Identifying students' research skills in a first year biology practical unit: a study applying the Research Skill Development (RSD) framework

Lynette Torres
Monash University

A thesis submitted for the degree of Master of Education, Faculty of Education, at Monash University in May 2018

This thesis has not been accepted for the award of any other degree or diploma in any educational institution and, to the best of my knowledge, contains no material previously published or written by another person, except where due reference is made.

Signed: [redacted]

The research for this thesis received the approval of the Monash University Standing Committee for Ethical Research on Humans (Reference number: CF14/2372 – 2014001290*).*

Copyright notice

Abstract

Introduction

Laboratory practicals engage students in complex thinking skills and processes to build knowledge and understanding of the nature of science. The emphasis on skill development in practical curricula is generally concerned with students' attaining proficiency with a range of manipulative, precision and technical skills. Surprisingly few studies draw connections between the development of students' cognitive and metacognitive processes for learning in the practical with foundational skills for researching.

Rationale

Librarians strive to establish teaching partnerships with academics to contextualise research skills within curriculum content. However, ambiguity surrounding the term 'research' and the lack of pedagogical tools to guide library-faculty collaborations often disconnects librarians from contributing to student learning. This study explored the potential of the Research Skill Development (RSD) framework (Willison & O'Regan 2006, 2013) to extrapolate students' research skills in a first year biology practical unit and, to consider how the framework might enhance library-faculty teaching collaborations in undergraduate practical coursework.

Methods and results

The research approach was shaped by a social constructivist epistemology and applied a qualitative research design using interpretive analysis techniques. Data was gathered from descriptive observations of students engaged in five consecutive practicals, triangulated with a document analysis of the unit's laboratory manual. Research skills identified in the data sources were interpreted and coded in alignment with skill categories informed by the RSD framework using NVivo (11) qualitative analysis software. Results showed that students were engaging in the range of research skills explicated by the RSD framework, yet these skills were generally an implied aspect of learning. Implications concerning curriculum design, the influence of teacher associate-student interactions and teaching methods for students' developmental preparedness for research are drawn from the results.

Conclusion and implications

A consequence of research skills remaining an unacknowledged element of learning overlooks an important opportunity to promote a learning benefit of this practical unit. The results of this study show that the RSD framework is a useful theoretical construct and a *priori* framework which assisted in clarifying what undergraduate students' research skills encompass and what may influence the development of these skills in the practical experience. The method applied to this study has potential to be reproduced in other

learning contexts to make research skills visible in curriculum design and teaching practice to enhance students' cognitive preparedness for researching as a shared endeavour between academics and librarians.

Declaration

This thesis contains no material which has been accepted for the award of any other degree or diploma at any university or equivalent institution and that, to the best of my knowledge and belief, this thesis contains no material previously published or written by another person, except where due reference is made in the text of the thesis.

Signature: [redacted]

Print Name: Lynette Torres

Date: 21st May 2018

Acknowledgements

It would not have been possible to complete this Master's thesis without the generosity and support of my family. Above all I would like to thank my husband David, for his unrelenting patience and encouragement, for listening as I shaped my ideas and assisting me to find appropriate resources. Thank you for your positive encouragement when I needed to be reminded why I was undertaking this journey. For the insightful and invaluable conversations I had with my step-daughter Carolyn and my daughter Sara who share knowledge of the discipline. Thank you Carolyn for helping me make sense of the data and contributing to its final presentation. To Sara, thank you for your willingness to read and painstakingly reread each chapter, for your critical eye and comments as the chapters progressed. Your contribution has been invaluable and I am deeply appreciative of your support and all the attentive hours you gave me. To my son Peter, thank you for the insightful theoretical discussions on qualitative research; they were crucial during the early phases of my planning.

To my supervisors, Gerry Rayner and Debra Panizzon, thank you both for sharing your knowledge, for your assistance, your guidance and for always being so approachable. Thank you also for your belief and encouragement over the years. To John Willison for your inspiring framework and the learning journey it has provided and continues to offer me. Thank you for your generosity over the years and for your interest in this study.

Finally, I would like to acknowledge Monash University Library. I value the study support I received over the years to be able to undertake and complete this study.

In sincere appreciation,
Lynette Torres

Table of Contents

Chapter One: Introduction

1.1 Background to the study

Research processes have at their core a set of foundational skills required by students to maximise learning and successfully engage with undergraduate university coursework. University educators consider these research-enabling skills important for study, higher degrees and to thrive in a complex future (Barnett, 2005; Litchfield, Frawley, & Nettleton, 2010). The value placed on students engendering skills for research is demonstrated by a substantial body of literature describing curriculum initiatives designed to equip students with thinking skills and processes associated with research (Brew, 2006; Brew, 2012; Healey & Jenkins, 2009; Willison & O'Regan, 2007).

Such initiatives are generally focused on inculcating students' research skills through purposefully designed final year research units in preparation for higher degrees, (Boyer Commission, 1998; Healey & Jenkins, 2009). The emphasis placed on students attaining research skills towards the end of their undergraduate studies however, overlooks the potential of explicitly and progressively cultivating research skills within regular undergraduate coursework.

Academic libraries have long explored ways to align the research skill expertise of library staff with skill development initiatives in their institutions (Bruce, 2001). Exemplars of academic library teaching practice in the literature describe how libraries strive to move from delivering piecemeal instructional library sessions disconnected from the curriculum, to approaches that bring research skills closer to disciplinary content (Callan, Peacock, Poirier, & Tweedale, 2001; Moselen & Wang, 2014; L. Smith, 2011; Torres & Jansen, 2016). Implicit in this endeavour is the notion that teaching skills for research within curricula enhances student learning. However, initiating and sustaining collaborative teaching partnerships with academics to achieve this aim has been an ongoing challenge for library staff (Bruce, 2001; Ivey, 2003). Misconceptions and perceptions of what librarians can contribute to student learning often impede the acceptance of librarians in the curriculum (Bradley, 2013; Bruce, 2001; Chanock, 2007; Peacock, 2001).

Establishing collaborative teaching partnerships between library staff and science educators to contribute to students' research skill development in the science practical is particularly difficult to realise. The practical has a well-established role in undergraduate science education and is recognised for the value it offers in promulgating students' understanding of the nature of science (NOS), and developing their scientific skills (Hofstein & Lunetta, 2003; Hunter, Laursen, & Seymour, 2007). Higher-order thinking skills that are associated with researching however, are only sporadically acknowledged as part of the skill repertoire students gain from a first year science coursework, as a greater emphasis is placed on students developing technical and precision skills for science (Chaplin, 2003; Di Trapani & Clarke, 2012; Gregory, 2013). Leggett, Kinnear, Boyce, and Bennett (2004) emphasise that these skills “need to be explicitly identified, selected and actively taught” (p. 298).

Challenging this notion are the many conceptualisations and terms in current usage to describe research skills, which presents a significant obstacle when librarians endeavour to explain how their research skill expertise might benefit student learning. A further challenge is the lack of appropriate pedagogical tools with the educational language and disciplinary flexibility to describe how research-related skills can be explicitly developed and articulated as valued skills for learning. As a result, sustainably and progressively developing undergraduate students’ research skills as an explicit and coherent element of learning generally remains aspirational, unclear and difficult to realise (Willison & O’Regan, 2007).

This research study described in this thesis focuses on identifying students’ research skills in a first year biology practical unit. The study was prompted by the challenges faced by librarians to move beyond one-shot instructional library classes disconnected from content, to a collaborative partnership model between librarians and science educators to explicitly develop students’ research skills within curricula. A collaborative model however, would be dependent on a number of factors including: a common understanding among educators as to what research skills might entail in the practical, a method of identifying context and discipline related research skills and a way to interpret how research skills are being developed within this learning environment. This study, motivated by my professional experience as a librarian aims to contribute to this understanding.

The Research Skill Development (RSD) framework (Willison and O’Regan 2006, 2013), a conceptual, flexible and adaptable model for developing students research skills suggested a suitable instrument to underpin this study. The RSD offers a way to “promote lecturers and students’ awareness of the process of research skill development …. To diagnose students’ positions, set goals and plan appropriate courses of action” (Willison & O'Regan, 2007, p. 404). The purpose of applying the RSD for this study was to consider its usefulness as a construct through which to identify and garner a picture of research skills developed by students’ in one first year biology first practical unit.

1.2 Rationale for the research

Of relevance to this study is discourse in science education demonstrating a continued interest in seeking ways to invigorate the practical experience (Burke da Silva, Auburn, Hunter, & Young, 2008; Wilson, Howitt, & Higgins, 2015) and ways of integrating students’ scientific skill development within content knowledge (Luckie, Maleszewski, Loznak, & Krha, 2012). Skill related discussion in the literature however, is largely centered on students gaining proficiency with manipulative and technical skills for the laboratory

(Bradley, 2013; Di Trapani & Clarke, 2012; Loveys, Kaiser, McDonald, Kravchuk, Gilliham, Tyerman, & Able, 2014). Di Trapani and Clarke (2012) note that students' attainment of competency in foundational skills for research is an overlooked outcome of learning in practical undergraduate coursework. The purpose of this study is to gain clarity as to what such skills might encompass in a first year laboratory practical unit, in order to bring the skills involved in research in the practical to the fore as acknowledged skills for learning. By doing so, this study enhances opportunities for library-faculty teaching collaboration in this learning environment.

This study will also contribute to the growing body of literature describing approaches, examples and disciplinary applications of the RSD framework (Peirce, Ricci, Lee, & Willison, 2009; Pretorius, Bailey, & Miles, 2013; Taib & Holden, 2013; Willison, Schapper, & Teo, 2009; Willison, et al., 2016), and the impact of the RSD from one Library's perspective (Torres & Jansen, 2016). To date, a study applying the RSD to interpret research skills in a first year biology practical not been undertaken. This study does not investigate the development of students' technical skills for science that involve the use of scientific apparatus since these skills do not lack attention in the literature. The purpose of this research is to identify students' cognitive skills and process related to researching given their lack of acknowledgement in practical undergraduate coursework.

This research study has been stimulated by the following perceived issues:

- The complexity of terminology in current use to articulate and describe undergraduate students' skills associated with researching
- The lack of a model to provide educators with conceptual guidance for designing a curriculum that makes research skills an explicit element of learning
- The challenges library staff face in contributing their expertise towards students' research skill development in laboratory practicals.

This study aims to explore the following research question:

With reference to the Research Skill Development (RSD) framework; which research skills and associated levels of autonomy, are students developing whilst undertaking a first year biology practical unit?

1.3 Contextualising the topic

1.3.1 Challenges to conceptualising research skills: The science practical

The importance and centrality of coursework laboratory practicals to undergraduate science education has been well established (Bugarcic, Zimbardi, Macaranas, & Thorn, 2012; Hofstein & Lunetta, 1982). Yet, the emphasis placed on developing students' technical skills for science in the practical tends to overlook the learning potential of this environment also to make research skills an explicit outcome of learning.

Science students are generally introduced to skills for researching through purposefully designed course-based units known as undergraduate research experiences (UREs) or capstone units (Corwin, Runyon, Robinson, & Dolan, 2015; Healey & Jenkins, 2009; Seymour, Hunter, Laursen, & DeAntoni, 2004). Placing value on students' research skill development within the context of final year research-oriented units presents an interesting interpretation of what research and this associated skill set might encompass. The term 'research', in this context, is conceptualised within a hierarchy of terms. Skills for researching are associated with the formal activity of academic or professional research performed by a researcher, rather than a skill set that is ideally developed and practised progressively as part of a science student's undergraduate learning journey.

1.3.2 Challenges to conceptualising research skills: The librarian's perspective

Although librarians generally rely on forging teaching partnerships with academic staff to gain access to the curriculum, this approach alone has not greatly progressed library involvement in curricula in almost two decades (Bruce, 2001; Ivey, 2003; Moselen & Wang, 2014). More specific to the context of this study, Bradley (2013) identified barriers to librarian's potential contributions to student learning in science education. This study showed that the involvement of librarians remains conceptualised through "library-centric terminology and information literacy related concepts" (Bradley, 2103, p. 82). The term, 'Information literacy' has been the term adopted by the library profession to describe the thinking skills and processes involved in information seeking that include; identifying information needs, finding and locating information, evaluating sources, analysing, synthesising, managing, and using information ethically (Australian and New Zealand Information Literacy Standards, 2004). However, the terminology is imbued with misunderstandings due to the association of 'literacy' with remedial learning and does not clearly identify with faculty as skills akin to research (L. Smith, 2011). This suggests that establishing effective library-faculty teaching partnerships to enhance students' research skill development requires reconceptualised methods that more clearly communicate the research skill expertise of librarians, including the relevance of this knowledge for student learning (C. Smith, 2011; Stamatoplos, 2009; Douglas & Rabinowitz, 2016).

1.4 The relevance of the RSD framework

The relevance of the RSD framework is in providing a broader interpretation of information literacy by explicating students' skills for researching and describing how these skills can be progressively developed within curricula through scaffolded learner autonomy (Willison & O'Regan, 2007; Willison, Sabir, & Thomas, 2016). Furthermore, the RSD framework offers a conceptual model that can be applied to a variety of learning contexts (Torres & Jansen, 2016). This suggests that the RSD framework may be a suitable tool for identifying students' research skills and their development in laboratory coursework practicals.

Willison (2012), explains that the RSD framework describes the cyclic and incremental development of students' research skills articulated through social constructivist learning (Vygotsky, 1978), incorporating student autonomy (Boud, 1988; Butler, 1999), Australian and New Zealand Information Literacy Standards (Australian & New Zealand Information Literacy Standards, 2004), and Bloom's cognitive realm taxonomy (Bloom, Engelhardt, Furst, Hill, & Krathwohl, 1956). The RSD framework presents two axes. The vertical axis articulates the interrelated skills and processes associated with research (see Table 1) in combination with a horizontal axis describing a learning continuum of research skill development through increasing stages of learner autonomy (see Table 2). For the complete RSD framework, please see Appendix A.

Table 1: Vertical axis of the RSD framework: Facets of Research

RSD Facets of Research	RSD Facets of Research - Descriptors
Embark and Clarify	Students respond to or initiate research and clarify or determine what knowledge is needed heeding ethical, cultural, social and team considerations.
Find and Generate	Find and generate needed information/data using appropriate methodology.
Evaluate and Reflect	Determine and critique the degree of credibility of selected sources, information and data generated. Metacognitively reflect on the research processes used.
Organise and Manage	Organise information and data to reveal patterns and themes, and manage teams and research processes.
Analyse and Synthesise	Analyse information/data critically and synthesise new knowledge to produce coherent individual/team understandings.
Communicate and Apply	Write, present and perform the processes, understandings and applications of the research, and respond to feedback, accounting for ethical, cultural, social and team (ECST) issues.

Table 2. Horizontal axis of the RSD framework: Extent of Student Autonomy

Prescribed Research	Bounded Research	Scaffolded Research	Open-ended Research	Unbounded Research
Highly structured directions and modelling from educator prompt research, in which students…	Boundaries set by and limited directions from educator channel research, in which students…	Scaffolds placed by educator shape independent research, in which students…	Students initiate the research and this is guided by the educator to…	Students determined guidelines for the research that are in accord with discipline or context to …

The RSD framework has been empirically researched, applied and drawn on to inform curriculum and assessment design in national and international contexts and disciplines (Bugarcic et al., 2012; Feldon, Maher, Hurst, & Timmerman, 2015; Peirce et al., 2009; Pretorius et al., 2013; Snelling & Karanicolas, 2008; Taib & Holden, 2013; Torres & Jansen, 2016; Venning & Buisman-Pijlman, August 2011; Willison, et al., 2009). Details pertaining to this research is presented in Chapter two.

1.5 Thesis structure

This thesis comprises five chapters. Chapter one concludes here, descriptions of subsequent chapters follow:

Chapter Two provides the literature review, commencing with a broad overview of the literature encompassing a number of pertinent areas and initiatives relevant to undergraduate students' research skill development in higher education. The development of students' research skills through final year research units are contrasted with promulgating this repertoire of skills though undergraduate coursework curricula. A significant part of this chapter is dedicated towards students' skill development in undergraduate science practicals. The challenges and barriers in establishing library-faculty teaching partnerships for students' research skill development are discussed. The RSD framework is explained in more detail and examples of empirical studies applying the RSD are presented.

Chapter Three presents the research methodology, methods, data collection and analysis. Chapter Four provides the results from analysing the descriptive observations and the practical manual. Chapter Five presents the discussion and conclusion and offers recommendations informed by the findings of this study.

Chapter Two: Literature Review and conceptual framework

2.1 Introduction

Literature pertinent to students' research skill development is firstly scoped broadly within context of higher education, then within science education and the field of librarianship, followed by biology practicals more specifically. A wide literature search was required within science education due to a dearth of studies exploring students' research skill development as part of the biology practical experience. The literature emanating from the field of librarianship was also sparse in relation to how libraries contribute to students' research skill development in science practicals.

This chapter acknowledges the Boyer Commission Report of 1998, which raised concerns about the diminishing quality of undergraduate education in research-intensive universities. It explores one approach inspired by Boyer, generally referred in the literature as Undergraduate Research Experiences (UREs), which emphasises the importance of students experiencing research as part of undergraduate learning. An overview of URE's and their effectiveness for developing students' skills for researching is explored within the context of science education. An exploration of instructional approaches for inculcating students' higher-order thinking skills through laboratory activities, as well as the challenges faced by educators in drawing parallels between these skills and those required for research is presented.

As this study considers the potential offered by the Research Skill Development (RSD) framework (Willison and O'Regan, 2006, 2013) as a conceptual model for explicitly developing students' research skills, studies applying the RSD are included. A longitudinal study underpinned by the RSD in a first year human biology unit at the University of Adelaide as well as RSD partnership approaches between librarians and academics is discussed in more detail. Importantly, an examination of the ideas and approaches presented in the literature has contributed to both informing the rationale for this study and the choice of research methods employed.

2.1.2 Searching the literature

Identifying the relevant literature involved comprehensive searches on the topic of students' research skill acquisition in scholarly journal databases with coverage in the fields of Science Education and Librarianship. The databases in which relevant journals were identified included; A+Education (Informit), Education Database (ProQuest), Education Research Complete (EBSCO), Educational Research Abstracts Online (Taylor and Francis), JSTOR and Elsevier Science Direct. Science education literature revealed a rich vocabulary in current usage to describe educational initiatives and pedagogical approaches to impart students' higher-order thinking skills. Literature pertaining to

Librarianship generally used terminology for skill development specific to the profession. To address the contrasting and broad range of disciplinary and professional terms, Boolean operators were applied when searching journal databases to screen, combine and modify the results. This approach also assisted in narrowing the large number of items retrieved to library involvement in science education and biology practicals more specifically. However, contributions from librarians in science education beyond citing, referencing and literature searching was uncommon. A literature database was compiled of the most relevant resources in Endnote referencing software. The publications were categorised into themed groups and further analysed for relevance, scope, context, timeliness and authority.

The following terms were explored in the literature in various combinations using Boolean operators AND, OR, NOT:

—Higher education/Tertiary education
—Academic libraries/University Libraries
—Science education/programs/higher education
—Laboratory practicals/practicals science education/biology/biological sciences
—First year biology/first year biology practicals/first year laboratories
—Inquiry oriented learning/scientific inquiry/inquiry-based teaching and learning/authentic
—Learning/research orientated learning/project-based science
—Research skills/inquiry skills/generic skills/practical skills/investigative skills/scientific skills
—Information literacy/ skills/competencies/library science
—Research skills/competencies/literacy
—Research process/es
—Library skills/literacies/competencies
—Library-faculty relationships/teaching partnerships/collaboration

2.2 Undergraduate research experiences: The university context

The Boyer Commission of 1998 challenged university educators by calling for a reconceptualised teaching model to meet the obligations and commitment made to their students. A central principle of this view advocated a transformed undergraduate curriculum, offering students opportunities to participate in research and inquiry through discovery-based methods (Boyer Commission, 1998). Boyer's models assert the central importance of students acquiring skills for researching within the acquisition of disciplinary knowledge. In this way the "skills of analysis, evaluation, and synthesis become the hallmarks of a good education, just as absorption of a body of knowledge once was" (Boyer Commission, 1998, p. 7). The vision presented is one of an inclusive community of learners where a "deep and abiding understanding that inquiry, investigation, and discovery are at the heart of the [university] enterprise" (Boyer Commission, 1998, p. 9).

University educators, motivated by Boyer’s call to mediate research and teaching in undergraduate coursework, designed pedagogical approaches and curricula for students to experience learning through research (Healey, 2005; Brew, 2006). Efforts to provide undergraduate students with authentic research experiences have seen the emergence of disciplinary-specific final year research oriented learning programs. Such programs are generally non-compulsory, competitive, and purposefully designed to prepare students for postgraduate study and future careers as researchers (Healey & Jenkins, 2009). Various disciplinary models of final year research experiences are presented in the literature, thus the terminology to describe undergraduate research is diverse. Healey and Jenkins (2009) note that the work of Griffiths (2004) and Healey (2005) identify four main ways of engaging undergraduates with research and inquiry that are inclusive of different pedagogies, although the authors note that the terms are used interchangeably:

— research-led: learning about current research in the discipline;
— research-oriented: developing research skills and techniques;
— research-based: undertaking research and inquiry;
— research-tutored: engaging in research discussions (Healey & Jenkins, 2009, p. 6).

Such models, designed to engage undergraduate students in research-like experiences, are generally subsumed in the literature under the umbrella term ‘Undergraduate Research Experiences (UREs)’ (Lopatto, 2004; Lopatto, 2007). UREs are designed as either semester length apprenticeship models, or as ‘closure’ or ‘capstone’ units that enable students to demonstrate their culminated skills and knowledge gained through undergraduate programs of study (GonzalezEspada & LaDue, 2006; Holdsworth, Watty, Davies, & University of Melbourne, 2009; Kardash, 2000; Lopatto, 2004; Lopatto, 2007). Models include undergraduate mentored research programs (Kardash, 2000; Lopatto, 2004), intensive summer scholarship programs (Healey & Jenkins, 2009) and semester-length undergraduate research-oriented courses within the regular curriculum (Luckie, et al., 2004).

Proponents of UREs have reported learning benefits to students that are considered important desirable outcomes of a well-rounded university education. These include the prerequisite skills, knowledge and dispositions for research, further study and valuable skills that transition to the workplace (Healey & Jenkins, 2009; Hunter et al., 2007; Lopatto, 2007; Eagan, Hurtado, Chang, Garcia, Herrera, & Garibay, 2013). Seymour et al., (2004) note that the usefulness of the URE for the development of students’ research skills may have short-lived benefits. Kardash (2000) concurs, explaining that students perceived that their higher order thinking skills related to researching skills were only ‘somewhat advanced’ as a result of undertaking the URE.

