concrete scientific evidence of change (or not) in the distribution or abundance of key organisms or assemblages in that habitat. To do this, we need to be able to identify the organism and measure its abundance and distribution.

The object of this assignment is therefore to describe how you would detect the effect of a given ‘impact’ on an organism (or organisms) in a given aquatic ‘habitat’ (both drawn out of a ‘hat’). For example, you may draw out of the hat a rocky intertidal platform as a habitat and an oilspill as an impact. If you decide that you want to determine the effect of the oil on attached sea-lettuce (*Ulva*), then we need:

a) a description of the rocky intertidal habitat, with emphasis on natural factors affecting the distribution and abundance of sea-lettuce
b) some predictions of the effects of oil on sea-lettuce (and perhaps a broad description of oilspills and their impacts on aquatic systems)
c) a simple survey design (including replication and randomisation of sampling units) to investigate these effects. For our example, this may entail an effective field sampling method for sea-lettuce such as quadrats or transects. Include a diagram to show your survey design.
d) a list of equipment required to carry out your study and a budget including estimated costs for equipment, salary, accommodation, travel and living expenses while doing field work and sample analyses.

This exercise is an ‘on paper’ exercise and does not involve actual sampling. Listing of possible habitats and impacts (a group exercise that will also serve as an introduction to a range of aquatic habitats) and a random draw will happen during the Residential School.

Where to start? Have a look at the literature and see how others have tackled this type of impact project. Were the methods quantitative or qualitative? Which target organism(s) would be appropriate? How does the biology of the organism influence your choice of sampling method?

The organisation of your report should be guided by our assessment weightings (see below). Notice that our emphasis is on a clear description of the habitat, the impact and its likely effects, and your sampling methods. Clearly stated hypotheses and an equipment list and budget are also important.

Assessment and presentation
In 1000 words or less, describe your approach to sampling HOOAH. Use diagrams, and at least five scientific references (not included in the word count). Tables also are not included in the word count. Submit your assignment double-spaced but on both sides of the paper if you like.

Our assessment criteria are:
- Complete description of habitat, with relevant details and a diagram - 20%
- Outline of the impact, emphasising the likely direct and indirect effects on the target organism or assemblage (with references) - 20%
- Clearly stated hypothesis or hypotheses to be tested - 10%
- A simple design for identifying the effects of the impact on the habitat and target organism, including an appropriate sampling method, suitable replication and randomisation (we shall discuss this), and a diagram of the design - 30%
- Equipment list and budget of time/expenses - 10%
- Overall logic, clarity, writing style, and reference citation - 10%

The due date is 5pm on September 5th 2008.
Assignment 2. The Practical Report (due October 10th)

During the Residential School, we shall explore a fundamental ecological process - the input, movement, and breakdown of various forms of organic matter - in several contrasting aquatic ecosystems. See Chapter 5 and the readings in the Resource Book for some background to this issue.

Basically, we want to answer some questions about how organic matter arrives and is used in aquatic habitats. For example, what is the fate of dead leaves that fall into rivers? How far do they drift? When wedged against a rock, how fast do they break down? What eats them? Do the same kinds of organisms that eat leaves in streams also eat leaves in estuaries?

At the Residential School, we shall discuss a few models that scientists believe describe organic matter processes in aquatic ecosystems. We shall then test predictions of these models in a North Coast river and estuary. In small groups, you will need to agree on your hypotheses, develop some simple methods, and, with equipment that we shall provide or that you can make, sample the habitats during your fieldtrip. On your return, we shall help you analyse the data. Each group will give a short talk on their findings and we shall see if we can combine the multidisciplinary approach of each group into a synthetic model to compare with the literature. Well, that's the theory anyway and the flexibility is up to us during the School. In previous years, projects have ranged from sampling leaf packs to tracking marked leaves and assessing algal cover on stones…

Although students will work in small groups to design the studies and gather the data, individual assignments using the group data must be submitted. The project report is to be presented in a standard scientific paper format and we shall discuss this during the Residential School.

The due date is 5pm on October 10th, 2008.

Assignment 3. The Thematic Review (ECOL 502 only)

This assignment is ONLY for students undertaking ECOL502. At this Masters level, we want you to demonstrate your grasp of one of the key themes of the unit by finding a paper from the recent published literature (since 1999) that illustrates one or more of the principal themes of this unit. The paper MUST NOT be one from your current set of readings but should be obtained from library/electronic resources, and a copy of the paper will need to be submitted with the assignment.