A key translator of Boyer's vision, Healey (2005) has urged university educators to recognise the importance of "active participation in research-like experiences integrated into classroom teaching" (p. 196), thereby mainstreaming research and inquiry in the curriculum through broader definitions of what counts as research. Discourse over the years indicates that the topic has remained alive for several decades and interpretations on where a student experiences research continues to ignite debate (Brew, 2013; Willison & O'Regan, 2007)

2.3 Research based learning experiences in undergraduate science education

The literature comprehensively describes ways to invigorate undergraduate science curricula to uphold the relevance of a science education, enrich the learning experience, and develop researcher capacity for the future (American Association for the Advancement of Science, 2011; Beckman & Hensel, 2009). Innovative pedagogy, such as inquiry-driven learning opportunities, have been infused into undergraduate science curricula to enrich the student learning experience and develop researcher capacity. Pedagogical approaches include research-led teaching practice (Healey, 2005), inquiry-based learning approaches (Luckie et al., 2012; Rayner, Charlton-Robb, Thompson, & Hughes, 2013), and final year UREs (Seymour et al., 2004).

A preference for the URE model in science education spans two decades, the literature presenting an ongoing evaluation of the benefits and challenges of the approach (Corwin et al., 2015; Fechheimer, Webber, & Kleiber, 2011; D. Lopatto, 2004; David Lopatto, 2007; Petrella & Jung, 2008; Seymour et al., 2004). Bangara and Bronwell (2014) explain that the focus of research experiences for science students is to provide "students with opportunities to improve their confidence, self-efficacy, skills, and knowledge about scientific research" towards a career in science (p. 605).

The volume of literature describing the efficacy, design and student perception of UREs in the sciences is substantial (Hunter et al., 2007; Sadler & McKinney, 2010; Wei & Woodin, 2011; Wilson, Howitt, & Higgins, 2015). Students predominantly self-report positively on their personal learning experiences of the URE, noting direct beneficial outcomes that relate to career advantages (Kardash, 2000; D. Lopatto, 2010). A study undertaken by Gonzales-Espalda and LaDue (2006) concurs, reporting that students perceived gains from their involvement in the URE that include self-confidence, improved attitudes towards study and future careers in science. Specific outcomes related to enhanced understandings of students' research skills however, remains difficult to affirm as the surveys poorly articulate skill related terms for researching (Seymour et al., 2004, p. 531). A recent evaluation of published UREs undertaken by Howitt, Wilson, Wilson & Roberts (2010) agrees, highlighting the contentious nature of the benefits claimed, particularly in relation to students' research skill development as "the evidence on which assertions are based, is at best anecdotal and at worst absent" (p. 406). This observation is supported by Kardash (2000) and Russell, Hancock and MCullough (2007) who confirm the benefit of the URE is in developing students' confidence with certain basic skills. In contrast, Kardash (2000) proposed that the development of higher-order thinking skills associated with researching was less apparent.

> *Although UREs are clearly successful in enhancing a number of basic scientific skills, the evidence is less compelling that UREs are particularly successful in promoting the acquisition of higher-order inquiry skills that underlie the foundation of critical, scientific thinking* (Kardash, 2000, p. 196)

On reviewing the published survey instruments designed to gain an understanding of students' self-perceived learning gains from the URE, it appears that finding the language to articulate specific skills related to researching has been challenging. Survey instruments related to UREs generally seek to determine students' self-reported ability to problem-solve, analyse data, and communicate scientific results. However, the questions designed to garner students' skill abilities are not considered as the same set of skills required for researching. To demonstrate, determining students' self-perceived ability to undertake research is often expressed as; 'an understanding of the research process' or 'carrying out research' (Bauer & Bennett, 2003; Lopatto, 2004; Petrella & Jung, 2008). Questions phrased in this manner might suggest that educators perceive higher-order thinking skills required for the practical as different skills to those needed for researching. This may also suggest that articulating what research skills encompass is challenging.

Reporting on the efficacy of the URE, Seymour, et al. (2004) identify a prevalence of 'descriptive accounts' in the literature rather than empirical 'research studies'. The authors highlight discrepancies in findings and state their concerns that in these accounts "evaluation methods are missing, incomplete or problematic" (Seymour et al., 2004, p. 496). This is supported by Willison and O'Regan (2007) affirming that, "in general, implementation of and rigorous study of [UREs] have, to date, been somewhat sporadic and haphazard, especially lacking any real theoretical underpinning" (p. 406).

In determining the value of the URE for students' research skill development, Howitt et al. (2010) speculate that a single research experience in the final year "may not be enough to allow the development of a deeper understanding of how science is done" (p. 406). Willison and O'Regan (2007) and Russell, Hancock and McCullough (2007) concur, identifying that competitive processes designed to direct students towards professional research careers miss an important opportunity to develop actual research skills as fundamental skills for learning in regular coursework. Willison and O'Regan (2007) suggest a model that cultivates students' research skills in regular undergraduate coursework, rather than through contended and elite co-curricular research experiences. This model would offer educators the opportunity to scaffold, nurture and develop the research skills of all students (Willison & O'Regan, 2007). However, for research skills to become a part of everyday learning, Willison and O'Regan (2007) advise that a new understanding of “research skills as both a product and a process of university education needs to transpire” together with a reconceptualisation of what research skills may encompass in the student learning journey (p. 394).

This notion raises important questions about how research skills are perceived, conceptualised and understood within the discipline of science and where the opportunities might lie in undergraduate science curricula for students to progressively hone and develop skills for researching as a regular part of their learning experience.

2.4 Instructional practices in laboratory practicals

Undergraduate science coursework practicals have historically been central to developing undergraduate students’ understanding of the ‘nature of science’ (Rice, Thomas, & O'Toole, 2009). In this learning environment students engage in the methods, skills and processes of scientific investigation (Bugarcic et al., 2012; Hofstein & Lunetta, 1982; Hofstein & Lunetta, 2004). The literature is largely in agreement that students perceive the practical experience as critical for their learning. Laboratory experiences influence student attitudes towards their science course and their consideration of a future career in science (American Assocaition for the Advancement of Science, 2011; Barrie, Bucat, Buntine, Burke da Silva, Crisp, George, Jamie, Kable, Lim, Pyke, Read, Sharma, Simon, Yeung, 2015).

Studies seeking understanding of how students experience the practical demonstrate a preference for Likert scaled self-perception survey instruments where students rate their interest levels and identify their learning gains (Rice et al., 2009). Outcomes of these studies show that students generally rate their interest and enjoyment of the practical experience highly (Collis, Gibson, Hughes, Sayers, & Todd, 2008; Deacon & Hajek, 2011). Despite surveys recording enjoyable laboratory learning experiences, the literature also evidences contrasting results: students indicate that they often disengage and fail to see the relevance of how the laboratory connects to a future career in science.

> *This suggests that students see an apparent discord or lack of context between what they are taught and how this might relate to their later employment. Such a perception, even if somewhat inaccurate, is of concern, and may reflect the broad lack of hands-on, open-ended learning opportunities in undergraduate biology laboratories* (Rayner, Familari, Blanksby, Young, & Burke da Silva, 2012, p. 2).

Reported student disengagement in the practical has led to an examination of instructional practices in laboratory learning (Rayner, Familari, et al., 2012; Rice et al., 2009). Enhancing student engagement in the practical by making it a relevant learning experience is at the heart of this endeavour (Barrie et al., 2015; Beck, Butler, & Burke da Silva, 2014; Lee, Lai, Yu, Lin, 2012). The literature evidences a long-standing criticism by science educators of predetermined experimental laboratory activities that use sequenced instructional learning approaches with pre-set results. However, instructional 'recipe-based' teaching methods persist in science education in spite of such approaches being considered detrimental to student motivation and learning (Rice et al., 2009; Thompson, et al., 2014).

Chaplin (2003) stresses that:

> *…. the learning aspect may be reduced when students faithfully follow the steps in an instructor-designed lab exercise without understanding or wondering why they are doing what they are asked to do* (Chaplin, 2003, p. 230).

The literature also reports a lack of opportunity in the practical for students to become cognisant of the skills they are using and developing whilst undertaking experimental activities and processes. For example, a study undertaken by Wilson, Howitt & Higgins (2015), identifies that educators find difficulty in meeting the practical's intended learning outcomes. Furthermore, when students remain focused on completing the final 'product' of recipe-based learning, they are unaware of the higher-order cognitive skills, processes and experiences of research embedded in the activity. Bugarcic et al., (2012) also noted that learning can be compromised when the "experimental outcome is already known to the students, and they are never challenged to think about how scientific experiments are used to answer specific research questions" (p. 174). This means opportunities for students to develop advanced skills, such as problem-solving and critical thinking are often sacrificed (Bugarcic et al., 2012). A report published by the American Association for the Advancement of Science (2011) also emphasises the importance of recognising students' higher-order thinking skill development as an element of the practical experience. This report highlights the need to make connections between skills developed in the practical with skills that today's biologists require, including the skills and abilities to:

> *… think and contribute outside their disciplinary boundaries… how to learn to integrate concepts across levels of organization and complexity and to synthesize and analyse information that connects conceptual domains for any career path graduates may take* (American Association for the Advancement of Science, 2011, p. ix).

2.4.1 Research skill development in the practical experience

There is a general consensus among science educators that the practical remains valuable in science education today (Henderson, Beach, & Finkelstein, 2011). Approaches for invigorating the practical to overcome 'recipe-driven' instruction through constructivist models of pedagogy, such as Inquiry-Oriented Learning (IOL) is well established in the literature (Brew, 2003; Spronken-Smith, 2010; Thompson, et al., 2014). Science educators consider IOL as a way to stimulate students' scientific knowledge acquisition and scientific skill development through student-driven and instructor-guided investigations (Spronken-Smith, Walker, Batchelor, O'Steen, & Angelo, 2010). The intention of IOL models is to actively bring research and learning together to enable similarities to be drawn between the skills and processes students require for inquiry with those needed for research. Justice, Rice, Warry, Ingliss, Miller and Sammon (2007) state "in learning to do inquiry, students begin to learn the process and enabling skills involved in establishing concepts and facts, preparing the way for them to become researchers" (p. 214). Feldon, et al., (2015) however, note an incongruence that "students' research skill development appears to be an implied or overlooked aspect of learning in the practical" (p. 3). The emphasis on students' skill proficiency in laboratory learning is generally centred on students acquiring manipulative, precision and technical skills for the laboratory. The cognitive skills associated with researcher development tend to be an overlooked element of learning (Bugarcic et al., 2012; Chaplin, 2003; Luckie et al., 2004; Wei & Woodin, 2011). It would thus appear that the practical as a valuable and integral research-like learning environment is under-utilised to explicitly develop students' skills for researching.

2.5 The complexity of defining students' research skills: Science practicals

An evaluation of the literature highlights that students' research skill development in the practical experience is either assumed, conceptually disconnected from the undergraduate research process or an unidentified element of learning. This would suggest that limitations are imposed on the potential development of students' research skills as an explicit outcome of the practical experience. Although there has been a long standing desire amongst science educators to improve and invigorate learning in practical coursework (Barrie et al., 2015; Rice et al., 2009), what may have been overlooked, is the ability to draw connections between the skills students are developing as outcomes of learning in the practical, and skills that also encompass the research skills and processes. Wilson, et al. (2015) explain that although laboratory experiences are "inherently entangled in the process of becoming a researcher", research skills are often overlooked as an outcome of laboratory learning as 'research' implies a degree of academic sophistication (p. 4). This effectively excludes such skills from instructional teaching practices common in undergraduate laboratory coursework (Wilson, Howitt, & Higgins, 2015, p. 4).

An analysis of science students' self-perceived learning gains related to skill development identifies a lack of consistency in skill related terminology. Skills tend to overlap or are dispersed across various categorisations. For example, the phrase 'generic skills' is defined broadly by Rice, et al. (2009) as "group work, report writing and problem solving" (p. 65). Alternately, Leggett et al. (2004) include communication skills and critical thinking as part of their definition of the generic skill set. Practical skills and competencies that are engendered through laboratory classes are defined by Rayner et al., (2012) as skills involving "observations and collecting data, handling biological materials, and developing accuracy and precision in the use of equipment and application of techniques" (p.2). Practical skills and core competencies are described by Goldey, Abercrombie, Ivy, Kusher, Moeller, Rayner, Smith and Spivey (2012) as:

> *…reading the primary literature, writing in the style of the discipline, presenting ideas orally, developing and testing hypotheses, conducting authentic research experiments, analyzing data using statistical methods, graphing and interpreting results, thinking creatively and critically, working effectively in teams, and applying knowledge to novel situations and civic problems* (p.354).

Hodgson, Varsavsky, Matthews and Kelly (2014) administered a student self-perception survey to capture graduating science students' perceived skill gains from their program of study. What research skills specifically encompass in this survey is unclear. 'Research skills' are defined in the survey instrument as "practical skills, critical thinking and critiquing" (Hodgson et al., p. 259). Responses for skills such as teamwork, ethical thinking and communication skills are collected in separate questions.

Research skills are generally presented in the literature as procedural skills, suggesting that the higher-order metacognitive skills of analysis, evaluation, reflection, critical thinking and synthesis are not conceptualised as part of the repertoire of skills required for researching. Furthermore, survey instruments that incorporate terminology used by science educators in the context of their teaching practice may not be easily understood, or be identifiable to students as questions seeking to identify learning gains associated with researching.

2.6 The complexity of defining students' research skills: A library perspective

For almost three decades libraries have promoted the range of skills required to meet the changing requirements to effectively identify, locate, use, evaluate and manage information as 'Information literacy skills' (ALA Presidential Committee on Information Literacy, 1989). The Council of Australian University Librarians subsequently adapted the ALA definitions for information literacy and published the Australian and New Zealand Information Literacy Standards (ANZIL) (ANZIIL, 2004). The ANZIL standards describe information literacy as the thinking and process skills that enable students to conceptualise, locate, interpret, evaluate, organise, synthesise and communicate information (ANZIIL, 2004).

For almost two decades, application of the ANZIIL standards as a curriculum tool to underpin and inform collaboration between librarians and academics has afforded libraries increased involvement in the curriculum (Creaser & Spezi, 2014; Peacock, 2001). However, sustained engagement in the curriculum to achieve broad impact for student learning has largely remained aspirational (Smith, L. 2011; Moselen & Wang, 2014). This suggests that the ANZIIL standards alone have not sufficiently supported efforts made to embed research skills into disciplinary content or inform curriculum and assessment design. Hensley, Shreeves and DavisKahl (2015) note the limitations of the standards, as they communicate traditional perceptions of information literacy as “locating information during course-related instruction” (p. 423).

Academic librarians publish and share models, approaches and strategies within the profession for developing and embedding information literacy skills within disciplinary contexts. An exploration of library literature shows involvement of librarians in biology practicals are generally single ‘one-shot’ sessions, with few exemplars of embedded approaches as reaching typically large student cohorts sustainably is challenging (Gregory, 2013). Published examples in library literature are primarily focused on presenting traditional library understandings and approaches to information literacy that are narrowly centered on library information-seeking skills (Bruce, 2001; Bradley, 2013; Fuselier, Detmering, & Porter, 2017). Restricted library involvement in science curricula also appears to be impeded by the varying conceptualisations of where and when students begin to research, and ambiguity surrounding the nomenclature to describe research skills. L. Smith (2011) notes further challenges to interpreting skill related terminology, particularly when information literacy becomes embedded with remedial interpretations of information seeking rather that transferable higher-order thinking skills associated with researching. A shared language between librarians and discipline academics may be warranted to facilitate how research skills may be conceptualised and conceived within a broad range of disciplinary contexts. To this end, Monash University Library introduced the Research Skill Development (RSD) framework as a conceptual model to inform the Library’s teaching practice. The intention of the approach was to strengthen library-faculty teaching relationships by finding a common language for students’ research skill development (Torres & Jansen, 2016).

The RSD framework presents a holistic interpretation of the concept of information literacy as a set of clearly articulated research skills that are undertaken as part of any research process. Importantly the RSD framework goes beyond traditional library conceptualisations of information literacy by extending the interpretation of information literacy skills beyond engagement with third party information. In utilising the RSD framework, Monash University Library discontinued the use of the traditional library terminology of information literacy and adopted ‘research skills’ to better communicate the synergies between library expertise and the cognitive skills for researching in a research intensive university (Monash University Library Strategic Plan, 2012-2015).

2.7 Conceptual framework: The Research Skill Development (RSD) framework

Willison and O’Regan (2007) introduced the Research Skill Development (RSD) framework (see Appendix A) as a concise, conceptual model that brings together multiple educational understandings related to requisite research skills. The cyclic and incremental development of students’ research skills is explicitly articulated through a constructivist learning approach incorporating student autonomy (Boud, 1988), Australian and New Zealand Information Literacy standards (ANZIIL: Bundy, 2004) and Bloom and colleagues' Taxonomy of Educational Objectives (1956). The RSD articulates research skills as: embarking on and clarifying the topic by determining researchable questions; finding and generating information/data, evaluating and reflecting on methods, sources/data; organising and managing information/data; synthesising and applying new knowledge; and communicating understandings with an awareness of ethical and social issues throughout the research process (Willison and O'Regan, 2006, 2013). The RSD framework operationalises research skills and research processes in a continuum of learner autonomy. Willison and O'Regan (2007), explain that the RSD framework represents,

> *… student research as a continuum of knowledge production, from knowledge new to the learner to knowledge new to humankind, moving from the commonly known, to the commonly not known, to the totally unknown. Students may be positioned at various stages along that continuum. Many commence undergraduate studies already familiar with the process of developing knowledge new to themselves. Few come to postgraduate studies ready to explore or create knowledge new to humankind. A dilemma for staff and students alike is how to chart the movement along this research continuum and how to facilitate that movement* (Willison & O'Regan, 2007, p. 394).

Willison and Buisman-Pijlman (2016) explain that the research skills described in the RSD are not:

> *...generic skills, as this would imply a ready transferability, but rather they are overarching perspectives about the research processes that are common across disciplines. In use, these general descriptions are made real by academics who operationalise them as discipline-specific and context-sensitive descriptors* (p. 66).

2.7.1 The concept of autonomy in the RSD framework

The skills and processes associated with researching are presented in the RSD in combination with graduating levels of student autonomy. Represented by the RSD's horizontal axis, the Extent of Student Autonomy provides descriptors that capture the degree of educator intervention or guidance required to build student independence over time, in relation to various skills and stages of the research process. Autonomy descriptors provide educators with guidance for designing incremental and progressive scaffolded research activities at the course or program level. Autonomy in the RSD ranges from a closed research inquiry (low autonomy) requiring focused research questions and highly structured directions from the educator, to open research (high autonomy) where students initiate and self-determine the guidelines for their own research. This is significant because the research process has been defined and articulated within a learning continuum. Therefore, the significance of the RSD framework is that it not only describes which skills are associated with the research process, but presents a conceptual model of how these skills can progress and be coherently taught and assessed in the curriculum (Peirce et al., 2009; Pretorius et al., 2013; Torres & Jansen, 2016).

While upon first impression these axes may appear rigid, suggesting a linear progression for both the research process and student autonomy, the RSD framework comprehensively describes the entire research journey in a non-prescriptive, flexible and adaptable manner. Within the framework, students may demonstrate varying levels of autonomy for the different research skills articulated in the Facets of Research in the RSD, and may oscillate between these research facets whilst undertaking the process of research. Furthermore, a student's level of autonomy for a particular research skill set can cycle 'backwards' when faced with less familiar research tasks or more conceptually demanding concepts. As explained by Willison et al., (2016), "this does not mean going backwards educationally, but rather provides insight into what happens in more conceptually demanding contexts, when students move into unfamiliar territory or when more rigour is required" (p. 3).

2.7.2 Evaluating the RSD framework: Studies and applications

The RSD framework has been empirically researched, applied and drawn on to inform curriculum and assessment design in national and international contexts and disciplines (Bugarcic et al., 2012; Feldon et al., 2015; Peirce et al., 2009; Pretorius et al., 2013; Snelling & Karanicolas, 2008; Taib & Holden, 2013; Torres & Jansen, 2016; Venning & Buisman-Pijlman, August 2011; Willison et al., 2009).

Multi-institutional studies applying the RSD framework have been undertaken to support individual educators and inter-professional collaborative teams to incorporate RSD approaches to curriculum and assessment design in a range of disciplinary semester length course contexts (Willison, 2012). The outcomes from these studies include discipline evaluations and applications of the RSD framework in practice that include: Business and Economics (Taib & Holden, 2013; Willison et al., 2009), Engineering (Cochrane, Goh, & Ku, 2009); Physics (Menke, 2013); English (Osborn, 2012) and clinical practice in Nursing and Midwifery (Pretorius et al., 2013). Studies applying the RSD framework in the Biological Sciences include: Biomedical Sciences (Munns & Chilton, 2014), Cell Biology (Bugarcic et al., 2012) and Plant Biology (Loveys et al., 2014). These studies largely describe common beneficial outcomes where the RSD was effective in engaging educators in conceiving how to make students' research skill development a more obvious element of the student learning experience.

A study of particular relevance to the context of this thesis was undertaken by Peirce, et al., (2009). The study sought to discover the effects, benefits and challenges of identifying and making the skills associated with researching explicit, fostered and assessed in a first-year human biology unit. It aimed to gain an insight into self-perceived and long term perspectives of research-building experiences gained from undertaking two Inquiry Oriented Learning (IOL) learning tasks over two semesters that were informed by the RSD framework. Student interviews were conducted over three years, 2005-2007, with three cohorts of students. Applying a curriculum improvement cycle approach, changes were made to the curriculum over this time, including reframing literature research tasks with the RSD framework and the inclusion of a new field-based inquiry task. In 2006 an additional literature task as well as two standard laboratory tasks were devised according to the RSD. Although not always apparent at the time, some students identified the benefits of progressively and incrementally developing skills for researching, and the applicability of these skills beyond university (Peirce et al., 2009, p.3).

The RSD has underpinned library-faculty teaching partnerships at Monash University. For example, such a partnership informed the design of learning activities and assessment in one Nursing and Midwifery unit, advocating the benefits of the RSD collaboration for constructive alignment of the curriculum (Pretorius et al., 2013). The RSD was applied for mapping research skills in Business and Economics (Taib & Holden, 2013). The authors note the benefits of the tool to underpin collaboration among educators using a language in common for student research skill development.

Furthermore, the RSD has increased library involvement and impact across curricula at Monash University. Data gathered through survey instruments indicates “increases in embedded skill development programs, improvements to assessment design, growth in use of RSD-informed marking rubrics, and increased library-faculty engagement in curriculum review and design” (Torres & Jansen, 2016, p. 8).

2.8 Conclusion

The literature evidences ongoing discussion dedicated towards enabling opportunities within the curriculum for students to develop the requisite skills for researching. Efforts to enable such opportunities by educators have given rise to a spectrum of undergraduate research initiatives, experiences and opportunities. However, these opportunities remain dependent upon the conceptualisation of the nature of research and associated skills by academic and professional staff leading initiatives in the curriculum.

The complexity of defining research skills and what they encompass may be attributed to the lack of clarity in the vast range of terminology currently used to refer to skills associated with researching. Studies undertaken by Willison and O’Regan (2007) note that developing research skills through the learning process makes it difficult for both students and educators to identify and articulate those skills. Furthermore, the profusion of nomenclature tends to cloud meaning, confuse the educator, create barriers to curriculum initiative and hinder effective and sustained library-faculty teaching partnerships (Torres & Jansen, 2016). Skills such as problem solving, critical thinking and communication are conceptually removed from skills associated with research and hidden in a taxonomy of educational terms. Furthermore, how research skills are perceived and conceptualised by science educators and librarians alike, may impede opportunities for effective collaboration.

The literature clearly indicates that the desire to enable students' skill development within the knowledge curriculum is both complex and dynamic. The discussion seeks ways to enhance the learning experience of science students in the laboratory to better meet learning outcomes and to communicate the transferable relevance of the practical experience (Barrie, et al., 2015). Librarians also consider the laboratory practical a learning setting where students' research skills could be explicitly enabled, as students are engaging in 'research-like' activities in this learning environment (Gregory, 2013). Studies in science education however, largely focus on students' practical skills that are inclusive of technical and manipulative skills. Surprisingly few studies examine the development of students' cognitive and metacognitive processes for learning in regular coursework practicals as foundational skills for researching.

Consequently, limited studies are available to inform our understanding of the repertoire of skills developed in students' first year practical experiences in relation to research skill development. This denotes the potential of the RSD framework as a conceptual, flexible and non-prescriptive model to explicitly articulate research skills and their development as a product of undergraduate learning.

Chapter Two concludes here. The following chapter presents the methodology and methods that have been applied to this study, including details of results analysis.

Chapter Three: Research methods and analysis

3.1 Introduction

A laboratory-based program is considered a "cornerstone of most science degrees because it provides students with an opportunity to develop many of the practical and critical thinking skills needed to become a scientist" (Barrie et al., 2015, p. 1810). The literature focuses on the importance of science students developing practical and generic skills that include higherorder cognitive processes such as "hypothesis testing, reading primary literature, analysing data, interpreting results, writing in disciplinary style, and working in teams" (Goldey et al., 2012, p. 353). However, conventional recipe-driven practicals tend to overlook the potential of this experience to draw explicit connections between higher-order thinking skills students engage with in the laboratory with the skills necessary for research proficiency (Gregory, 2013; Peirce et al., 2009; Rice et al., 2009; Talgar & Goodey, 2015). This thesis seeks to garner a picture of the skills associated with researching that first year biology students are developing through the laboratory practical with the view to assisting to make research skills a more explicitly acknowledged outcome of learning.

The unit examined in this thesis, a first year biology unit BIO1022 is firstly contextualised within the Bachelor of Science degree at Monash University. A brief overview is then provided of the pilot studies undertaken to inform the research design for this study. Finally, the methodology, methods and the phases of data analysis are described.

3.2 Bachelor of Science (BSc) at Monash University

The Bachelor of Science (BSc) at Monash University is a three year comprehensive single degree course that aims to provide students with requisite skills and knowledge that lead to careers in general science. The degree also promotes the transferability and applicability of these skills beyond specialised areas. The BSc degree is structured in three equal parts comprising a science specific area of study, a listed major and units taken as electives. The learning outcomes state that upon successful completion of this course, students are expected to demonstrate a broad range of knowledge and skills in at least one area of science. Graduate outcomes encompass skills for researching that include: the ability to develop, apply, integrate and generate scientific knowledge; collect, organise, analyse and interpret data meaningfully; convey ideas and results effectively; and work and learn both independently and collaboratively (Monash University Handbook, 2014). The Bachelor of Science Learning outcomes can be found in Appendix B. It is clear from these learning outcomes that the value of a science degree goes beyond students acquiring theoretical scientific knowledge. Engendered in the learning outcomes is a broad range of sophisticated skills associated with researching.

3.3 Studies exploring students' research skill development in the practical experience

Ways of enhancing undergraduate student learning in the science practical, includes a focus on students' generic and practical skill development (Beckman & Rayner, 2011; Johnson, Herd, & Tisdall, 2002). Students' research skill development however, as an acknowledged part of learning gained from the laboratory experience is generally only given a cursory mention (White, Benore, Sumter, Caldwell, & Bell, 2013). Few studies have explored the potential of the laboratory to develop students' cognitive skills related to research, explicitly and incrementally, as part of the practical experience (Chaplin, 2003; Peirce et al., 2009; White et al., 2013). The section that follows provides an overview of studies that have influenced the research presented in this thesis.

A study undertaken by White et al. (2013) in the field of biochemistry and molecular biology (BMB) sought to ascertain the skills students require to demonstrate proficiency for functioning in the laboratory environment. Methods included focus groups with science educators to identify and articulate the disciplinary skills students require. The authors note the critical importance of skills related to "experimental design, data interpretation, analysis, teamwork and, the ability to communicate findings to a diverse audience" (White et al., p. 297). The skills identified were gathered and then expressed as skill statements, before being organised and grouped into conceptual areas or categories relevant to the process of science. White et al. (2013) stressed the value of developing a framework of skills for organising and targeting desired student learning outcomes "for program development, teaching and learning methods and styles, and assessing student learning and abilities" (p. 301). Noting this deficiency, White et al. (2013) state that "in the effort to cover content, these skills are frequently ignored, avoided or assumed to be the responsibility of others to be fulfilled through institutional general educational requirements" (p. 297).

Another relevant longitudinal study was conducted in an undergraduate Human biology unit at the University of Adelaide, by Peirce, et al., (2009). This study employed the RSD framework to underpin learning activities so that research skills were made more explicit to the students. The RSD scaffolded students' research skill development in the activities by acknowledging incremental and increasing levels of learner autonomy.

An earlier study undertaken by Shepardson (1997) sought to determine the nature of student thinking by comparing structured inquiry and open inquiry laboratory treatments in bioscience by observing student-teacher interactions within laboratory activities. Shepardson (1997) sought to identify students' thinking skills for science through observation, noting that the method "allows inferences to be drawn about the classroom based on the observational data collected and methods of analysis" (1997, p. 38). Shepardson (1997) refers to skill categories in this observational study that share much in common with the RSD framework and include: information gathering, remembering, organising, analysing, generating, integrating and evaluating (1997, p. 39).

The studies listed below have aimed to gain an understanding of undergraduate students' research skill development and have employed either survey instruments, focus groups assessment and examination results, mapping exercises, and observational approaches. The studies by White et al. (2013), Peirce, et al., (2009) and Shepardson (1997) in particular have influenced the research question and the study design study adopted in this thesis.

1. Survey instruments administered pre and post learning experience or unit engagement Kardash (2000); Bauer and Bennett (2003); Leggett et al. (2004); Di Trapani and Clarke (2012); Willison (2012).

2. Student and educator interview/focus groups
Lopatto (2004); Luckie, Maleszewski, Loznak and Krha (2004); Seymour et al. (2004); Peirce et al. (2009); Lee et al. (2012); Willison (2012); White et al. (2013).

3. Student examination and assessment results
Luckie et al. (2004); Lee et al. (2012); Bugarcic et al. (2012); Peirce et al., 2011

4. Skill mapping of the STEM curriculum
Fraser, Crook and Park (2007).

5. Observation of students in the laboratory
Shepardson (1997).

3.3.1 BIO1022 Biology II: Unit structure

BIO1022 is a laboratory-based unit comprised of practical experiences. BIO1022 learning outcomes state the importance of students being able to demonstrate a sound understanding of foundational scientific concepts and theory, and a range of technical skills for the laboratory. Several BIO1022 learning outcomes encompass skills for researching for example; "utilise skills in the use of library catalogues and databases to locate published information and synthesize such into essays", and in "gathering data and analysing and presenting summative data in meaningful and accurate ways" and to "communicate scientific principles (Biology II: BIO1022 Practical Manual, 2014). The learning outcomes for BIO1022 can be found in Appendix C.

In order to gain an understanding of the particular research skills students might gain whilst engaged in the BIO1022 coursework practicals specifically, it was essential to become familiar with an additional set of learning aims that were stated for each practical experience. The topics and learning aims for BIO1022 practicals one to five can be found in Appendix D.

Students enrolled in BIO1022 are required to complete the six coursework practicals to meet unit requirements. Practicals one to three are designed as conventional 'recipe-driven' practicals and, practicals four and five are designed as inquiry-oriented learning (IOL) approaches and badged as IDEA (Idea-Design-Explore-Answer) experiments (Thompson et al., 2014). This provided an opportunity to compare and contrast the skills students are engaging with in conventional recipe-driven practicals with a purposefully designed IOL approach. Practical six was not conducted as a laboratory practical as this session was allocated for student groups to present on the topic of animal feeding and nutrition. There was little value in taking descriptive observations of the students' presentations as they were an outcome of preparation that was unable to be observed. Therefore practical six was not included. The learning outcomes suggest that the intention of this unit is for students to gain investigative skills by conducting experiments. Thus, BIO1022 was a suitable unit to apply the research objectives of this study. Furthermore, as a second semester unit, students are also becoming more familiar with applying theoretical learnings to experimental procedures in a laboratory setting.

3.4 Informing the methods: An overview of pilot studies

The research approach applied to this study was informed by three separate pilot projects undertaken in 2012 and 2013. These distinct but related projects were developed as part of my role as a librarian responsible for library programs that focus on embedding research skills within disciplinary curricula. The experience gained from collecting and analysing the data from the pilot projects have provided valuable insights to justify and support the choice of methodology, methods and phases of analysis. The pilot projects are briefly described here.

<u>Pilot project 1: The development of a research skills mapping tool (2012)</u>

A study to develop and test a skills mapping tool informed by the RSD framework at Monash University was initiated in 2012 through a library collaboration to support accreditation processes for the Bachelor of Pharmaceutical Sciences. Documentary analysis of unit guides was undertaken to identify specific research related skills. Identified skills were mapped to an RSD-informed Excel mapping tool developed for the project. Each identified skill was further analysed to evaluate whether it was taught, practised or assessed in respect to content and related activities. It was then aligned and mapped to student autonomy levels explicated in the RSD framework to gain a picture of how research skills were scaffolded across the degree. The findings indicated that in furnishing a consistent yet flexible language of research skill acquisition, the RSD is well suited to identify and map research skills in the curriculum (Stewart, Styles, Torres, and Horne, 2012).

<u>Pilot project 2: First year biological science student skill survey (2013)</u>

An online skill survey (adapted from Willison, 2012) was administered to first year biology students (BIO1011) at Monash University (N=1810). The survey sought to gain an understanding of students' self-perceived skills for research. Survey comments from respondents show that students are focused on achieving the requirements of the practical as a mere sequence of steps and lack awareness of the research skills they are using through laboratory activities. Students' lack of awareness of their research skill development has been substantiated in a study by Peirce et al. (2009) conducted at the University of Adelaide in a first year human biology unit.

Pilot project 3: Descriptive observations of students during the practical (2013)

Data were gathered by observing first year students whilst undertaking a laboratory practical for BIO1011 (N=8 students x 2 practicals). Descriptive observations were taken during the practicals to capture the interactions and behaviours between student pairs and their Teaching Associate (TA). Reflections, questions and insights that came to mind whilst transcribing the observations were noted. Transcribed data were analysed and interpreted to find emergent themes related to students' skill development. Themes were coded and mapped to the six facets of research of the RSD framework. This pilot study demonstrated descriptive observations of students' in the practical would not provide sufficient data for a comprehensive picture of students' research skill development to emerge. This highlighted the importance of triangulating the observational data with a document analysis of the BIO1022 laboratory manual. The method applied in this pilot informed the principle project presented in this thesis.

3.5 Ethics and recruitment of participants

Qualitative data collected for this research involved human participants – first year BIO1022 students at Monash University. An ethics application was prepared for the Monash University Human Research Ethics Committee. The Committee was satisfied that the proposal met the requirements of the National Statement on Ethical Conduct in Human Research and granted approval (CF14/2372 – 2014001290). Data sources consisted of (1) taking descriptive observations of participants in the learning setting - the laboratory practical and (2) document analysis of a curriculum artefact - the practical manual for BIO1022. The data was collected in relation to five compulsory coursework practicals for BIO1022.

Participants were introduced to the research project by the TA and students were then invited to participate in the study. Formal consent was sought from the students by a letter distributed in class. The letter explained the research purpose, how students would be observed within the practical, how the data would be collected and how the findings would be used. Student signatures were sought to verify their consent to participate. All students in the laboratory bay [N=8] consented to participate.

3.6 Research methodology

This study was informed by a qualitative research design underpinned by social constructivist epistemology (Vygotsky, 1978). Social constructivist theory suggests that learners construct knowledge and meaning from their experiences and play an active role in the construction of this new knowledge, this means that "students need to be actively, purposefully and energetically engaged in the process of learning, in order that meaningful learning takes place (Fraser & Deane, 1997, p. 27). Quantitative approaches draw upon and utilise "the methods and techniques of other traditions" in the search for meaning and understanding of complex interrelationships (Denzin & Lincoln, 2003, p. 10). Creswell (1994) defines the qualitative researcher as one who:

> *…undertakes qualitative research in a natural setting, where the researcher is the instrument of data collection, who gathers words or pictures, analyses them inductively, focuses on the meaning of participants, and describes a process that is expressive and persuasive in language* (p. 14).

Rudestam and Newton (2015) explain that in qualitative research emphasises processes and meanings over quantity and frequency. However, within a qualitative study where 'the currency of choice is words', a hybrid research approach may be appropriate to the context In this way, "words maybe coded, categorised and expressed in numerical form, and analysed quantitatively" (Rudestam & Newton, 2015, p. 39).

The intention of this study is not to arrive at a definitive or conclusive 'truth' or 'reality'. The objective has rather been to gain a clearer picture of the research skills students might be developing whilst engaged in their laboratory practicals. This study seeks to gain a deeper understanding of ways that social phenomena shape learning – students' research skill development in first year biology practicals.

This study is guided by the following research question:

With reference to the Research Skill Development (RSD) framework; which research skills and associated levels of autonomy, are students developing whilst undertaking practicals in BIO1022?

3.6.1 Descriptive observations of BIO1022 practicals

Denzin and Lincoln (2003) explain that qualitative researchers "deploy a wide range of interconnected interpretive practices, hoping always to get a better understanding of the subject matter at hand" and to make that world visible (p. 5). Observing students in the practical, taking descriptive notes of their behaviours and interactions and then applying interpretive processes to identify the research skills involved in these activities in alignment with a *priori* framework, appeared to be relatively unexplored in the literature. This gap inspired the decision to adopt rigorous and systematic fieldwork observational methods for data collection, taking the stance of a distant observer (Spradley, 1980). Observations involved prolonged engagement in the laboratory. Leech and Onwuegbuzie (2009), note that extended time in the field with the same group of participants contributes to the trustworthiness of the data as a greater understanding of culture and context is developed over time. To this end, five laboratory practicals for BIO1022 were attended and extensive observational field notes were collected over 5 weeks.

Experience gained from the pilot study in 2013 determined that the process of observing and taking notes of a laboratory bay of 16 students proved extremely difficult. Therefore, only one bench of the same eight students was observed in each practical. The interactions and conversations between the TA and student pairs were noted in the descriptive observations. The descriptive observations were then transcribed and the events were interpreted and coded thematically according to the skill categories in the RSD framework. The sections that follow describe the methods adopted during the phases of analysis in more detail.

3.6.2 The laboratory as research setting

BIO1022 practicals take place in a large laboratory environment that accommodates 96 students. Practicals were scheduled fortnightly over 12 weeks throughout the second semester. The laboratory is arranged in bays, comprising of 16 students across two benches, with eight students per bench. This seating is fixed for all practicals in the semester. The same TA is assigned to the group of 16 students. Practicals four and five as mentioned were IOL inspired practicals branded as IDEA experiments. The intention of the IDEA practicals is for students to take responsibility to develop their own experimental procedure in response to a scenario-based problem (Monash University, Biology II-BIO1022 Practical Manual, 2014). Practicals four and five were led by a different (specialist microbiologist) TA. The duration of each practical is three hours.

Each practical commenced with a pre-lab quiz on the topic to be investigated. All 96 students participated in the quiz. Students recorded their responses to the quiz using clickers. A presentation summarising the pre-lab readings, the scientific concepts and the experimental procedure was delivered by one of the Tutors. Critical points in the experiment were emphasised and students were given the opportunity to ask questions related to the practical.

A smaller classroom environment was achieved dividing the large space into two benches of eight students and one TA. The TA explained the experiment again briefly, demonstrated the use of scientific apparatus and the relevant techniques of the experiment. Another opportunity was provided for students to briefly ask the TA questions before commencing the practical.

The students worked through the experiment in pairs, guided by the instructional content of the laboratory manual and the TA. The TA walked from pair to pair and monitored how each student was managing their time. This provided opportunity for questioning and interactions between the TA and students. For example, the TA asked students to explain what part of the process they were up to, what they were doing and why. In this way, the TA provided opportunities for students to reflect, predict and summarise concepts and procedures, and to make corrections should they discover inaccuracies, discrepancies or issues in sequencing.

3.6.3 Fieldwork protocols

Being appropriately situated as researcher in a learning environment required careful consideration. The pilot study undertaken in 2013 concluded that assuming the role of participant observer would be disruptive to student learning, due to a lack of knowledge of both the discipline and laboratory processes. Spradley's observational protocols (1980) offer five types of observation from passive or detached participation to complete participation. The most suitable stance to take in an unfamiliar learning setting was of a detached observer. This observational method ensured a discreet presence, whereby student learning remained undisrupted. It is important to acknowledge that the observer cannot be separated from the object of inquiry (Hammersley, 1990) and the presence of an observer may create a hierarchy of power that alters the behaviour of those being observed, known as the Hawthorne effect (Rudestam & Newton, 2015). To minimise the Hawthorne effect, a repeated presence in practicals each fortnight ensured students' familiarity with my presence.

The protocols employed for observing students included applying a systematic way of capturing field notes. The observational matrix template offered by Spradley (1980) was attempted in the pilot study. This involved making observational notes using a matrix populated by questions relating to space, object, act, activity, event, time, actor, goal and feeling. This matrix proved too complex for observing four student pairs engaging in laboratory activities. Creswell (2009) offered an adapted observational protocol based on Spradley's matrix that captures descriptive notes and reflections as they arise (Creswell, 2009, p.137). Creswell's simplified approach informed the design of the template that was employed for observing students in this study. This template focused on capturing notes that incorporate the following elements; time, people in the setting, events, individual behaviours, transactions between the student pairs and the TA, thoughts, ideas and questions as they come to mind (See Appendix E).

Descriptive observations were captured electronically using an iPad with Evernote software. The notes were then imported directly to NVivo®11 qualitative analysis software. Observations were re-read and additional thoughts and insights captured as memos in NVivo. This process is explained in more detail in sections that follow.

3.6.4 Content analysis of BIO1022 practical manual

Content analysis is defined by Silverman (2006) as a method where researchers "establish a set of categories and then count the number of instances that fall into each category" (p. 159). Therefore, in the search for meaning in complex relationships "words may be coded, categorised and expressed in numerical form, and analysed quantitatively" (Rudestam & Newton, 2015, p. 39). The value of including a content analysis of the BIO1022 practical manual is that it offers a view into the practicals not possible through observations of students alone. The content, structure and language used in the practical manual provide information about how research skills are communicated by science educators to students and the consideration given to the development of these skills. The descriptive observations were triangulated with the BIO1022 practical manual. The manual contributed to the emergent picture of students' research skill development in the practical experience. Components of the practical manual that were relevant to this study were; the learning aims for each practical, the instructional content for the experimental procedures and the instructions for assessment activities and tasks. The products of assessment that students completed outside the practicals were not included in this study. Practicals observed were Practicals one to five. Practical six was not included as this session was allocated to student presentations and preparation towards the presentations was unable to be observed.

3.7 Analysis of data sources

A content analysis of the research skills embedded in the BIO1022 practical manual and analysis of the research skills students were observed using in each corresponding practical was undertaken. Identifying research skills in the data sources involved applying interpretive analysis techniques (Strauss & Corbin, 1998). Strauss and Corbin (1998) explain that "analysis is not a structured or static rigid process", it is "free-flowing and creative", and where the analyst moves back and forth through the data during the coding phases (p. 58). Creswell (1994) succinctly describes the qualitative analysis as a "sorting procedure" with no one right way of conducting it (p. 764). The qualitative approach adopted for this study focuses "systematically on the cultural behaviours and events recorded in field notes and from artefacts specific to the domain to reveal patterns, relationships and language" (Spradley, 1980, p. 95).

Strauss and Corbin (1998) stresses the importance of clearly showing how the phases and processes of analysis have been approached to clarify how relationships were drawn among concepts emanating from the data. The analytical procedures applied in this study reduced skill concepts in the data sources to central categories informed by the 'Facets of Research' and 'Extent of Student Autonomy' as explicated by the RSD framework. In this way, the RSD framework served as the schema through which research skills were interpreted. Coding categories (nodes) were created in NVivo (11) qualitative analysis software based on the descriptors and skill categories of the RSD framework. NVivo offered a robust yet flexible project architecture to systematically guide the process of data analysis and the means to organise, manage and store, coded data.

Silverman (2006) notes the critical importance of "categories being sufficiently precise to enable different coders to arrive at the same results with the same body of material" (p.

159). Coding decisions in this study were reviewed by a 'category challenger' with relevant expertise in the unit investigated from another institution. Coding was undertaken over two iterations to review coding decisions before coming to a final coding conclusion. The reporting functionality offered by NVivo enabled results to be exported to Microsoft Excel (Professional Plus 13) and represented in graphs as frequency counts.