Your thematic review should:
(a) identify the theme that you wish to explore, and in a couple of paragraphs, describe its implications for aquatic ecology;
(b) identify how the paper you have selected is a good example of this theme, giving specific details on how the paper extends your lecture notes and readings (this is the core of the assignment);
(c) conclude with a summary that reiterates the key points of the theme and its development in your paper of choice.

As an example, consider the paper in your readings by Boulton et al. (2003) on imperilled subsurface waters. Although this paper deals mainly with biodiversity, it does explore the theme of ‘linkages’ of surface and subsurface ecosystems and the problems that arise when these linkages are disrupted. For example on page 44, the section on natural linkages explains how the strength of the linkages with surface (epigean) systems governs environmental conditions in groundwater systems. Your assignment could then go on to describe these links in the hyporheic zone or in caves or whatever.

The due date is 5pm September 26th 2008.

Format for written assignments

All assignments should be submitted double-spaced, with a 4 cm margin on the right-hand side for feedback, and either word-processed or typed. To save paper, we are happy for them to be double-sided or on the reverse-side of used paper providing the original material is clearly crossed out. Subheadings demonstrate a logical arrangement of your thoughts. For the practical report assignment, you should follow the standard headings of a scientific paper (Abstract, Introduction, Study Area, Methods, Results, Discussion, and References). Look at a few examples of this type of scientific paper in the Resource Book on the CD. There is no need for a Table of Contents section. referencing should use the Harvard (author-date) system as shown in the UNE Referencing Guide at http://www.une.edu.au/tlc/students/publications/referencing.pdf. For all assignments, a word-count must be included and given on the front page of the assignment. Assignments exceeding the word count by more than 10% will be penalised by 5% because effective communication is succinct. Make extensive use of figures and tables where appropriate. Ensure you acknowledge sources of figures and diagrams as well as using relevant scientific papers.

Referencing style should be consistent - have a look at http://www.une.edu.au/aso). If you are uncertain about any details, contact Darren Ryder to check.
Written assignment submission and deadlines

Late submission of work
In principle, all assignments should be submitted by the due date. Punctuality on your part ensures that assignments can be marked and returned with feedback. Late assignments without extensions will be penalised at the rate of 10% of available marks for each working day that they are late. Work submitted more than ten (10) days after the due date may be returned unmarked. This action will be taken to prevent students who do get their work in on time being disadvantaged.

Applications for an extension must be made **in writing** (email is fine) **before** the work is due. Extensions will usually only be granted for medical reasons supported by medical certification. Work commitments are seldom considered as reasonable excuses, unless you can demonstrate an unexpected long-term event. I will not grant extensions lightly, but will consider all circumstances carefully. If you are granted an extension, affix a copy of the written extension from me (e.g. printed email message) on your assignment so that no penalty results.

Word limits
You are required to comply with word limits. They have a dual role. In the first instance, they limit the burden on the person marking them. More importantly, they encourage conciseness, a hallmark of good academic writing. They also provide a good indicator of the depth to which you are expected to go. You are, of course, not expected to achieve exactly the required length and a 10% leeway on either side is acceptable. However, deviations beyond that 10% may be penalised at the discretion of the unit coordinator. Any penalty imposed for exceeding the word limit will be in the order of one mark per hundred words of excess, or shortfall, as the case may be.

Special extension of time (SET)
A student who has been prevented through illness or other unavoidable circumstances from completing, by the end of the teaching period, work which the School considers essential, may seek a Special Extension of Time in which to complete the work. Special Extensions of Time apply to an assignment(s) that is unable to be submitted prior to the commencement of the examination period.


Your application should explain your circumstances and must be accompanied by appropriate supporting documentation confirming the circumstances which prevented you from completing the work by the
due date. Please be aware there are deadlines for submission of these applications.

**Plagiarism**

You must comply with the University's policy on Plagiarism and Academic Misconduct (go to [http://www.une.edu.au/rmo/policies/acad/plagiarismpolicy.pdf](http://www.une.edu.au/rmo/policies/acad/plagiarismpolicy.pdf) for details). Your work will be checked for plagiarism.

Plagiarism is the action or practice of taking and using as one's own the thoughts or writings of another without acknowledgment. The following practices constitute acts of plagiarism and are a major infringement of UNE's academic values:

- where paragraphs, sentences, a single sentence or significant parts of a sentence are copied directly, are not enclosed in quotation marks and appropriately referenced;
- where direct quotations are not used, but are paraphrased or summarised, and the source of the material is not referenced within the text of the paper; and
- where an idea which appears elsewhere in any form* is used or developed without reference being made to the author or the source of that idea.