This section describes how the architecture for the analysis phase of the research was developed and how the methods of analysis and interpretation were applied to uncover patterns and themes in the data sources.

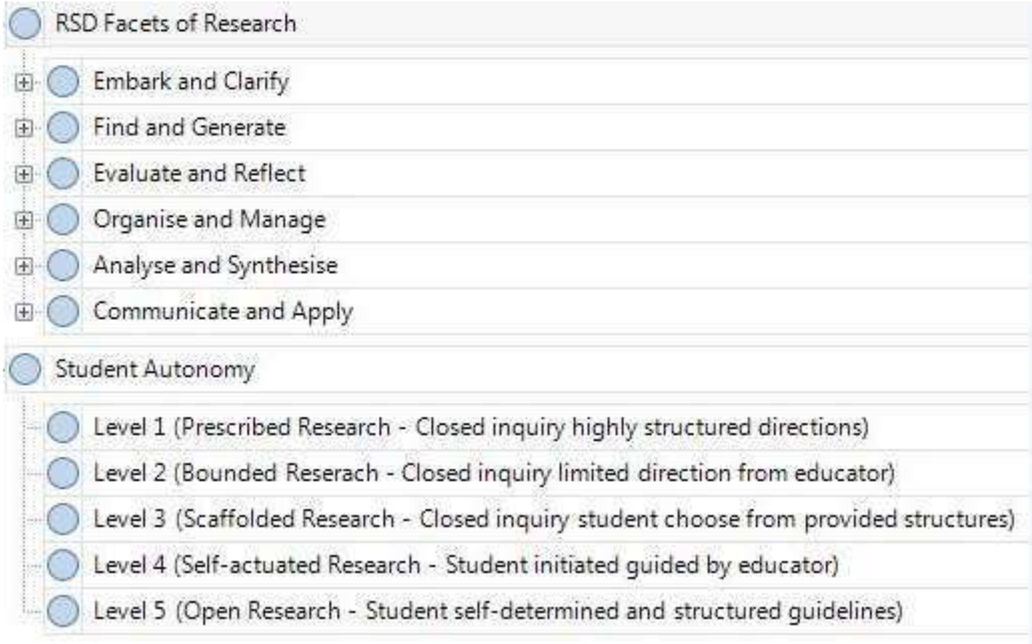
3.7.1 Phase 1: Creating the project infrastructure using NVivo qualitative data software

Creating a robust project infrastructure in NVivo was essential for all phases of data analysis and interpretation. By preparing a directory folder structure in NVivo and labelling each folder according to date and the topic of the practical, a logical foundation was systematically laid for this study. The transcripts of the descriptive observations of each practical were exported from Evernote and imported to the appropriate folder prepared in NVivo. Once imported to the NVivo project, memo documents were generated in NVivo that corresponded to each practical to capture the descriptive observations and the practicals as outlined in the practical manual. This enabled the means to capture any comments, insights and reflections from the data sources as they came to mind. It is important to note that descriptive observations were transcribed directly after each practical concluded while the event was still fresh. Notes were revisited so that additional details could be recalled and noted. This iterative method supported the evolutionary process of growing ideas as they developed (Creswell, 2009).

3.7.2 Phase 2: Creating a coding matrix

As previously described in chapter one, the vertical axis of the RSD framework, the Facets of Research, articulates the skills and processes of research. The horizontal axis of the RSD framework, the Extent of Student Autonomy, provides descriptors ranging from low student autonomy (Prescribed research) to high autonomy (Unbounded research). The axes were captured as separate nodes in preparation for coding the data sources. Figure 2.1 below shows how the axes of the RSD framework were structured and represented as a coding matrix in NVivo (11) qualitative analysis software.

Figure 3.1 Coding matrix informed by the RSD framework Facets of Research and Student Autonomy using NVivo (11)



3.7.3 Phase 3: Coding the data from descriptive observations

Data elements in the observational notes consisted of the interactions, conversations and behaviours of the students participating in the laboratory practicals. Sorting and making sense of the data involved transcribing notes soon after they were taken and conducting subsequent detailed readings in order to proceed through each analytical phase. The first phase of analysis involved open-coding (Glaser & Strauss, 1967). This involved analysing the events and interactions in the observational data and the content of the practical manual for themes, patterns and associations that related to a facet of research of the RSD framework and the corresponding level of Student Autonomy interpreted for the skill. The phases of analysis revealed a comprehensive set of context and disciplinary relevant subskills related to the broader skills or Facets of Research of the RSD framework.

3.7.4 Identifying subskills in the data

Coding decisions were revised through multiple coding episodes as part of an iterative analytical process (Spradley, 1980). This process allowed the emergent research skills identified in the data sources to be compared, contrasted and aligned with the research skill facets and levels of student autonomy of the RSD. To gain a deeper understanding of context and disciplinary specific research skills relevant to student learning in the laboratory, the events in the data sources related to research skills were articulated as a skill statement to arrive at a set of subskills. In this way research skills relevant to the specific context of the practical emerged.

To guide the process of identifying and articulating the subskills, the Biology Threshold Learning Outcomes were referenced to assist with the language used in science education (Ross, Taylor, Johnson, & Jones, 2013). The process of creating sub-categories from broader categories is known by grounded theorists as axial-coding (Strauss & Corbin, 1998). The identification and articulation of subskills provided the granularity required to identify disciplinary specific research skills in activities, events and instructions appearing in the BIO1022 practical manual and within the practical experience.

Please see Appendix F for the subskills related to the RSD Facets of Research that emerged during the process of analysing the descriptive observations and the content of the practical manual.

The process of analysis required relevant events and interactions related to students' skill development to be interpreted in alignment with the RSD framework. Deciding which facet of research each skill corresponded to was not always a straightforward process. Making coding decisions was reliant on determining the best fit for the skill identified in each data source based on where the skill logically occurred.

Each skill drawn from the data was also considered in terms of how independently the students were performing the skill. Therefore, analytical processes also involved attributing and coding the skill against a corresponding level of student autonomy from the RSD framework. The skill categories were revisited, revised and refined as the process of analysis progressed to gradually build a picture of skills emergent in the data and their corresponding level of student autonomy. The process of coding skills to student autonomy during the second iteration of coding provided an additional opportunity to gain further insights to how autonomy was being developed in the practical.

The ability to attribute data to predetermined codes and to create additional nodes during the process of analysis meant that the interpretive and iterative process of analysis and coding was not compromised. Working with the data therefore proceeded through the stages of inductive and deductive analytical techniques to gradually move from a "descriptive personalized view of the text to an increasingly conceptual and theoretical understanding of the participants' experience" (Rudestam & Newton, 2015, p. 220).

The analytical process applied aligns with Creswell's (2009) definition of the qualitative researcher developing themes from the "bottom-up", which involves the process of "working back and forth between themes and the database" until a comprehensive set of themes emerge (p. 39).

3.7.5 Phase 4: Coding the data from the practical manual

The practical manual is a document provided to students undertaking BIO1022. Silverman (2014) explains that written organisational documents exemplify many important features that contribute to depicting the setting being observed, as the construction, layout and language of the document offers another view to understanding a given social situation (p.281). Hodder (2000) expounds that the interpretation of documents contributes to context definition by drawing comparisons between the spoken and active situation, thus "texts can be used alongside other forms of evidence so that the particular biases of each can be understood and compared" (p. 394). The practical manual for BIO1022 provides background and guidance on the topics that were covered in each practical. The content of the manual includes: the learning aims of the practical, an overview of the topic and the experimental procedure; diagrams and visual information; learning activities and assessment tasks.

As a documentary data source, the internal structures and content of the practical manual provide valuable insights into what science educators consider important in the laboratory experience, including the value placed on students' research skill development. The practical manual therefore complements the descriptive observational data by offering another window through which to interpret and build understandings relevant to students' research skill development. The elements analysed in this curriculum artefact included: the learning aims, instructional information on experimental procedures; and instructional information for assessment tasks. These elements were thematically analysed, interpreted and coded using the same interpretive and reflexive method applied to the observational transcripts.

3.8 Trustworthiness and strengths of the research approach

In recognising the importance of qualitative criteria such as trustworthiness, credibility, dependability and confirmability to support rigour, several approaches were applied to this project to ensure a robust research design. In order to gain a picture of students research skill development in BIO1022 practicals, this study is underpinned by an empirically tested conceptual framework, the RSD framework. It is important to note that that this study was designed based on prior knowledge and experience of the RSD framework. Subjectivity to this regard was addressed by selecting to apply the RSD in unfamiliar territory - the biology laboratory practical.

Triangulation of data, the process of combining and comparing findings from different data sources enhances rigour and support trustworthiness in the research approach (Silverman, 2006). Data collected through two methods - descriptive observations obtained over time, supported with a document analysis of the practical manual, presents the triangulated approach applied to this study to enhance the trustworthiness and credibility of the findings and contribute to reducing personal subjectivity.

Creswell (2009) notes the importance of having the study "reviewed and corrected by participants or other researchers" as a validation strategy (p. 45). With this in mind, the interpretive processes applied during the data analysis and coding phase were reviewed

by a ‘category challenger’. The challenger was a PhD qualified tutor with previous experience as a
TA in first year biology at The University of Sydney. The perspectives and argument contributed by the challenger enabled the process of interpreting, identifying and articulating the skills emergent in the data and the student levels of autonomy to be clarified and refined. A more precise articulation of subskills within the broader skill categories of the RSD has in this way been achieved. The incorporation of quantitative representation of data through numerical frequency counts further contributes to verifying the interpretation of the findings and the story being told. A methodical approach utilising an empirically researched conceptual framework may also support the transferability of the findings to other science disciplines where the practical is core to student learning.

3.9 Limitations and generalisability

Methodological limitations of this study include the small data sample and variables associated with the teaching methods of the TAs and differences in structure of the practicals. This may affect generalisability as BIO1022 coursework structures, teaching methods and cohorts in other university contexts may differ. Limitations will be discussed in more detail in Chapter five.

Chapter Four: Results

4.1 Introduction

The literature rarely draws parallels between the higher-order thinking skills undergraduate students require for learning in the practical arena, with the foundational skills needed for researching. This would suggest that a range of skills potentially inculcated through the practical experience are overlooked as potential outcomes of learning. This study has sought to identify and garner an understanding of the research skills developed by students in a practical-based, first year biology unit through the application of the RSD framework. The purpose of applying the RSD was to consider its usefulness as a construct through which to identify students' research skill development within this learning context. The research question informing this study was:

With reference to the Research Skill Development (RSD) framework; which research skills and associated levels of autonomy, are students developing while undertaking practicals in BIO1022?

4.2 Results overview

The structure of the unit BIO1022 afforded an opportunity to compare students' research skills developed through recipe-driven practicals with an Inquiry Oriented Learning (IOL) inspired approach branded as IDEA (Idea-Design-Explore-Answer) experiments.

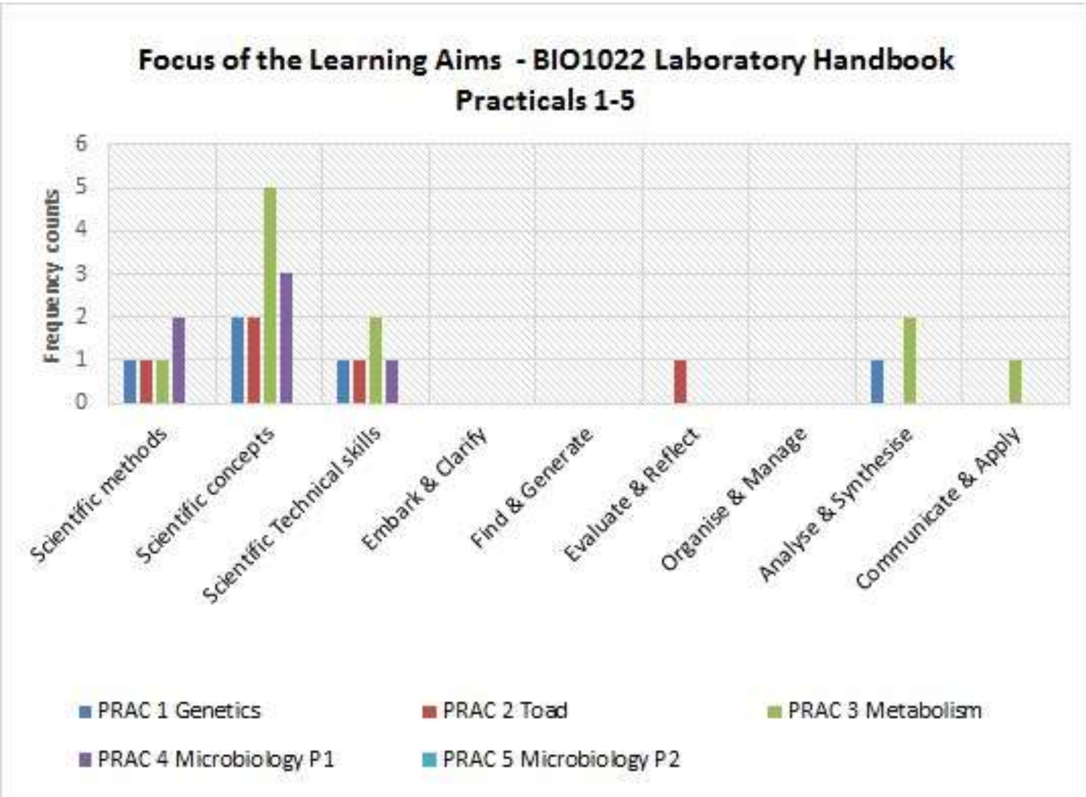
A primary finding of this study is that research skills are an overlooked element in the unit design, despite students engaging with a broad range of research skills and processes in the practical. The instructional content of the practical manual and the practicals themselves were predominantly categorised within the Prescribed levels of autonomy, as defined by the RSD framework. Where the instructions of the practical manual were communicated with an expectation that students had developed the ability to perform skills at a higher level of autonomy, observational data showed that students needed considerable guidance from the Teaching Associate (TA) to perform a range of research skills. The contrasting teaching styles of two different TAs delivering the recipe-driven and the IOL-inspired IDEA experiments provided insights as to what might be required to increase students' ability to become more autonomous in using research skills.

The sections that follow present results identifying students' research skills and their development in BIO1022 practicals one to five, commencing with an analysis of the unit's learning aims. Analysis then moves to interpreting research skills across the unit through the practical manual and the student observations. A detailed analysis of each practical is then provided, followed by a granular perspective which is presented through the identification and articulation of subskills related to the Facets of Research. Results presented graphically are shown as aggregated occurrences.

4.2.1 BIO1022 learning aims

Figure 4.1 below presents an analysis of the stated learning aims for BIO1022 Practicals one to five (see Appendix D for the full list of learning aims). Each learning aim was thematically interpreted for learning emphasis in alignment with the RSD Facets of Research. Results show that acquiring scientific methods, scientific concepts and scientific technical skills appear recurrently in the learning aims, in contrast to the lack of emphasis placed on higher-order thinking skills for research.

Figure 4.1 Analysis of BIO1022 learning aims in the BIO1022 practical manual for each of the five practicals examined



Learning aims related to research skill development in the practical manual are stated in broad terms. For example, 'To develop skills' (Practical two), or 'To further develop skills' (Practical three). The learning aims only use research-related terms in Practical two, for example: 'To interpret', 'To identify' and 'To investigate'. Practical four (Part one Microbiology) and five (Part two Microbiology), designed as IDEA experiments, do not articulate skill development as an outcome of learning. Practical five omits learning aims in the practical manual, and is therefore are not represented in Figure 4.1 above. IDEA practicals did not articulate skill related learning aims despite these practicals aimed to:

> *...align with the fundamental principles of a tertiary science education, in which students build upon prior knowledge, refine skills and apply higher order learning*

such analysis, evaluation and synthesis to their critical thinking and problem-solving skills (Thompson et al., 2014, p. 8).

Analysis of the BIO1022 learning aims corresponds with the science education literature which notes a higher emphasis placed on acquiring laboratory technical skills versus higher-order thinking skills related to research (Di Trapani & Clarke, 2012). Although research skills are generally overlooked in the BIO1022 learning aims, the results presented below show that students were applying research skills throughout the unit.

4.2.2 RSD Facets of Research and the Level of Student Autonomy identified across BIO1022 Practicals one to five.

Analysis of the BIO1022 practical manual and observations show that the unit engages students with all research skills described by the RSD, to varying frequencies and varying levels of autonomy (Figures 4.2a and 4.2b). The Prescribed level of autonomy dominated both the instructional content and the practical experience, conforming to the transmissive nature of highly guided 'recipe-driven' instructional approaches. For example, Figure 4.2a, captures Facet B: Find and Generate at the Prescribed level as the most frequently occurring skill in the manual across all practicals. This is not surprising given the instruction required to step first year students through experiments and procedures involving data generation. In contrast, Figure 4.2b shows that Facet A: Embark and Clarify recorded the highest frequency counts across all practicals observed, suggesting students needed considerable clarification before commencing the experiment, and guidance to this effect from the TA.

Figure 4.2a. Number of instances each Facet of Research and Level of Student Autonomy is identified in the instructional content of the practical manual

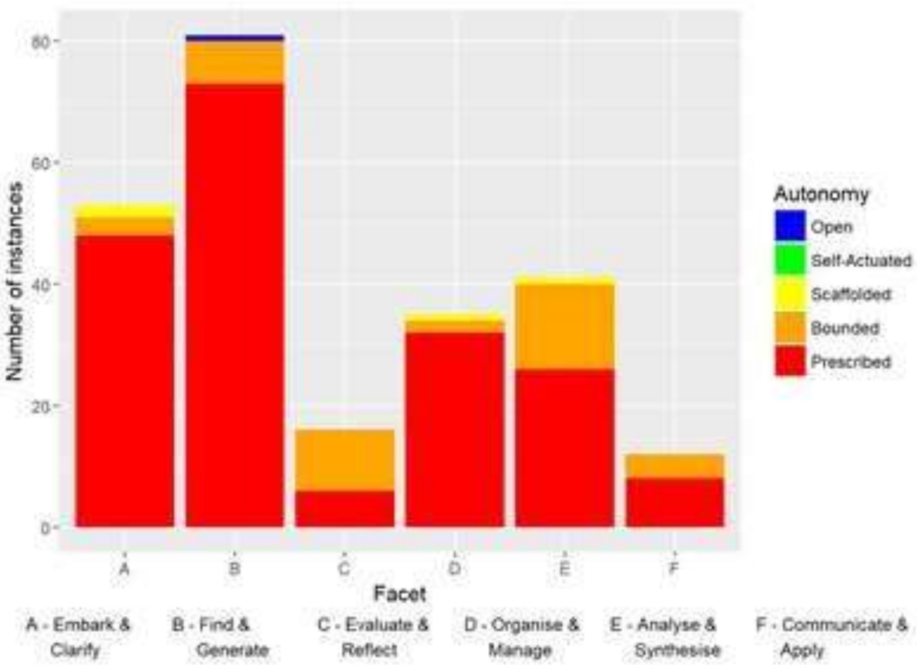
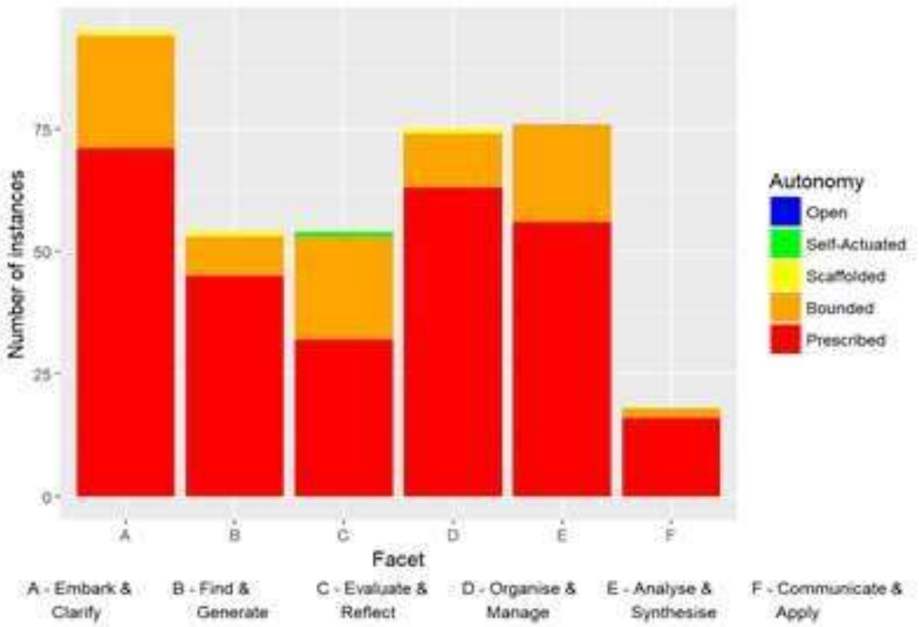


Figure 4.2b. Number of instances and the Level of Student Autonomy for each Facet of Research was observed in each practical



Although the instructional content was largely Prescribed, the manual content also conveyed instructions at higher levels of autonomy (Fig. 4.2a). Scaffolded skills occurred in the practical manual (Figure 4.2a) in relation to Facets A: Embark and Clarify, Facet D: Organise and Manage and Facet E: Analyse and Synthesise. Self-Actuated research was not identified, and a single instance of Open Research was noted.

Although Facet C: Evaluate and Reflect and Facet E: Analyse and Synthesise occurred with less frequency in the manual (Figure 4.2a), these skills were captured at significantly higher levels of autonomy than other Research Skill Facets. Yet, observational data (Figure 4.3b) students needed considerable guidance from the TA to perform the skills of evaluation, reflection, analysis and synthesis, as occurrences of Prescribed autonomy increased for these skills. Hence, when students *were* guided to evaluate, reflect, analyse and synthesise through the instructional content of the manual, Figures 4.2a and 4.2b show, the skills attributed proportionately higher levels of autonomy in the practical in comparison to other Facets.

Results for Facet F: Communicate and Apply (Figure 4.2a) capture instructional content in the practical manual where students were directed to communicate scientific understandings. Facet F: Communicate and Apply (Figure 4.2b) shows occurrences of students applying these skills within the practical, through interactions between student pairs, prompts by the TA, and where students were observed responding to written activities from the manual. Figures 4.2a and 4.2b show that Facet F is the most underrepresented skill range across the unit, however the low occurrence of communication skills may reflect a limitation of this study.

The following graphs (Figures 4.3a and 4.3b) illustrate students' research skill development within each practical experience.

Figure 4.3a. Number of instances each Facet of Research and the corresponding Level of Student Autonomy was noted in the practical manual for each practical

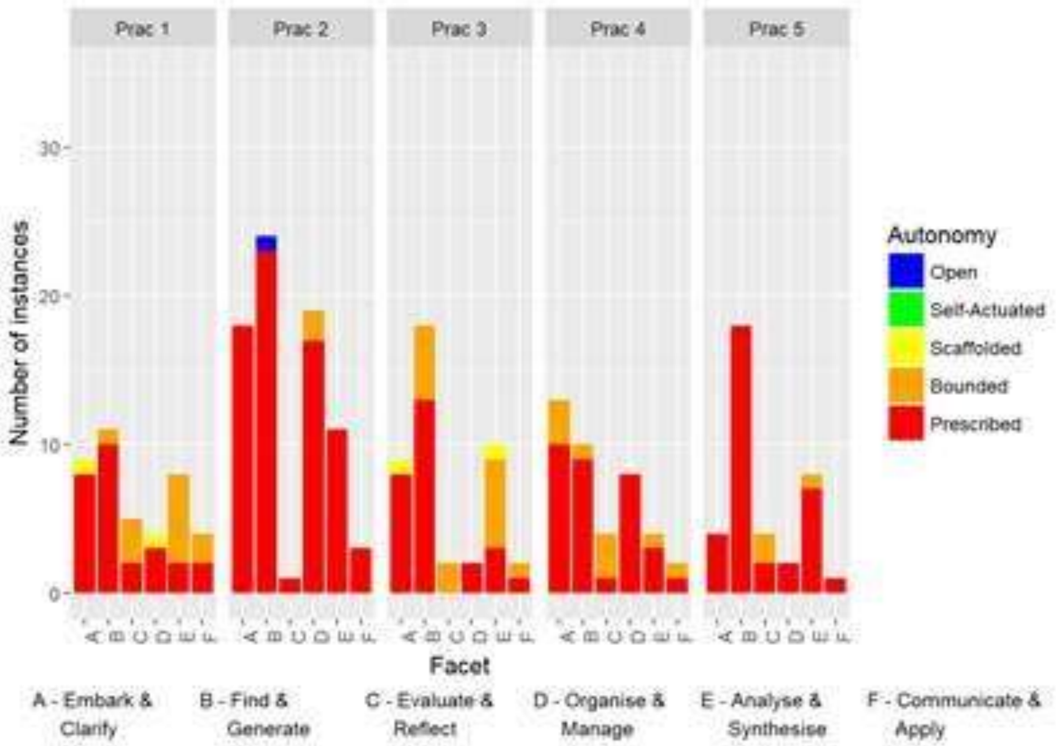


Figure 4.3b. Number of instances each Facet of Research and corresponding Level of Student Autonomy was observed in each practical

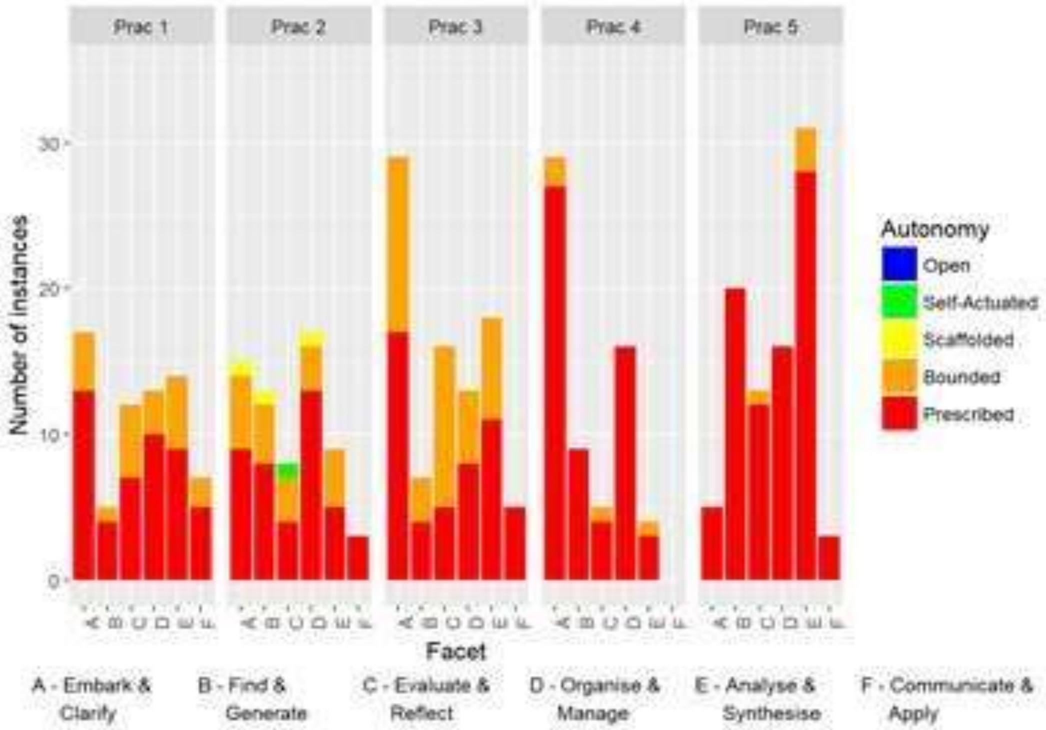


Figure 4.3a above shows the emphasis placed on each Facet of Research in the practical manual and the level of autonomy attributed to each Facet in each practical. Figure 4.3b above shows the emphasis placed on each Facet of Research in the observations and the level of autonomy attributed to each Facet in each practical. All Facets of Research were represented in each practical, but again mainly at the Prescribed level of autonomy.

Practical one showed that the instructional content of the practical manual (Figure 4.3a) was predominantly prescribed, particularly for Facet B: Find and Generate. Facet A: Embark and Clarify also occurred mostly at Prescribed levels, however Facet A moves quickly into Scaffolded instruction as does Facet D: Analyse and Synthesise. There was also an expectation that students had skills to work beyond Prescribed levels and into Bounded levels of autonomy for Facet C: Evaluate and Reflect and Facet F: Communicate and Apply. In contrast, Figure 4.3b shows that students needed close guidance at the Prescribed level to perform all Facets of Research, particularly Facet C: Evaluate and Reflect and Facet D: Analyse and Synthesise.

Practical two, involving a toad dissection was highly guided in the instructional content of the practical manual (Figure 4.3a), particularly in relation to Facet A: Embark and Clarify and Facet B: Find and Generate. Facet B also shows the only occurrence of Open research, which appears unexpectedly. The manual directs students to:

> *Do your own research to find the information using resources other than your textbook* (Practical two: Toad dissection, practical manual).

The highly autonomous directive suggests that students have previously acquired and honed skills to undertake a literature-based activity at this level of sophistication. Yet, there is no indication in the manual of students having previously practiced literature-based research activities to complete the task to the degree of autonomy expected.

Although Facet C: Evaluate and Reflect was negligible in the manual, (Figure 4.3a) students applied evaluation and reflection skills within Bounded and Scaffolded ranges of autonomy in the practical itself (Figure 4.3b). Observational data related to these events shows how a prescribed directive led to increased levels of autonomy in application. For example, the practical manual (Figure 4.3a) directed students though a Prescribed statement to decide who would dissect the toad and who would take notes. Observing the interaction between students (Figure 4.3b) shows that this instruction elicited ethical concerns. The extract below indicates that although the manual directed students at a Prescribed level to assign roles, the directive resulted in students engaging with evaluation skills at a sophisticated level.

> *Student pairs seem to have already negotiated roles according to which student will dissect the toad and which student will take notes. One student pair have not come to a decision yet. They discuss how they feel about the dissection, one student says, "I'm uncomfortable about this - ethically"* (Practical two Toad Dissection, observations).

Practical two recorded the highest occurrences of Facet D: Organise and Manage across the unit in the manual, which may be attributed to the number of instructions required to guide students through the delicate processes of dissection. However, Figure 4.3b shows that Facet D: Organise and Manage occurred proportionately to Facets A and B in the practical. The manual, as shown in Figure 4.3a, provided Prescribed direction for Facet D: Analyse and Synthesise, with students moving to Bounded levels of autonomy in the practical for this Facet (Figure 4.3b).

Practical three shows that instructional content in the manual (Figure 4.3a) for Facet C: Evaluate and Reflect only provides instruction at Bounded levels of autonomy. The observations (Figure 4.3b) show students working at both Prescribed and Bounded levels for this Facet, suggesting that they needed support from the TA to apply these skills. Results from the manual (Figure 4.3a) imply that students have the ability to use analysis and synthesis skills with more sophistication, as Facet D captures both Bounded and Scaffolded instructional content. However, the observational data (Figure 3b) shows that students required guidance from the TA during the practical to be able to apply evaluation, reflection, analysis and synthesis skills and that they were underprepared to work at the

Scaffolded levels expected. Practical three also shows students engaging proportionately more with all Facets except for Facet F: Communicate and Apply.

Despite the IOL intentions of IDEA practicals four and five, these practicals remained highly prescriptive and restrictive in both instructional content of the manual (Figure 4.3a) and the practical itself (Figure 3b). The highly guided teaching methods used by the TA to step students through the experiment in practicals four and five provided little opportunity for students to progress along the autonomy continuum. There was an expectation in the manual instruction (Figure 4.3a) that students would be able to work at bounded levels for Facets A, B, C, E and F in practical four, however observations (Figure 4.3b) show that prescriptive guidance increased in the classroom. In practical five, students did not move beyond Prescribed levels for Facet A: Embark and Clarify, Facet B: Find and Generate and Facet D: Organise and Manage.

Figure 4.3b shows that although students generally engaged with skills at higher levels of autonomy in Practicals one to three, IDEA Practical five showed the highest frequency counts for Facet B: Find and Generate, Facet C: Evaluate and Reflect and Facet D: Analyse and Synthesis, albeit at the Prescribed level. This might suggest that practicals which take place over two sessions provide more time for students to engage with research skills despite the influence of highly guided teaching methods.

4.3 RSD Facets of Research, Student Autonomy and related subskills across the unit

The following figures 4.4 to 4.10 present a more granular view of each RSD skill facet by presenting the subskills that emerged during the process of analysing the practical manual and student observations for each practical.

Figure 4.4. Facet A: Embark and Clarify: Subskills identified in the practical manual and student observations across all practicals

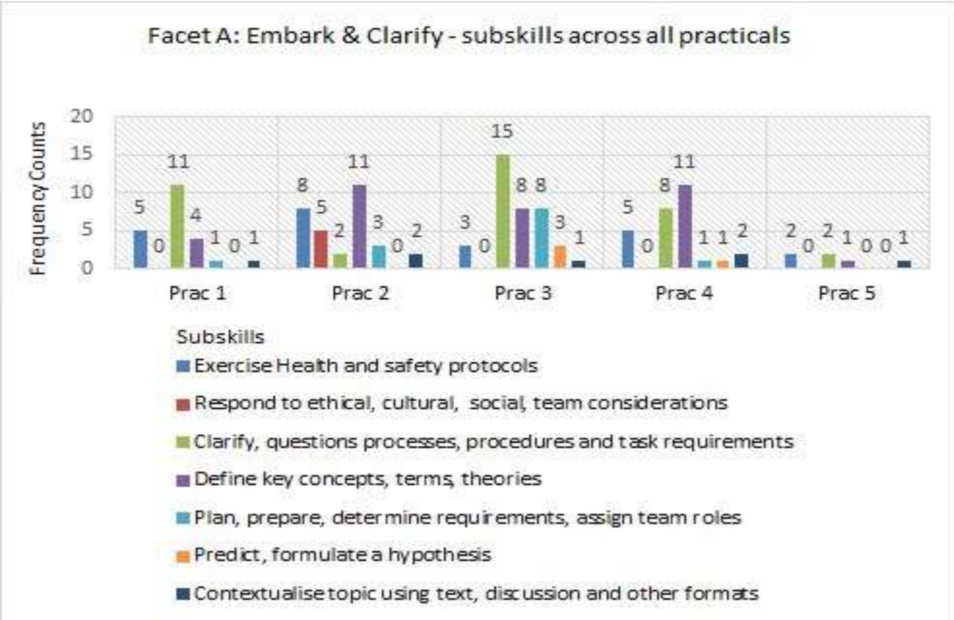


Figure 4.4 above shows the skills pertaining to RSD Facet A: Embark and Clarify, where students respond to or initiate research, "clarifying or determining what knowledge is required, heeding ethical, cultural, social and team considerations" (Willison & O'Regan, 2006, 2016).

Subskills related to Facet A: Embark and Clarify (Figure 4.4) were generally exhibited as part of clarifying laboratory, experimental procedures and terminology. The laboratory manual generally guided students to clarify concepts, procedures, and terminology before undertaking the experiment.

> *"In the instructions which follow, standard terms to describe spatial relationships within the animal have been used. To ensure that you understand these instructions, it is necessary for you to understand the terms"* (Practical two: Toad dissection, Practical Manual).

Students exemplified Facet A in the practical by checking their pre-lab notes, discussing the topic and experimental processes in pairs or with the TA and by referring to the laboratory manual. For example:

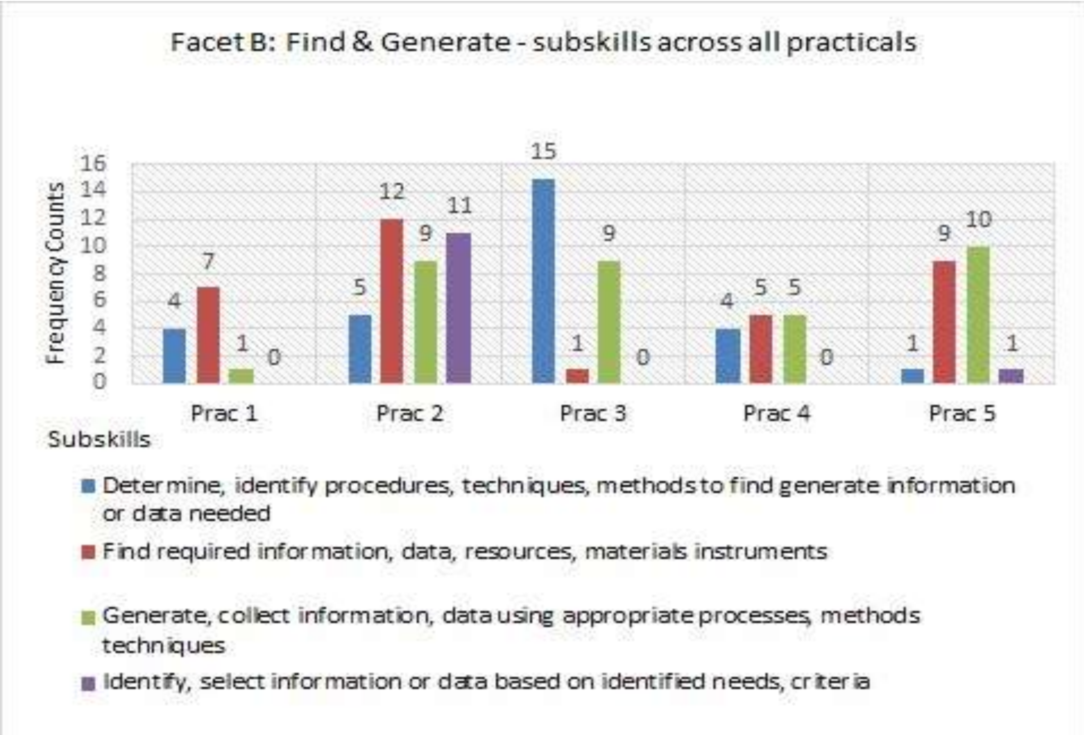
> *"Students were reading over their pre-lab notes, one student pair were cross referencing each other's notes looking confused as the TA*

> *introduces the topic. The students waited to ask a question"* (Practical three: Metabolism, Observations).

Practical three was the only practical that provided students with formal instructions to formulate a hypothesis based on readings. Guided questioning from the TA in practical three; however, prompted students to predict what would happen in the experiment. Students applying planning skills associated with Facet A were mostly noted in practical three. Planning skills were not apparent in observational data gathered from Practicals four and five, possibly due to the highly-guided teaching style of the TA.

Figure 4.5 below shows the skills pertaining to RSD Facet B: Find and Generate, described as skills where students "find and generate needed information/data using appropriate methodology" (J. Willison & O'Regan, 2006/2013).

Figure 4.5. Facet B: Find and Generate: Subskills identified in the practical manual and student observations across all practicals



Subskills related to Facet B: Find and Generate (Figure 4.5) involved processes related to gathering information, scientific instruments, or generating data as part of the process of conducting experiments. Practical two shows students engaging with this skill range more frequently than other practicals, possibly due to the complex nature of the toad dissection. Practicals one and four showed that Facet B skills were used less frequently and the need to identify and select information to support the experimental procedure was not demonstrated. Practical three showed the highest occurrence of students applying procedures and techniques to Find and Generate data.

Observational data capturing Facet B subskills is shown in the following examples:

> *The students refer to manual to find out where they should be looking. One student points out the pancreas.* (Practical two: Toad Dissection, Observations)
>
> *The student pair keep going over the notes they prepared before coming to the practical, back and forth trying to find the answer* (Practical one: Genetics, observations).

The practical manual exemplifies Facet B through the following example:

Using the textbook, and your lecture and practical notes, make sure you understand and are able to define the following terms… (School of Biological Sciences, Biology II-BIO1022 Practical Manual 2014)

Practical five showed higher frequency counts for generating data possibly due to this practical being the second part of a two-part practical allowing more opportunity for students to engage with finding and generating skills.

Students heat the wires and make stripes with the wires on the dish. They appear to know what they are doing from the last practical and are confident in their approach to the experiment. (Practical five: Microbiology Part two, observations).

Figure 4.6 below, shows the skills pertaining to RSD Facet C: Evaluate and Reflect, where students 'determine and critique the degree of credibility of selected sources, information and of data generated and metacognitively reflect on processes used'.

Figure 4.6. Facet C: Evaluate and Reflect Subskills identified in the practical manual and student observations across all practicals

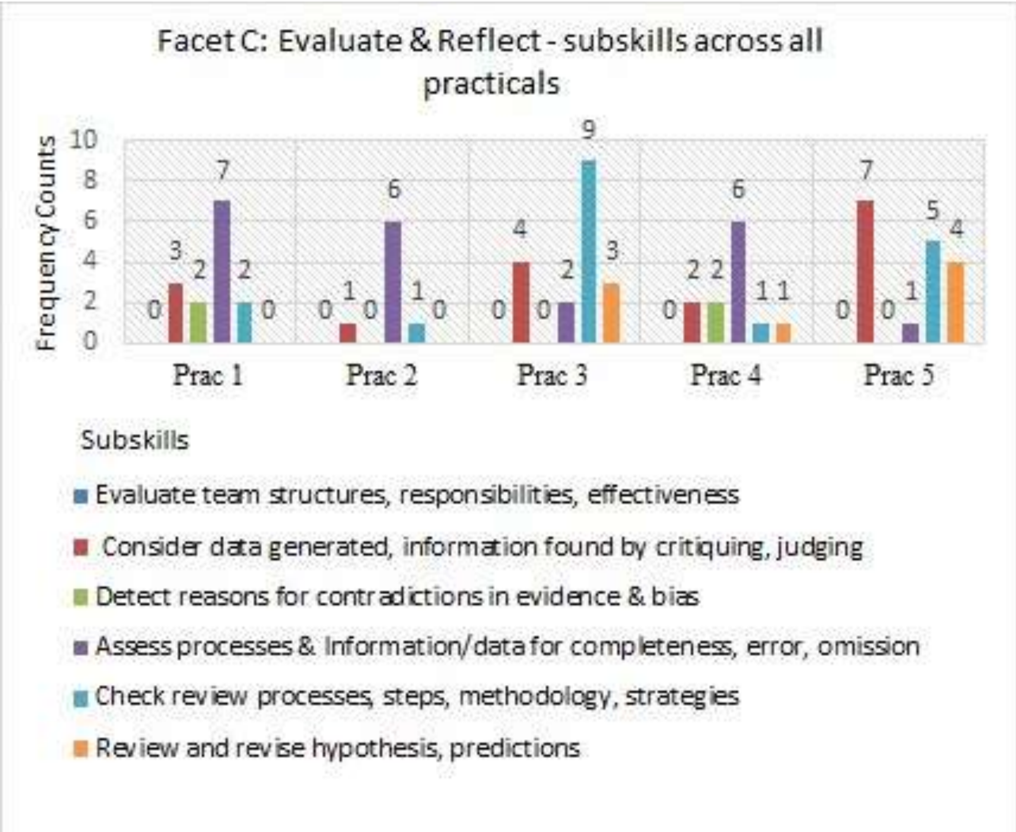


Figure 4.6 above shows that subskills related to Facet C: Evaluate and Reflect were identified less frequently in the instructional content of the laboratory manual than the subskills related to other RSD Facets. Questioning from the TA in practicals one to three enabled students to apply these skills at increased levels of autonomy. Sophisticated questioning appeared to be

paramount for activating evaluation and reflection skills and prompting students' thinking, thus moving students from Prescribed to the Bounded Level of Autonomy. This was particularly evident in practical three:

> *"The TA keeps asking students questions at the fume cupboard while they wait in line. "What have you already added?" she asks. "What is the difference?" "Why? Why add different solutions? What are you looking at? Why? So what do you think?" The TA persists with questions. One student turns excitedly to her partner. "I know!" she says and explains to her partner what could happen when…"* (Practical three: Metabolism, Observations).

A single instance of students evaluating team structures, responsibilities and effectiveness was noted across practicals. This event occurred in practical two on the toad dissection. A Prescribed directive in the manual instructed students to decide who would dissect the toad and who would take notes. Students negotiated roles in respect to their ethical concerns, displaying Self-Actuated autonomy.

> *"The student pairs seem to have already negotiated roles according to which student will dissect the toad and which student will take notes. One student pair have not come to a decision yet. They discuss how they feel about the dissection, one student says, 'I'm uncomfortable about this - ethically'"* (Practical two: Toad Dissection, Observations).

During practical two, sophisticated examples of students 'evaluating team effectiveness' was also observed. At times, a student would become detached from this practical. The other students, noting their team member's discomfort, supportively brought them back into the laboratory activity.

Figure 4.7 below shows Facet D: Organise and Manage, where students *"organise information and data to reveal patterns and themes, and manage teams and research processes*" (Willison & O'Regan, 2006, 2016).

Figure 4.7. Facet D: Organise and Manage subskills identified in the practical manual and student observations across practicals.