*Some examples of this are books, journals, WWW material, theses, computer stored data and software, lecture notes or tapes.

**Your responsibility**

You need to:

- read, understand and respect the policy on Plagiarism and Academic Misconduct found in the University Handbook and at the website above, and use the Turnitin process to inform yourself of the level of originality;
- familiarise yourself with the conventions of referencing for your discipline(s);
- avoid all acts which could be considered plagiarism;
- seek assistance from appropriate sources with any academic writing areas where you are aware you need more knowledge and skills;

**Avoiding Plagiarism and Academic Misconduct**

You should refer to the University Handbook and to the following websites or to academic units for further advice and assistance:

Appendices


The Theory Examination

The compulsory, final examination is 2 hours long, and will consist of both short answer questions that seek to test your knowledge of relevant and specific subject matter, and longer essay-type questions that require you to integrate your knowledge and demonstrate deeper understanding of broader concepts.

Check available past examination papers and throughout the Study Guide, there are review questions designed to help you test your comprehension of the material. These questions are likely to appear on the examination paper, often emphasizing contrasts and processes. We cannot over-state the value of self-testing your comprehension as you work through the study-guide. If you are not comfortable with your answers, re-read the Study Guide, Resource Book papers, the recommended textbook and other textbooks, and always feel free to call us for help. We are always happy to discuss approaches to working through the questions and helping you focus your answers.
Appendix 2.

UNE Human Research Ethics Committee (HREC), approval number HEO7/150

Student information sheet and consent form
INFORMATION SHEET FOR PARTICIPANTS: ALIGNING ASSESSMENT IN HIGHER EDUCATION

Dear Student

I would like to invite you to participate in a research project into assessment methods of written reports in a tertiary setting, which contributes to the research component of my Masters in Education. Assessment in Ecology often focuses on the progression of independence, by the student, in research design and report writing. This research project seeks to examine the essence of this learning outcome and how it may be better taught through classification by a cognitive framework.

Research Methods:

The study, examined written assessment items from internal students of Aquatic Ecology, in 2007 and plans to examine assignments for both internal and external students of ecology units in 2008 including Ecosystem Rehabilitation EM351-551. Assessment reports will be collected from those students whom have given consent to participate in the study. Students are asked to submit an unmarked copy of their assignments either in hard copy or electronically to the research associate, Dr Adrienne Burns. Assessment tasks will be numbered and student names and numbers will be deleted with only a record of the participants being known to the researchers. Assessment outcomes from the research project will not influence grades for the units in any way.

Return Date:

Consent forms should be returned to Dr Adrienne Burns directly or via your unit coordinator prior to the due date for each assessment. An unmarked copy of the consented assignment is also requested around the due date for assessment.

Confidentiality and personal issues

This research is entirely voluntary. Your name or student number will not be disclosed with any results and your identity will remain confidential in any results and the thesis. The participant is free to withdraw consent and to discontinue participation in the activity at any time without prejudice. All data will be de-identified by Dr Adrienne Burns and destroyed after five years. It is unlikely that this research will raise any personal or upsetting issues.

Availability of Research findings

Findings from the survey will be collated and presented for my masters thesis. The study has the approval of the Human Ethics Committee of the University of New England (Approval No. HEO 07/150). The project is likely to be completed on October, 2009, if you would like to view a summary of the results please feel free to contact Dr Adrienne Burns. If you have any concerns with any aspects of the study please contact the Human Resources Ethics Officer at The University of New England at the following address. Research Services, The University of New England, NSW 2351, ph (02) 6773 3449, fax (02) 6773 3543, Email ethics@une.edu.au.

Please fill out the following request for participation.

Many thanks,

Dr Adrienne Burns
Honorary Associate, School of Environmental & Rural Science, UNE, ARMIDALE, 2351
Email: aburns3@une.edu.au
CONSENT FORM

ALIGNING ASSESSMENT IN HIGHER EDUCATION

I (the participant) have read the information contained in the information sheet for Participants. Aligning Assessment in Higher Education: using a cognitive structural model to gain insight into student understanding of ecological practise. I have been made aware of the purpose of the study and the measures that will be taken to ensure anonymity and confidentiality, and understand that I am free to withdraw from the study at any time without penalty. I agree that research data gathered from the study may be published provided that my name is not used.

Participants Name……………………………………………………………………

Participants Student Number………………………………………………………

Unit Name ……………………………………………………………………………

Assignment Task …………………………………………………………………

Signature………………………………….. Date………………………………..