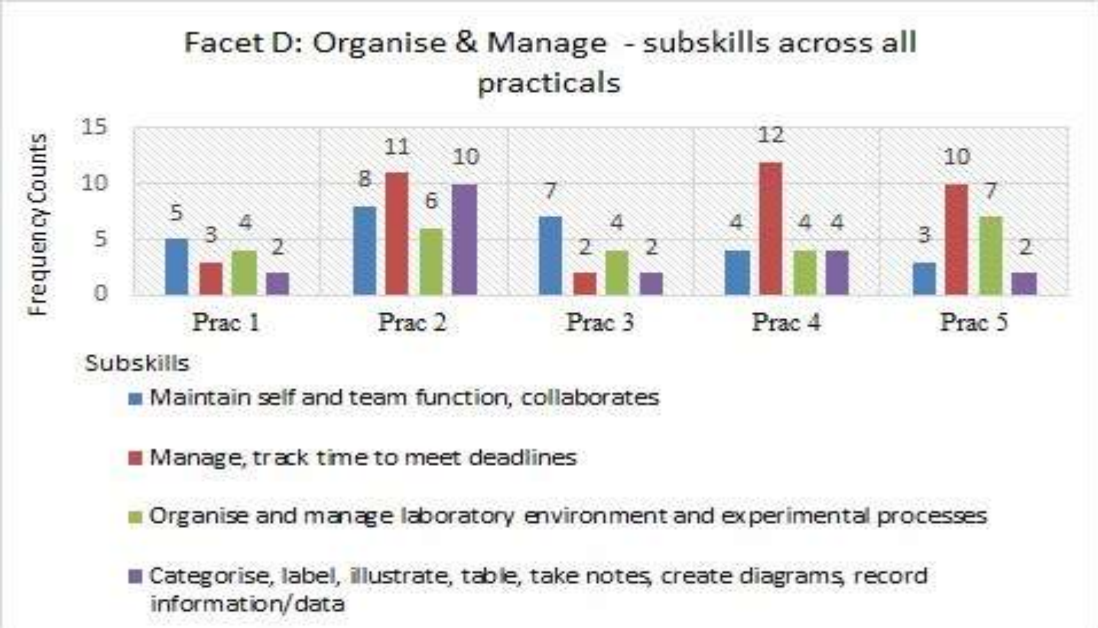


Figure 4.7 above shows that students displayed skills associated with organising and managing significantly more in Practicals two, four and five. The nature of the dissection in Practical two required students to work very collaboratively in pairs in respect to their self-assigned roles, though all three of these practicals revealed that students needed prompting from the TA to sequence activities and manage time.

However, higher frequencies captured for managing time in Practicals four and five results from the highly guided approach of the TA instructing and walking students through the experimental process. This involved instructing students to stop, wait and watch her demonstrate the next part of the experiment and to check with her before continuing. This resulted in students applying these skills more often at prescribed levels as the TA's instructional approach reduced opportunities for students to manage themselves and with more self-reliance as they conducted the experiment. The following example demonstrates that close guidance to this degree was time consuming and to the detriment of students' ability to complete this experiment.

> *The students appear organised, they commence setting up the burners. The TA checks the time, looking concerned she announces that the burners won't be needed anymore. She moves to the whiteboard. (I wonder - has the experiment changed? Have they run out of time?) The TA says 'look guys, we are going to do it this way instead, and she explains what would have happened if they had time to use the burners* (Practical five: Microbiology Part two, observations).

The following example from the practical manual in Practical one instructs students how to organise their data into tables:

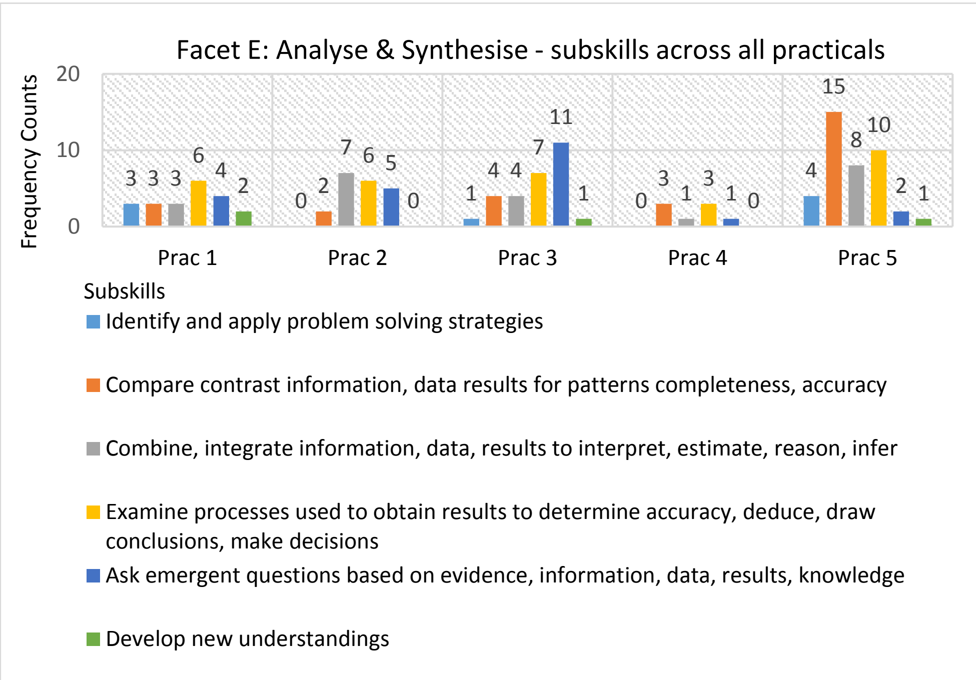
> *Complete the first 2 columns of Table 1 with your data for your strain. Obtain the results from the students opposite you for the other strain and complete the other 2 columns, so that you have a set of data for strain A and a set for strain B* (Practical one: Genetics, practical manual).

Practical one also showed an example of students managing the laboratory environment:

> *One of the students looks worried, she walks over to Karen and explains she has knocked over the contents of her test tube. The TA tells her to wash her hands carefully and clean up the liquid and explains to check that liquid hasn't spilt on the paper. The student washes her hands. Cleans the bench and re-washes her hands* (Practical one: Genetics, observations).

Figure 4.8 below details skills pertaining to Facet E: Analyse and Synthesise, described as skills where students "analyse information/data critically and synthesise new knowledge" (Willison & O'Regan, 2006, 2016).

Figure 4.8. Facet E: Analyse and Synthesise: Subskills identified in the practical manual and student observations across all practicals



Subskills related to Facet E: Analyse and Synthesise (Figure 4.8) primarily occurred through questioning and examining processes for accuracy. Comparing data and information also occurred relatively frequently, particularly in practicals two and five. The event captured below from practical one demonstrates the adept teaching style of the TA in recognising an opportunity to guide students towards applying the skills of analysis and synthesis by suggesting that the students compare and contrast their results with another student pair.

> *"A student pair are checking they have the correct results with the TA. They go through the procedure in the laboratory manual step by step. The students are comparing the results they have with what the results should be. The TA suggests that they have a chat to another pair of students about their results to compare"* (Practical one: Genetics, Observations).

The advantage of having time to analyse and synthesise was highlighted in practical five, as this practical was conducted over two practical sessions.

> *The students take their time and slowly move about the laboratory to view each other's results. They interpret what they observe in the slides, comparing and contrasting differences.* (Practical five: Microbiology part two).

Analysis and Synthesis skills were shown in Practical five where students compared and contrasted information after prompting from the TA.

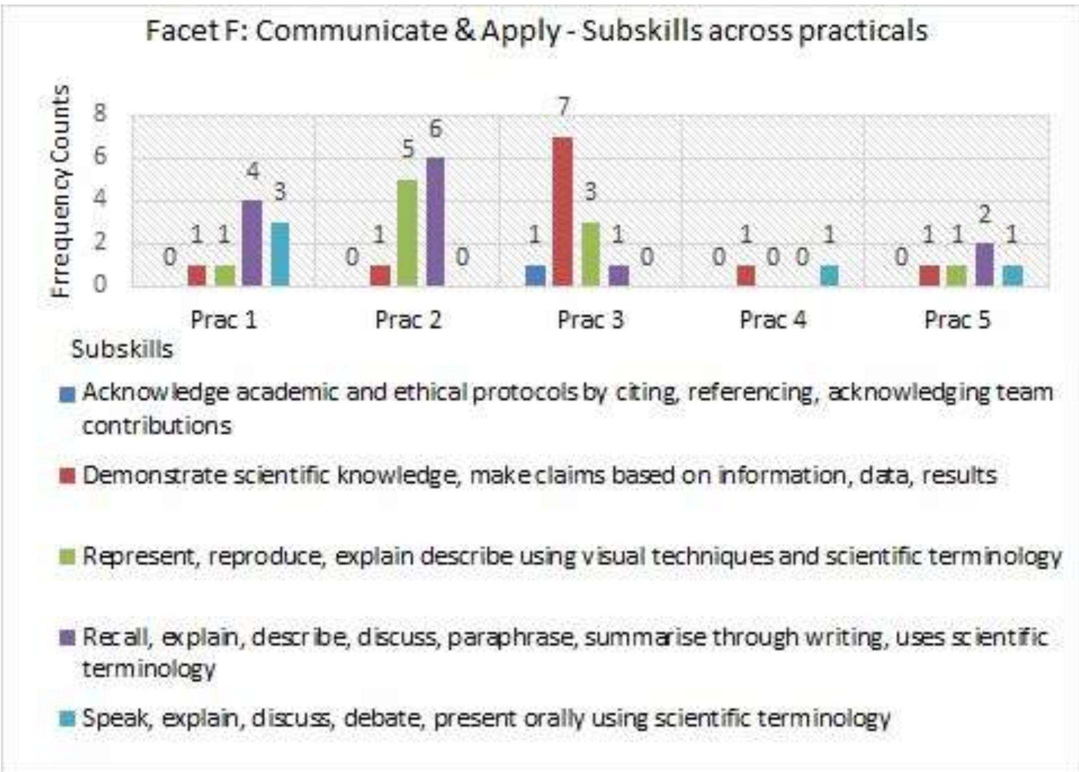
> *"What was the cell shape, the colour and the arrangement?" asks the TA. A student flicks through her lab notes and finds what she is looking for, she looks at her drawing and compares with the drawing the TA has prepared on the whiteboard. Students refer to the whiteboard and start to complete the table* (Practical four Microbiology, observations).

The instructional content presented for Practical three asks students the following question:

> *"Why is amylase able to break down starch into maltose, but unable to break down the cellulose in the cell wall into smaller molecules?* (Practical three: Metabolism, practical manual).

The following figure (4.9) shows the skills pertaining to Facet F: Communicate and Apply, described as skills where students "write, present and perform the processes, understandings and applications of the research, and respond to feedback, accounting for ethical cultural, social and team (ECT) issues" (Willison & O'Regan, 2006, 2016).

Figure 4.9. Facet F: Communicate and Apply: Subskills identified in the practical manual and student observations across all practicals



Skills associated with Facet F: Communicate and Apply (Figure 4.9) indicate the lowest frequency counts in the data sources across all practicals. This result is most likely attributed to a limitation of this research as the products of assessment were not included in this study therefore, Facet F was confined to representation in the laboratory manual and from observing students in the practicals.

The following extract from the practical manual instructs students to explain what is being observed using scientific language:

> *Explain using molecular genetic terminology, exactly what is happening in the wild type cells…* (Practical one: Genetics, practical manual).

An example of students applying communication skills in Practical three is provided below. In this example the TA guides the students through questioning to share and communicate their results among their peers. By encouraging discussion, the TA provides an important opportunity for students to develop the skills of evaluation and reflection, and analysis and synthesis.

> *"How did you go? Did you change anything?" asks the TA. The students explain their results before writing anything further. Another student overhears and joins*

the discussion, explaining what he interpreted from the results. The TA listens and slowly moves away, leaving the students to share their results amongst themselves (Practical three: Metabolism, observations).

The following example shows instructional content for the practical manual directing students how to communicate the outcome of the toad dissection.

You will submit a drawing today which should clearly depict the results of your dissection revealing the nervous system of the cane toad, so work through the following steps carefully to make sure you can recognise, locate and therefore accurately draw all of the associated bones and nerves required (Practical two: Toad Dissection, practical manual).

Acknowledging academic protocols such as academic integrity and citing and referencing were only noted in one instance in Practical three in relation to a research task.

4.4 Summary of findings

4.4.1 Curriculum design and BIO1022 learning aims

Analysis of BIO1022 learning aims (Fig 4.1) using the RSD framework showed that research skills were poorly defined and largely absent from these statements. As noted in Chapter four, the emphasis on skill development in the learning aims was predominantly related to students' technical skill development rather than students' higher order thinking skills for researching. Observations of the students undertaking BIO1022 practicals (Figure 4.2b) however, showed that students did exhibit foundational skills for researching. The omission of research skill related learning aims (Figure 4.1) in this unit, may suggest the difficulty faced by educators in conceptualising research skills and aligning them with skills gained from the practical experience. This concurs with the literature identifying that research skills tend to be subsumed within skill taxonomies and categorisations that tend to differentiate rather than manifest their connection with researching (Willison & O'Regan, 2007).

4.4.2 Research skills and their development in BIO1022

Comparing occurrences of each research skill across the unit captured in the practical manual (Figure 4.2a and 4.3a) with occurrences of students observed applying research skills within each practical experience (Figure 4.2b and Figure 4.3b) offers insights into their research skill development. Although skills were generally categorised across data sources at the prescribed range of autonomy, when students were in the learning context of the laboratory (Figure 4.2b and 4.3b) responding to the instructional content of the manual (Figure 4.2a and Figure 4.3a) students generally demonstrated increased self-reliance, particularly in practicals one to three (Figure 4.3b). This was mostly noted for skill pertaining to Facet A: Embark and Clarify, Facet C: Evaluate and Reflect, Facet D: Organise and Manage.

Interestingly, greater occurrences of Bounded levels of autonomy for Facet A: Embark and Clarify, Facet C: Evaluate and Reflect, Facet D: Organise and Manage were recorded in the instructional content of the laboratory manual across the unit (Figure 4.2a and 4.3a). This infers that students had the ability to apply these skills at the level of sophistication stated. However, students needed the intervention of the TA to activate these skills as captured in the student observations (Figure 4.2b and 4.3b).

Figure 4.2a exemplifies this result and shows that the instructional content in the practical manual for Facet C: Evaluate and Reflect was predominantly at the Bounded range of autonomy. However, prompting by the TA (Figure 4.3a) increased students' ability to apply evaluation and reflection skills at the Self-Actuated range of autonomy. For example, the ability for students to increase autonomy in the application of evaluation and reflection skills was dependant on the ability of the TA to ask students strategic questions to prompt thinking (Figure 4.2b and 4.3b). This was particularly evident in practicals one to three. Comparing the IDEA Practicals four and five with Practicals one to three therefore demonstrate that quality teaching methods, not the pedagogy alone, influence students' ability to apply research skills.

Students generally remained within Prescribed and Bounded levels of autonomy across all practicals (Figure 4.2b and 4.3b). However, Scaffolded autonomy, although underrepresented was recorded across the skill Facets of Embark and Clarify, Find and Generate, Organise and Manage and Analyse and Synthesise (Figure 4.2a and 4.3a). A single instance of Self-Actuated research was recorded in the observations for Practical two in relation to Facet C. The category of Open research was also only captured once across all practicals and occurred in in the practical manual for Practical two (Figure 4.2a and 4.3a) in association with Facet B: Find and Generate. As discussed earlier, this was related to a literature research task.

Although Facet E: Analyse and Synthesise was recorded at the Scaffolded level of autonomy in the laboratory manual (Figure 4.2a), a Scaffolded response was not demonstrated by students in the practical experience (Figure 4.3b). The skills of Facet D: Analyse and Synthesise also occurred proportionately more frequently within the practical (Figure 4.2b and 4.3b) than directed in the manual (Figure 4.2a and 4.3a). This may suggest that students need more support in developing and applying this skill range for the practical experience. Practical five however provided proportionately more opportunity for students to apply the skills of analysis and synthesis (Figure 4.3b), suggesting that the opportunity afforded by a two-part practical to practice and hone skills.

The skills associated with Facet D: Organise and Manage were also underrepresented in the instructional content of the manual across the unit (Figure 4.2a and 4.2b) although in the learning context students did demonstrate the ability to apply these skills (Figure 4.2b and 4.3b). Facet D did exhibited some prominence in Practical two and Practical five (Figure 4.3b). Practical two involving a toad dissection required students to apply these skills more frequently, and Practical five – part one of a two part experiment provided time for students to prepare and organise the experimental procedure. Interestingly the nature of the experiments conducted in Practical two and Practical five involved contaminants which may have required students to apply organising and managing skills more frequently. However, the student's ability to apply the skills of organising and managing were dependent on the teaching style of the TA. For example, students demonstrated more opportunity to apply these skills when they could work at their own pace and manage their time and the team roles in order to complete the task. When students were given this scope in Practicals one to three, they took the initiative to check their notes, consult the manual and converse with each other. Whereas in the highly guided IDEA practicals four and five (Figure 4.3b) students fell into a pattern of waiting for instructions to be given and displayed reduced initiative to organise and manage themselves and the experimental process. The time involved in a stepped instructional approach resulted in students not completing the experiment.

The most underrepresented skill range was Facet F: Communicate and Apply (Figures 4.2a, 4.2b, 4.3a 4.3b). As previously mentioned assessment outputs were not analysed in this study which likely reduced frequency counts. However, a range of communication skills were observed in the practical when students wrote up the experiment and when students used scientific language in conversation with the TA (Figure 4.3b). Nonetheless, a marked underrepresentation of this skill set is concerning. The structure of the practical itself may have impacted on students' ability to practice this skill as the post-lab wrap-up discussion had recently been removed from each practical. Thus, an opportunity for students to metacognitively activate and practice a repertoire of research skills through discussion and reflection was not available.

An interesting finding in this study suggests that guided and prescribed instructions in the practical manual generally move students to Bounded levels of research through quality teaching methods. This was exemplified by comparing Practicals one to three and Practicals four and five. These findings offered insights into how teaching strategies assist with increasing learner autonomy.

Chapter Four concludes here. Chapter Five presents the discussion and conclusion.

Chapter Five: Discussion and Conclusion

5.1 Introduction

First year science laboratory practicals have long been considered important for promulgating students' understanding of the nature of science and for acquiring the requisite skills of the discipline. This study has sought to identify which research skills first year biology students are developing through five BIO1022 coursework practicals. Extrapolating students' research skills offers an opportunity to promote additional learning benefits of the practical experience and open opportunities for library-faculty teaching collaboration in laboratory curricula. The Research Skill Development (RSD) framework was the conceptual model applied to identify students' research skills in this study. This chapter presents the discussion, recommendations, limitations and the conclusion. The discussion is underpinned by theoretical constructs that include Vygotsky's theory of constructivism (1978) and learner autonomy (Boud, 1988).

5.2 Discussion

The research question guiding this study was:

With reference to the Research Skill Development (RSD) framework; which research skills and associated levels of autonomy, are students developing whilst undertaking practicals in BIO1022?

The RSD framework assisted in identifying students' research skills and provided a picture of how students' research skills are being developed in this unit. The process of identifying skills also revealed important insights into what might influence students' ability to become more cognisant of the research skills they are attaining and what might influence their ability to use these skills with increasing self-reliance. The key findings were:

1. Research skills were implied, not explicit, in the learning aims
2. Students engaged in research skills as described by the RSD framework
3. Student autonomy was dominated by prescriptive approaches
4. The respective teaching methods of the TAs impacted both positively and negatively on students' ability to increase autonomy
5. Exploring a topic over two laboratory sessions gave students time to engage with underrepresented research skills

The findings related to students' research skill development have been distilled around two principal themes, underpinned by the nuances of learner autonomy. These are:

Theme 1: Making research skill development more explicit through curriculum design.
Theme 2: Making research skill development more explicit through teaching methods.

5.3 Theme 1: Making research skill development more explicit through curriculum design

This section explores the BIO1022 learning aims for each laboratory practical and how research skills are represented in these statements. Implications for curriculum design is discussed.

5.3.1 Learning aims

Learning aims are recognised as important determinants in achieving effective laboratory experiences (Hegarty-Hazel, 1990). The application of the RSD framework assisted in revealing that the skills encompassed in BIO1022 align with foundational skills for research, however, the stated learning aims did not reflect that this unit develops this range of skills (Figure 4.1). This is concerning, in light of a recent study undertaken by Hodgson et al. (2014), where graduating science students reported that their practical experience was valuable for developing a range of skills inclusive of research skills. Overlooking a potential benefit of the practical experience for engendering students' research skills has implications for curriculum design. This study has shown that there is potential to explicitly articulate the skill repertoire engendered by this unit beyond the current focus on students' technical skill development and knowledge acquisition.

Although skill development is considered important in the practical arena (Johnson et al., 2002; Rayner et al., 2012), the range of skill-related terms and categorisations currently used in science education often overlap or hold various interpretations. Research skills are generally dispersed amongst these categorisations, which creates difficulty in clearly articulating what research skills actually entail and may be a contributing factor to their omission in the learning aims of this unit. Furthermore, omitting learning aims inclusive of students' research skills risks research skill terminology being removed from disciplinary vocabulary and thus, from the awareness of science educators, librarians and students alike.

5.3.2 Developing underrepresented skills

Results from this research study showed that communication skills were underrepresented in both the manual and laboratory observations (Figure 4.2a and 4.2b), and that there was proportionally less opportunity for students to apply the skills of evaluation and reflection across the unit (Figure 4.2a and 4.2b). Contextualising these findings in the literature demonstrates that much attention has been directed towards determining what might be needed to enhance student learning in the practical (Hofstein & Lunetta, 2004; Lee et al., 2012; Rice et al., 2009). Yacoubian and BouJaoude (2010) have emphasised the importance of reflective discussions following laboratory activities to strengthen and develop students' communication skills. Wass and Golding (2014) note the importance of enabling a teaching environment that encourages students to challenge and ask questions, and which is also conducive to critical evaluation and discussion. However, White et al. (2010), explain that laboratory experiences do not necessarily provide opportunity for students to hone their communication skills, noting that; *...even students with extensive laboratory experience often are restricted by an inability to communicate their knowledge or experiences. Communicating the problem and the results to diverse audiences is an ability that, like other skills, must be learned and practiced* (White et al., 2010, p. 298).

What may have contributed to communication skills being less apparent in relation to BIO1022, was the removal of the post-laboratory wrap-up which had previously concluded each practical. In doing so, the opportunity afforded at the end of the practical for students to communicate, reflect, evaluate and discuss experimental processes and outcomes was lost. This also removed an important and highly valuable opportunity to demonstrate the worth and relevance of these skills for the science practical.

Findings showed that students did require an opportunity to reflect and discuss what took place during the practical. An example of this was demonstrated after Practical one concluded, when several students stayed back after the session to ask questions and discuss the experiment with the TA. Interestingly, the discussion that ensued between the TA and students incorporated all the research skill facets of the RSD using research related terminology.

Practicals four and five also contributed findings in relation to the advantages of a practical conducted in two parts (Figure 4.3a and 4.3b). Investigating a topic over two practicals gave students the time to engage with research skills more frequently than Practicals one to three, albeit primarily at the Prescribed level (this will be discussed in the following sections). For example, the two-part practical (Figure 4.3b) allowed students more time to work through and engage with each skill. This is exemplified in the following observation:

> *The students take their time and slowly move about the laboratory to view each other's results. They interpret what they observe in each other's slides, comparing and contrasting differences* (Practical five: Microbiology part two).

The skills of Facet B: Find and Generate occurred most frequently across all practicals (Figure 4.2a). This skill set generally occurred in association with the process of conducting experiments, however Leggett et al. (2004b) stresses that literature-based information finding skills are those students require more support with (p. 307). The BIO1022 practical manual provides only one noted opportunity (Figure 4.2a) for students to engage with a literature-based research task, where the task instruction reads, "Do your own research to find the information using resources other than your textbook" (BIO1022 Practical two, practical manual). As previously noted, the directive suggests students have acquired the skills to undertake a literature-based activity at the inferred level of sophistication. Yet there is no indication in the manual of students having previously practised literature-based research activities to complete the task without guidance.

5.4 Theme 2: Making research skill development more explicit through teaching methods

This section discusses questioning techniques as a teaching strategy that incorporate research related terminology. The influence of teaching style and instructional approach for scaffolding students' research skills is discussed.

5.4.1 Questioning techniques using research skill terminology

Hegarty-Hazel (1990) highlighted the importance of quality TA-student interactions and the implications for student learning when staff act as "laboratory managers but not as questioners, challengers and promoters of scientific enquiry" (p. 21). Questioning challenges learners to "actively construct meaning that makes sense to them, rather than to acquire understanding through exposure to a format exclusively organised by the teacher" (Borich, 2014, p. 289). Questioning techniques are a complex teaching strategy aligned with constructivism and are considered an integral part of interactive learning to assist students to reorient their thinking (Korkmaz & Yesil, 2010; Roth, 1996; Borich, 2014).

Observation of TA-student interactions (Figure 4.3b) revealed significant differences in the way the observed TAs posed their questions to the students. Observational data from Practicals one to three (Figure 4.3b) showed that one TA invested considerable time asking students open-ended questions that encouraged metacognitive engagement with research skills. For example, the observation from Practical three below (Figure 4.3b) captures one such TA-Student interaction where the TA demonstrates skilled and effective questioning strategies, prompting students to communicate a response by drawing on evaluation, reflection, prediction and communication skills.

> *"Do you understand what is happening?" asked the TA to a student pair. "Yes," replied the students. "Then, can you explain what is happening?" asks the TA. "Starch is breaking down," the student replies. "So over time what do you predict will happen to the starch? What will you observe as you add the drops?" asks the TA. "It will go yellow," replies the student* (Practical three: Metabolism, Observations).

Insights drawn from the observational data (Figure 4.3b) show the importance of the use of research-oriented language when interacting with students. For example, the TA facilitating Practicals one to three (Figure 4.3b) drew on a rich vocabulary of research skill-related terms to formulate questions (words such as; predict, evaluate, observe and analyse). Contrastingly, the TA delivering IDEA Practicals four and five (Figure 4.3b) lacked research skill-related vocabulary. This TA defaulted to the word 'see' frequently in place of terms such as identify, examine, conclude, observe, infer, etc. The omission of skill-related terms in student interactions removed an important opportunity to bring skill-related terminology into the students' vernacular, and in doing so make research skills visible to the students.

This study shows that the application of sophisticated questioning prompted students to engage in reflective and analytical thinking processes, potentially contributing to increased levels of student autonomy in recipe-based practicals. These findings are therefore considered significant because the literature is in general consensus that recipe-driven practicals sacrifice students' ability to think about experimental processes and develop their own thinking skills (Bugarcic et al., 2012).

5.4.2 Influence of instructional approach

There is consensus among science educators that recipe-based approaches limit student learning, as students follow a predetermined experimental method to arrive at an expected answer. Bugarcic et al. (2012) emphasise this point stating that;

> *…as the experimental outcome is already known to the students, they are never challenged to think about how scientific experiments are used to answer specific research questions, let alone develop their own skills in hypothesis formulation and experimental design. Unfortunately, developing advanced professional skills such as problem-solving and critical thinking is often sacrificed* (p. 174).

Hofstein and Lunetta (2004) have suggested that promoting students' understanding of science in the laboratory can be achieved by reshaping science curricula to incorporate more open-ended laboratory activities. Such approaches are considered beneficial for engaging first year student cohorts with varying skills, abilities, cognitive preferences and knowledge of science (Kempa & Diaz, 1990). These alternatives to the instructional model have evolved to promote learning through student-driven and instructor-guided investigations of questions sparked by student curiosity (Justice et al., 2007).

As explained previously, BIO1022 incorporates two instructional approaches; Practicals one to three were recipe-driven practicals exploring a different topic in each, whereas Practicals four and five were IDEA practicals investigating a topic in two parts. Therefore, this unit offered an opportunity to consider students' research skill development in recipe-driven and Inquiry Oriented Learning (IOL) inspired IDEA practicals (Figure 4.3a and 4.3b). The IDEA practicals explored a problem-based scenario intended to encourage "deductive reasoning and critical thinking to determine the nature of a mystery substance" (practical manual, Practical four, p. 7). The practical manual explains to students that "these exercises will not come with procedure mapped out for you; instead you will work in small teams and be charged with the responsibility of developing your own experimental procedures" (Practical four: Microbiology part one, practical manual). As noted, the recipe-driven practicals and the IDEA practicals were facilitated by two different TAs. The TAs had contrasting teaching styles, providing insights into teaching methods that encourage opportunities for students to engage with and become more autonomous in applying research skills in practical settings (Figure 4.3b).

Shepardson (1997) investigated differences in students' thinking in standard instructional recipe-based and IOL science practicals. Of significance to this thesis findings from the study by Shepardson (1997), suggesting no differences in students' thinking processes between standard instructional practicals and inquiry approaches. However, differences did occur to students' thinking processes through the influence of quality teaching interactions. The findings of this thesis concur with Shepardson (1997), noting that in guided laboratories, teacher-student interactions and not the pedagogy alone, contributed significantly to student thinking processes.

The intent of IDEA experiments is to foster authentic research practice by being less instructional (Rayner, Charlton-Robb, Thompson, & Hughes, 2013). However, this aim did not appear to be met as students were observed working predominantly at Prescribed levels of autonomy in Practicals four and five (Figure 4.3b). The highly guided instructional approach of the TA provided minimal opportunity for students to work as Boud (1988) suggests, with more decision-making opportunities and less instructor guidance.

This is a concern given what is understood about learning theories that guide teaching practice to maximise the potential for learning. For example, Wass and Golding (2014), in interpreting Vygotsky's Zone of Proximal Development (ZPD) as a concept for teaching, note that teachers can maximise student learning by providing teaching environments that are conducive for the greatest ZPD for a particular task. However, there are implications for student learning in providing too much guidance so that "the challenge evaporates and there is no learning to be had" (p. 679). Willison et al. (2016) concur, noting that as educators, "finding the optimal extent of student autonomy is paramount" (p. 2) to be able to expand on what students already know.

> *...ideally teachers should provide the level of guidance which produces the 'sweet spot' for optimum learning and thinking. Hence, education generally, and the development of research skills in particular, would progress most successfully for a whole cohort when in this middling educational 'Goldilocks zone' (p. 2).*

Interestingly however, students' engagement with research skills was proportionately more frequent in the IDEA experiment than in Practicals one to three (Figure 4.3b). For example, students demonstrated increased application of the skills of evaluation, reflection, analysis and synthesis in practicals four and five, supporting the intention of the IDEA initiative to develop higher order thinking skills such as critical thinking, problem solving, and analysis (Rayner et al., 2013, p. 3). A two-part practical appears to have afforded opportunity for students to engage with these skills more frequently, albeit as noted in this case, at Prescribed level of autonomy.

5.5 Implications

This study has shown that foundational skills for research are part of the repertoire of skills students' gain from the practical experience although they are largely implied in this curriculum and in its teaching practice. This has implications for curriculum design and student learning, particularly within a higher education environment that promotes the skills students' gain from an undergraduate degree as important outcomes of a university education. Although science education has acknowledged the importance of determining the skills students attain through laboratory learning, the emergent skill-related terms and overlapping skill categorisations rarely draw connections between research skills as skills acquired in the practical, suggesting that a lack of clarity and some confusion still remains as to what research skills entail. White et al., (2010) emphasise that:

> *Universities have always provided opportunity for students to develop discipline-related and generic skills. In the past these skills were considered to lie within the realm of tacit knowledge, and acquired gradually, however we now find that they are considered to be explicit knowledge. As such they need to be identified, selected, and actively taught (p. 298).*

This suggests that the way in which science educators conceptualise research and the relationship between research skills and knowledge acquisition may require new understandings for such skills to become visible in curriculum design and teaching practice. This notion of a reconceptualising what research skill entail also extends to librarians in seeking ways to transform their teaching practice and make a meaningful and recognised contribution to student learning. The application of the RSD framework to identify students' research skill in a challenging learning context, suggests it's potential in providing a new vernacular and a pedagogically sound approach to underpin library teaching practice. Importantly, the RSD extends traditional library definitions and interpretations of 'information finding' or information literacy skills, where students are consumers of information, to a reconceptualised interpretation where information finding is aligned with generating information and data, where students are producers of information. Thus connecting library research skill development agendas directly to skill sets specifically required in the laboratory context.

This argues well for designing a holistic curricula that considers how students' thinking skills and processes for research will be explicitly enabled as a shared responsibility amongst library and faculty.

The following section provides recommendations related to the benefits and challenges of identifying students' research skills, including ways of making research skills more visible in practical curricula through a new interpretive lens.

5.6 Recommendations

This study has shown that the RSD framework was a suitable construct through which to identify students' research skills within one first year biology practical unit. The following sections provide recommendations that relate to the two themes previously identified in this chapter. Recommendations also consider the potential of the RSD to inform and underpin library-faculty collaboration by offering a shared dialogue for student' research skill development.

5.6.1 Theme 1: Making research skill development visible through curriculum design

Lazonder and Harmsen (2016) note that in science education, the process by which students achieve skill related learning outcomes is unclear. The authors identify a limitation - the lack of a *priori* theoretical framework to effectively guide educators to incrementally guide and enable skill development. This study confirms that realising research skills as an explicit outcome of learning calls for a taxonomy of terms to enable evidence and guide learning practices. The outcomes of this research argue for the RSD framework to assist in overcoming ambiguity surrounding the term 'research' and in doing so enable a means to make research skills and their development an acknowledged outcome of the practical experience. One of the purposes of the RSD framework is explained by the authors;

> *We see one practical application as being both to chart and to anticipate students' development as researchers. It can, therefore, be used to inform course design, to frame assessment and learning tasks and to identify students' development at any time as well as their progression over time* (Willison & O'Regan, 2007, p. 404).

The method applied to this study to identify students' research skills using the RSD framework offers an approach to inform course design and achieve transparency by showing *what* skills are being developed, *where* and *how* they are being developed. This is significant as tools to map skills in curricula, although offered in the literature, are generally document centred (Oliver, Ferns, Whelan, & Lilly, 2010) or presented as matrices or checklists (Fraser et al., 2007; Sumsion & Goodfellow, 2004). In contrast the method applied to this study offers an evidence-based approach to mapping research skills in the curriculum underpinned and informed by a *priori* pedagogical framework.

Identifying where opportunities lie in the curriculum for targeted research skill development would clarify how librarians can contribute to student learning. For example, results show that there is opportunity for students to hone skills related to Facet B: Find and Generate in respect to literature tasks (figure 4.2a). This brings an opportunity to draw parallels between Facet B skills required for conducting experiments such as; collecting, recording, analysing and interpreting data, within the context of information and literature-based searching. Analysis of the practical manual also showed that students had minimal opportunity to formulate hypotheses. The gap revealed in the findings presents educators with scope to enhance activities that also bring a focus to students practicing this skill. The experience of searching the literature through student driven questions, where students adjust and refine search queries could be one such approach.

Communication skills were underrepresented in this unit. The value of the post-lab wrap up as a means for students to practice a range of cognitive skills related to research, including the ability to formulate ideas and communicate one's thinking, was discussed earlier. This study therefore recommends that consideration be given to reintegrate this activity into the practical structure, as it suggests an opportunity for students to practice the range of skills that were less apparent in this unit. Reinstating the post-lab wrap-up could open an opportunity to involve librarians at the end of practical and contribute to enhancing the development of students' research skills that were underrepresented in this study. For example, the non-disciplinary specific language of the RSD enables connections to be drawn between the skills required for finding and generating data in experimental process with the information seeking skills librarians are familiar with. A post-lab wrap-up informed by the RSD framework would contribute to making research skills visible to students and support the teaching partnership between librarians and science educators.

The recommendations above draw attention to the value of the RSD in offering a model for educators to interpret and articulate discipline specific research skills as demonstrated in this study through the context specific subskills related to the Facets of Research. The process of identifying subskills would assist educators to ascertain whether or not discipline related research skills are adequately or underrepresented in the practical. Therefore, mapping skills informed by the RSD is recommended as the first stage in aligning research skills within a curriculum, and a means to make them explicit outcomes of learning. Furthermore, a more coherent and scaffolded focus to skill development would more appropriately bring the librarians' contribution to student learning at targeted points of need throughout the unit.

5.6.2 Theme 2: Making research skill development visible through teaching methods

Findings presented in this thesis demonstrated the importance of educators being adept at guiding students through the strategic question prompting as a means to scaffolded skill development. An early study by Shepardson (1997), noted that quality teacher-student interactions in guided laboratories contribute significantly to student thinking processes, however a challenge for science educators, is in providing sufficient instructional support to promote students' ability to think about the processes of laboratory experiments. The notion of instructional support is explored more recently in a study by Talgar and Goodey (2015). The authors sought to determine which skills biology students perceived were required for research and found that students considered the ability to work independently as a desired skill. Yet, as Wass and Golding (2014) explain, there are challenges supporting students to become more autonomous in the practical. Positive outcomes can be achieved when educators ‘scaffold’ students’ skill development, rather than ‘structure’ this development through close instructional support. The authors explain that;

> *Scaffolding involves providing support so that students can autonomously complete a task, while structure involves directing students through a prescribed set of actions so that they can complete the task almost mindlessly and without having to make autonomous judgements* (Wass & Golding, 2014, p. 676).

The differences between teaching methods that scaffold and those that structure student learning were gained from observing contrasting teaching practices in BIO1022. These findings concur with those of Wass and Golding (2014). Of particular relevance to this thesis is the observation made by the authors that draw distinctions between scaffolded and structured teaching approaches for developing learner autonomy. Wass and Golding (2014) explain that while the teaching assistance can appear very similar the outcomes differ (p. 679). Insights drawn from this thesis concur with the ability of the TA to scaffold student thinking in order to promote opportunities for students to increase autonomy in the practical. For example, the contrasting teaching styles of the BIO1022 TAs revealed which approaches might influence the development of learner independence. Findings strongly indicated that the structured teaching style of the TA in the IDEA practicals reduced opportunities for students to become more autonomous, whereas the TA that used effective questioning techniques and skill related vocabulary scaffolded students’ ability to work at increased levels of autonomy. Shepardson (1997) also emphasised the importance of educators being adept at scaffolding students’ research skills through teaching methods inclusive of questioning techniques that incorporate research related skill terminology.

This signifies the importance of science teaching teams receiving appropriate training in question posing in order for questions to become more than a request for “low-level factual information”, and instead become a call for “reflection and analysis that promotes a view of science as a dynamic search for answers” (Roth, 1996, p. 711). However, providing students with consistent levels of instruction is known to be challenging as practicals are often facilitated by teaching teams with variable levels of teaching experience and backgrounds (Rice et al., 2009).

To this end, findings from this study indicate that the RSD may provide a pedagogically sound approach to address several challenges faced by science educators related to teaching approaches for engendering research skills, and may assist in equalising variations of experience and quality of individual teachers. Wass and Golding (2014) explain that distinguishing between the teaching methods of ‘scaffolding’ and ‘structuring’ can be difficult. The RSD framework demonstrates a suitable model to support these understandings. Introducing the RSD to professional development programs for science teaching teams may enhance: the explicit articulation of research skills in teacher-student interactions, guide question posing using research related terminology and clarify important instructional differences between structuring and scaffolding skill development. Benefits may extend to a vernacular for informing a consistency of instruction, where research skills are incorporated into teaching practice and within curriculum artefacts.

Such professional development activities could also be made open to library staff contributing to student learning in practical units. These opportunities may facilitate shared understandings and a new discourse among educators for students' research skill development, guided by the common platform and language of the RSD. Such an approach has potential to guide library-faculty teaching partnerships using reconceptualised methods that have long been called for in the field of library science (Doskatsch, 2003).

5.7 Limitations of the study and approach

A number of variables influences this study, resulting in several limitations. The students observed in this study may not be representative of the entire first year cohort as students' prior knowledge and experience of studying science would differ. Additionally, observational methods were deliberately limited to a narrow segment of students; in doing so, the results only capture a small sample size of this cohort (n=8). A further variance concerns the different teaching style of the TAs facilitating the practicals and the pedagogical approaches and structure of the unit itself. The student voice and perspectives from librarians was not incorporated in this study. Therefore, these variables could threaten the reliability and generalisability of the findings. However, educational settings often share similar conditions, characteristics and variances, referred to as 'comparability' by Goetz and LeCompt (1984, cited in Schofield, 2002). Comparability recognises the extent to which one study's findings are applicable to other similar situations. For example, TAs may feature differing teaching styles and first year student cohorts are likely to have a range of experiences of the discipline. Therefore, the author proposes that despite these limitations, the findings could provide a rich sense of some students' experiences, and be informative for similar educational contexts.

5.8 Challenges of the approach

The RSD adequately supported and informed the process of identifying research skills in the unit investigated. However, interpreting skills in alignment with the RSD was not always a straightforward process. At times the skill identified in the data source could be associated with more than one Facet of Research. The processes of analyses assisted in clarifying and highlighting the multifaceted nature of skills associated with researching, revealing insights into how skills may share elements of each other, and the way in which skills have a particular emphasis and focus at different stages of the research process.

5.9 Directions for further research

5.9.1 Mapping research skills

Curriculum mapping tools are generally designed to map a range of skills and capabilities to be achieved at the end of a course (Oliver et al., 2010; Snape & Spencer, 2011; Thomson et al., 2017). Methods for mapping research skills and their development across a unit or program of study is more difficult to locate in the literature. Thus, what might be needed to acknowledge skills for researching as outcomes of learning is a method to interpret curriculum and guide educators in making research skills in disciplinary content explicit.

To this end, the constituent parts of the RSD framework, the Facets of Research and Levels of Student Autonomy informed the coding schema through which data sources were interpreted for specific research skills. The functionality offered by NVivo qualitative analysis software in conjunction with the RSD provided a coding infrastructure to support analysis. Mapping research skills as such revealed *where, when* and *how* research skills were manifested in the practical, also serving to make skill gaps and inconsistencies in this curriculum visible. The method applied suggests a way to inform constructive alignment of the curriculum. Further research utilising the RSD in other learning contexts may provide the insight required to make informed decisions for curriculum design and renewal processes, and a way to improve the alignment of research skills using an evidence-based approach.

5.9.2 TA-Student interactions

This study highlighted the importance of quality TA-student interactions in the practical for inculcating students' research skills. Interpreting TA-Student interactions with the RSD framework contributed insights into how learner autonomy is enabled or averted, particularly in respect to scaffolded or structured teaching approaches and posing questions inclusive of research terminology. Thus, further research that explores the nuances of learner autonomy through TA-student interactions within a larger sample size, incorporating observations of varied teaching styles, would expand on findings presented here. Importantly, future studies that are inclusive of the student perspective may deepen understandings of how TA-student interactions may positively or negatively influence how students' research skills are nurtured.

5.9.3 Library-faculty collaboration

Collaborative teaching partnerships are considered to bring institutional benefits for teaching and learning (Creaser & Spezi, 2014). Such models support and encourage academic and professional staff to work in seamless teaching partnerships, an approach which mitigates against complementary or piecemeal classes disconnected from the curriculum (Kift, Nelson, & Clarke, 2010). Despite a long-standing view advocating benefits of teaching research skills in context, such skills are generally taught outside the curriculum and separated from content knowledge (Peacock, 2001).

Findings from this study signal that a reconceptualised approach for fostering library-faculty teaching partnerships may be warranted, given that strategies to achieve library-faculty collaboration for the past two decades have gained limited foothold in the curriculum. Arriving at a shared understanding of what skills for research encompass across disciplines appears to be critical for harnessing the collaborative potential of library-faculty teaching partnerships. This study shows that the RSD framework, as a conceptual model, demonstrated flexibility and adaptability for interpreting research skills and articulating related subskills embedded in the context of the science practical. The RSD supported this process because the framework does not present research skills using disciplinary specific and library-centric terminology. Rather, it is by contextualising the RSD that supported the means to identify students' research skills relevant to the biology practical.

Therefore, the non-prescriptive nature of the RSD may assist in overcoming the cultural, professional and disciplinary boundaries defining the many conceptualisations and terminology to describe skills for researching held among educators. Further research into library-faculty collaboration underpinned by the RSD in other disciplines has potential to deepen understandings of the effectiveness of the RSD as a model for establishing and advancing teaching partnerships and research skill agendas.

5.10 Conclusion

The attention placed on the research skill development of students has a long history. Over the years a number of higher educational strategies and initiatives have focused on students' becoming skilled for research (Boyer Commission, 1998; Healey & Jenkins, 2009). Given this attention, it is interesting that educators are still "talking about graduates' lack of them, and how best to teach and promote them" (Leggett et al., 2004b, p. 295). Similarly, the field of library science continues to discuss ways of fostering library-faculty teaching collaborations for embedding research skills in curricula to demonstrate the value that librarians bring to student learning (Bundy, 2004; Creaser & Spezi, 2014).

However, where research skills are developed in a student's learning journey, and *what* research skills encompass can be contentious in academic environments. The term 'research' can be imbued within a hierarchy of terms and not perceived as something that happens through everyday learning. Furthermore, the proliferation of terms and nomenclature describing the skills involved in research can confuse educators as the range of terms have their own adherents and definitions rising from science practical curriculum reform (Leggett et al., 2004).

Prompted by these challenges, this study was ignited by questions relating to what research skills were encompassed in a first year biology practical unit as a means to ignite a new dialogue between academic and library staff in enabling students' skills for research. Establishing shared understandings among educators of what research skill entail in the practical experience is particularly important for librarians as their contribution to student learning in this learning context rarely goes beyond 'one-shot' instructional sessions on how to locate library resources to complete assignments or tasks (Kearns & Thrasher Hybl, 2005, Bradley, 2013). However, establishing common understandings has challenges as librarians commonly limit their interpretation of research skills to information seeking skills where students are consumers of third party information. Thus librarians themselves may be effectively reducing their contribution to student learning for the practical experience. The science practical focuses on students being actively involved in the generation of information and data, identifying students' research skills through the RSD may enable such library centric interpretations of information seeking skills to become more broadly defined as the developmental skills and processes involved in knowledge creation - students as information producers.

The authors of the RSD framework explain that the intention of the RSD is to provide educators with a tool to effectively formulate a scaffolded curriculum for the thinking processes and skills encompassed in research, in any discipline (Willison and O'Regan 2007). The RSD assisted in showing that although research skills were present across the unit, there was a lack of explicit emphasis on student research skill development, which suggests a relatively low priority towards research skills as outcomes of learning. Although Science educators have over the years drawn attention to the repertoire of skills students require to engage with the discipline, 'research skills' are lost in the many skill categorisations and nomenclature of the discipline. Consequences of the skills involved in research remaining hidden suggests that engendering students' research skills in BIO1022 is implied and haphazard rather than coherent, thus undervaluing the learning potential of this unit. This study shows that there is scope to foster clarity and understanding around research skill development in practical curricula. Closer ties with library staff in this learning environment may assist in increasing the visibility of research skills and bring them to the student fore as valued skills for learning. Furthermore, establisher greater clarity as to what research skill entail resonates with library strategies seeking approaches to explicitly embed research skills within curricula (Bennett & Gilbert, 2009).

The purpose of the RSD echoes efforts made in science education to be more than teaching students about what scientist know, to teaching students to *think* about what they are doing (Leggett et al., 2004; Roberts, 2001). The RSD framework assisted in demonstrating that the thinking skills and processes students require for researching were evident across all BIO1022 practicals, albeit with varying emphasis. The skills of finding and generating information and data were the most prevalent skills, with communication skills occurring less frequently across practicals. The skills of evaluation and reflection required educator support to be enabled, despite expectations in the practical manual suggesting students had the ability to apply these skills with some autonomy. The skills of organising and managing also required educator intervention and occurred less frequently in comparison to other research skills. The skills of analysis and synthesis occurred more frequently in the two-part practicals, possibly due to the additional time offered to explore a topic. Guided by the RSD Facets of Research, discipline related research skills were identified in the BIO1022 data sources, interpreted and then distilled and expressed as subskills. This distilling process enabled the RSD to reveal the research skills contextualised within a specific learning context.

The RSD also provided insights into what might support the development of research skills in the practical. Contrasting teaching methods observed were interpreted through the Levels of Student Autonomy and how the approaches positively or negatively influenced students' ability to work at increased levels of independence. Importantly the RSD framework assisted in revealing differences between scaffolded and structured teaching approaches and the pivotal importance of teaching methods that incorporate research skill terminology to support students' ability to apply skills with increasing self-reliance in the practical.

To conclude, this study investigated the usefulness of the RSD framework as a construct through which to identify students' research skills and their development in BIO1022, a first biology practical unit. The RSD demonstrated a suitable model for identifying the research skills encompassed in this unit, and a way for educators to nurture that growth, thus achieving the aims of this study. Importantly, the RSD also signals potential as an enabling tool to strengthen and underpin library-faculty collaboration and to guide a shared response for students' research skill development. Outcomes presented here strongly indicate that the insights generated through the application of RSD framework places this enabling tool well to inform research skill agendas in other programs of study and contribute to broader research skill initiatives at the institutional level. Finally, given the attention placed on skill development in higher education in the current literature and the time invested in exploring skill-enabling pedagogical approaches, it is concerning that university educators today still lament students' lack of skills.

References

American Association for the Advancement of Science. (2011). *Vision and change in undergraduate biology education: a call to action. Final Report.* C. Brewer & D. Smith (Eds.). Retrieved from http://visionandchange.org/files/2011/03/Revised-Vision-andChange-Final-Report.pdf

American Library Association (ALA) Presidential Committee on Information Literacy: Final Report, released January 10, 1989. Retrieved from: http://libguides.ala.org/InformationEvaluation/Infolit

Australian and New Zealand Institute for Information Literacy (ANZIIL) and Council of Australian University Librarians (CAUL) (2004).

Bangara, G., & Bronwell, S. (2014). Course-Based Undergraduate Research Experiences can make scientific research more inclusive. *CBE Life Sciences Education, 13* (Winter), 602-606.

Barnett, R. (2005). Recapturing the Universal in the University. *Educational Philosophy and Theory, 37*(6), 785-797. doi:10.1111/j.1469-5812.2005.00158.x

Barrie, S., Bucat, R., Buntine, M., Burke da Silva, K., Crisp, G., George, A., Jamie, I., Kable, S., Lim, K., Pyke, S., Read, J., Sharma, M., Simon M., Yeung, A. (2015). Development, Evaluation and Use of a Student Experience Survey in Undergraduate Science Laboratories: The Advancing Science by Enhancing Learning in the Laboratory Student Laboratory Learning Experience Survey. *International Journal of Science Education, 37*(11), 1795-1814. doi:10.1080/09500693.2015.1052585

Bauer, K. W, & Bennett, J. S. (2003). Alumni Perceptions Used to Assess Undergraduate Research Experience. *The Journal of Higher Education, 74*(2), 210-230. doi:10.2307/3648256

Beck, C., Butler, A., & Burke da Silva, K. (2014). Promoting Inquiry-Based Teaching in Laboratory Courses: Are We Meeting the Grade? *CBE-Life Sciences Education, 13*(3), 444-452.

Beckman, J., & Rayner, G. (2011). Embedding academic-professional collaborations that build student confidence for essay writing: Student perceptions and quality outcomes. A Practice Report. *The International Journal of the First Year in Higher Education, 2*(2). doi: 10.5204/intjfyhe.v2i2.87

Beckman, M., & Hensel, N. (2009). Making explicit the implicit: Defining undergraduate research. *Council for Undergraduate Research (CUR) Quarterly, 29*(4), 40-44.

Bennett, O., & Gilbert, K. (2009). Extending liaison collaboration: partnering with faculty in support of a student learning community. *Reference Services Review, 37*(2), 131-142. doi:10.1108/00907320910957170

Bloom, B., Engelhardt, M. D., Furst, E. J., Hill, W. H., & Krathwohl, D. R. (1956). *Taxonomy of educational objectives*. NewYork: David McKay.

Borich, G. D. (2014). *Effective teaching methods: research-based practice* (Eighth ed.): Boston: Pearson Education.

Boud, D. (1988). *Developing student autonomy in learning* (2nd. ed.). London: Kogan Page.

Boyer Commission. (1998). *Re-inventing undergraduate education: a blueprint for America's research universities.* Retrieved from: https://dspace.sunyconnect.suny.edu/bitstream/handle/1951/26012/Reinventing%20Undergraduate%20Education%20%28Boyer%20Report%20I%29.pdf?sequence=1&isAllowed=y

Bradley, C. (2013). Information literacy articles in science pedagogy journals. *Evidence Based Library and Information Practice, 8*(4), 78-92. doi:http://dx.doi.org/10.18438/B8JG76

Brew, A. (2006). Learning to develop the relationship between research and teaching at an institutional level. *New Directions for Teaching and Learning, 2006*(107), 11-22. doi:10.1002/tl.241

Brew, A. (2012). Teaching and research: new relationships and their implications for inquiry based teaching and learning in higher education. *Higher Education Research & Development, 31*(1), 101-114. doi:10.1080/07294360.2012.642844

Brew, A. (2013). Understanding the scope of undergraduate research: a framework for curricular and pedagogical decision-making. *Higher Education,* (66.5), 603-618. Brew, A. (2013). Understanding the scope of undergraduate research: a framework for curricular and pedagogical decision-making. Higher Education, (66.5), 603-618. http://go.galegroup.com.ezproxy.lib.monash.edu.au/ps/i.do?id=GALE%7CA352040864&v=2.1&u=monash&it=r&p=AONE&sw=w&asid=cb20b58b371b247056e1fc7b9bca1a24

Bruce, C. (2001). Faculty-Librarian partnerships in Australian Higher Education: Critical dimensions. *RSR: Reference Services Review, 29*(2), 106-115.

Bundy, A. (2004). *Australian and New Zealand information literacy framework: Principles, standards and practice*. Available from: http://www.caul.edu.au/content/upload/files/info-literacy/InfoLiteracyFramework.pdf

Bugarcic, A., Zimbardi, K., Macaranas, J., & Thorn, P. (2012). An inquiry-based practical for a large, foundation-level undergraduate laboratory that enhances student understanding of basic cellular concepts and scientific experimental design. *Biochemistry and Molecular Biology Education, 40*(3), 174-180.

Burke da Silva, K., Auburn, Z., Hunter, A. B., & Young, J. (2008). Engaging students and improving learning outcomes with inquiry based biology practical classes In A. Hugman & K. Placing (Eds.), *Symposium Proceedings: Visualisation and Concept Development* (pp. 24–29.). The University of Sydney: UniServe Science.

Butler, S. (1999). Catalysing student autonomy through action research in a problem centred learning environment. *Research in Science Education, 29*(1), 127-140. doi:10.1007/BF02461184

Callan, P., Peacock, J., Poirier, J., & Tweedale, R. (2001). Practice Makes Information Literacy Perfect: Models of Educational Collaboration at QUT [online]. In: Frylinck, John (Editor). Partners in Learning and Research: Changing Roles for Australian Technology Network Libraries. [1-18]. Retrieved from: <http://search.informit.com.au.ezproxy.lib.monash.edu.au/documentSummary;dn=230377463849550;res=IELHSS>

Chanock, K. (2007). What academic language and learning advisers bring to the scholarship of teaching and learning: Problems and possibilities for dialogue with the disciplines. *Higher Education Research and Development, 26*(3), 269-280.

Chaplin, S. B. (2003). Guided development of independent inquiry in an anatomy/physiology laboratory. *Adv. Physiol. Educ., 27*(4), 230-240. doi:10.1152/advan.00002.2003

Cochrane, S., Goh, S. & Ku, H. (2009). An investigation into the application of research strategies in the final-year undergraduate engineering and surveying projects. *20th Annual Conference for the Australasian Association for Engineering Education, Engineering the Curriculum*, A.C.T., Engineers Australia, Barton, 6-9 December, pp. 193-198.

Collis, M., Gibson, A., Hughes, I., Sayers, G., & Todd, M. (2008). The Student View of 1st year Laboratory Work in the Biosciences — Score Gamma? *Bioscience Education, 11*(1), 1-14. doi:10.3108/beej.11.2

Corwin, L. A., Runyon, C., Robinson, A., & Dolan, E. L. (2015). The Laboratory Course Assessment Survey: A tool to measure three dimensions of research-course design. *CBE-Life Sciences Education, 14*(4), 1-11. doi:10.1187/cbe.15-03-0073

Creaser, C., & Spezi, V. (2014). Improving perceptions of value to teaching and research staff: The next challenge for academic libraries. *Journal of Librarianship and Information Science, 46*(3), 191-206. doi:10.1177/0961000613477678

Creswell, J. W. (1994). *Research design: qualitative & quantitative approaches*. Thousand Oaks, Calif.: Thousand Oaks, Calif.: Sage Publications.

Creswell, J. W. (2009). Quantitative methods. In *Research design: qualitative, quantitative, and mixed methods approaches* (3rd ed., pp. 145-171): Thousand Oaks, Calif.

Deacon, C., & Hajek, A. (2011). Student Perceptions of the Value of Physics Laboratories. *International Journal of Science Education, 33*(7), 943-977. doi:10.1080/09500693.2010.481682

Denzin, N. K., & Lincoln, Y. S. (2003). *The landscape of qualitative research: theories and issues / Norman K. Denzin, Yvonna S. Lincoln, editors* (2nd ed.). Thousand Oaks, CA: Thousand Oaks, CA : Sage.

Douglas, V. A., & Rabinowitz, C. E. (2016). Examining the Relationship between Faculty Librarian Collaboration and First-Year Students' Information Literacy Abilities. *College & Research Libraries, 77*(2), 144-163. doi: 10.5860/crl.77.2.144

Di Trapani, G., & Clarke, F. (2012). Biotechniques laboratory: An enabling course in the biological sciences. *Biochemistry and Molecular Biology Education, 40*(1), 29-36. doi:10.1002/bmb.20573

Doskatsch, I. (2003). Perceptions and perplexities of the faculty-librarian partnership: an Australian perspective. *Reference Services Review, 31*(2), 111-121.

doi:10.1108/00907320310476585

Eagan, M. K., Hurtado, S., Chang, M. J., Garcia, G. A., Herrera, F. A., & Garibay, J. C. (2013). Making a Difference in Science Education. *American Educational Research Journal, 50*(4), 683-713. doi:10.3102/0002831213482038

Fechheimer, M., Webber, K., & Kleiber, P. B. (2011). How well do undergraduate research programs promote engagement and success of students? *CBE-Life Sciences Education, 10*(2), 156-163. doi:10.1187/cbe.10-10-0130

Feldon, D. F., Maher, M. A., Hurst, M., & Timmerman, B. (2014). Faculty mentors', graduate students', and performance-based assessments of students' research skill development. *American Educational Research Journal, 52*(2), 334-370. doi:10.3102/0002831214549449

Fraser, G. A., Crook, A. C., & Park, J. R. (2007). A tool for mapping research skills in Undergraduate curricula. *Bioscience Education e-Journal, 9*. doi:10.3108/beej.9.1 Fraser, S., & Deane, E. (1997). Why Open Learning? *Australian Universities' Review, 40*(1), 25-31.

Fuselier, L., Detmering, R., & Porter, T. (2017). Contextualizing and Scaling up Science Information Literacy in Introductory Biology Laboratories. *Science & Technology Libraries, 36*(2), 135-152. doi:10.1080/0194262X.2017.1307158

Glaser, B. G., & Strauss, A. L. (1967). *The discovery of grounded theory: strategies for qualitative research*. New York: New York : Aldine.

Goldey, E. S., Abercrombie, C. L., Ivy, T. M., Kusher, D., Moeller, J. F., Rayner, D. A., Smith, C.F., Spivey, N. W. (2012). Biological inquiry: A new course and assessment plan in response to the call to transform undergraduate biology. *CBE-Life Sciences Education, 11*(4), 353-363.

Gonzalez-Espada, W., & LaDue, D. (2006). Evaluation of the impact of the NWC REU Program compared with other undergraduate research experiences. *Journal of Geosciences Education, 54*(5), 541-549.

Gregory, K. (2013). Laboratory logistics: strategies for integrating information literacy instruction into science laboratory classes. *Issues in Science and Technology Librarianship,* (Fall), 13. Retrieved from: http://www.istl.org/13-Fall/refereed2.html

Griffiths, R. (2004). Knowledge production and the research–teaching nexus: the case of the built environment disciplines. *Studies in Higher Education, 29*(6), 709-726. doi:10.1080/0307507042000287212

Hammersley, M. (1990). What's wrong with ethnography? The myth of theoretical description. *Sociology, 24*(4), 597-615. doi:10.1177/0038038590024004003

Healey, M. (2005). Linking research and teaching to benefit student learning in Higher Education. *Journal of Geography in Higher Education, 29*(2), 183–201.

Healey, M., & Jenkins, A. (2009). *Developing undergraduate research and inquiry*. Retrieved from: http://www.heacademy.ac.uk/assets/documents/resources/publications/developingundergraduate_final.pdf

Hegarty-Hazel. (1990). *The student laboratory and the science curriculum.* London: Routledge.

Henderson, C., Beach, A., & Finkelstein, N. (2011). Facilitating change in undergraduate STEM instructional practices: An analytic review of the literature. *Journal of Research in Science Teaching, 48*(8), 952-984. doi:10.1002/tea.20439

Hensley, M. K., Shreeves, S. L., & Davis - Kahl, S. (2015). A Survey of Library Support for Formal Undergraduate Research Programs. *College and Research Libraries, 75*(4), 422-411.

Hodder, I. (2000). The interpretation of documents and material culture. In N. K. Denzin & Y. S. Lincoln (Eds.), *Handbook of qualitative research* (2nd. ed.). London: Sage.

Hodgson, Y., Varsavsky, C., & Matthews, K. E. (2014). Assessment and teaching of science skills: whole of programme perceptions of graduating students. *Assessment & Evaluation in Higher Education, 39*(5), 515-530. doi:10.1080/02602938.2013.842539

Hofstein, A., & Lunetta, V. (1982). The Role of the Laboratory in Science Teaching: Neglected Aspects of Research. *Review of Educational Research, 52*(2), 201-217.

Hofstein, A., & Lunetta, V. (2003). The laboratory in science education: Foundations for the twenty-first century. *Sci. Ed, 88*, 28-54. doi:10.1002/sce.10106

Hofstein, A., & Lunetta, V. N. (2004). The laboratory in science education: Foundations for the twenty-first century. *Science Education, 88*(1), 28-54. doi:10.1002/sce.10106

Holdsworth, A., Watty, K., Davies, M., & University of Melbourne. (2009). *Developing capstone experiences*. Parkville, Vic.: Centre for the Study of Higher Education, University of Melbourne.

Howitt, S., Wilson, A., Wilson, K., & Roberts, P. (2010). 'Please remember we are not all brilliant': undergraduates' experiences of an elite, research-intensive degree at a research-intensive university. *Higher Education Research & Development, 29*(4), 405420. doi:10.1080/07294361003601883

Hunter, A. B., Laursen, S. L., & Seymour, E. (2007). Becoming a scientist: The role of undergraduate research in students' cognitive, personal, and professional development. *Science Education, 91*, 36-74. doi:10.1002/sce.20173

Ivey, R. (2003). Information literacy: how do librarians and academics work in partnership to deliver effective learning programs? *Australian Academic & Research Libraries, 34*(2), 100-113.

Johnson, E., Herd, S., & Tisdall, J. (2002). Encouraging generic skills in science courses. *Electronic Journal of Biotechnology, 5*(2), 1-4.

Justice, C., Rice, J., Warry, W., Inglis, S., Miller, S., & Sammon, S. (2007). Inquiry in Higher Education: Reflections and Directions on Course Design and Teaching Methods. *Innovative Higher Education, 31*(4), 201-214. doi:http://dx.doi.org/10.1007/s10755006-9021-9

Kardash, C. (2000). Evaluation of an undergraduate research experience: Perceptions of under- graduate interns and their faculty mentors. *Journal of Educational Psychology, 92*(1), 191-201.

Kearns, K., & Thrasher Hybl, T. (2005). A Collaboration between faculty and librarians to develop and assess a science literacy laboratory module. *Science & Technology Libraries, 25*(4), 39-56. doi: 10.1300/J122v25n04_04

Kempa, R. F., & Diaz, M. M. (1990). Students' motivational traits and preferences for different instructional modes in science education-Part 2. *International Journal of Science Education, 12*(2), 205-216. doi: 10.1080/0950069900120209

Kift, S., Nelson, K., & Clarke, J. (2010). Transition pedagogy: A third generation approach to FYE--a case study of policy and practice for the higher education sector. (First Year Experience) (Report). *The International Journal of the First Year in Higher Education, 1*(1), 1-20.

Korkmaz, O., & Yesil, R. (2010). A comparison of different teaching applications based on questioning in terms of their effects upon pre-service teachers' good questioning skills. *College Student Journal, 44*, 1006-1020.

Lazonder, A., & Harmsen, R. (2016). *Meta-Anaysis of Inquiry-Based Learning: Effects of Guidance, 86*(3), 681-718. doi:10.3102/0034654315627366

Lee, S. W.-Y., Lai, Y.-C., Yu, A. H.-T., & Lin, Y.-T. K. (2012). Impact of biology laboratory courses on students' science performance and views about laboratory courses in general: innovative measurements and analyses. *Journal of Biological Education, 46*(3), 173-179. doi:10.1080/00219266.2011.634017

Leech, N., & Onwuegbuzie, A. (2009). A typology of mixed methods research designs *Qual Quant* (43), 265–275. doi:10.1007/s11135-007-9105-3

Leggett, M., Kinnear, A., Boyce, M., & Bennett, I. (2004). Student and staff perceptions of the importance of generic skills in science. *Higher Education Research and Development, 23*(3), 295-312.

Litchfield, A., Frawley, J., & Nettleton, S. (2010). Contextualising and Integrating into the Curriculum the Learning and Teaching of Work-Ready Professional Graduate Attributes. *Higher Education Research and Development, 29*(5), 519-534.

Lopatto, D. (2004). Survey of Undergraduate Research Experiences (SURE): First Findings. *Cell Biology Education, 3*(4), 270-277. doi:10.1187/cbe.04-07-0045

Lopatto, D. (2007). Undergraduate Research Experiences Support Science Career Decisions and Active Learning. *CBE-Life Sciences Education, 6*(4), 297-306. doi:10.1187/cbe.0706-0039

Lopatto, D. (2010). Undergraduate Research as a High-Impact Student Experience. *Peer Review, 12*(2), 27-30.

Loveys, B., Kaiser, B., McDonald, G., Kravchuk, O., Gilliham, M., Tyerman, S., & Able, A., (2014). The development of student research skills in second year plant biology. *International Journal of Innovation in Science and Mathematics Education, 22*(3), 15-25.

Luckie, D. B., Aubry, J. R., Marengo, B. J., Rivkin, A. M., Foos, L. A., & Maleszewski, J. J. (2012). Less teaching, more learning: 10-yr study supports increasing student learning through less coverage and more inquiry. *Advances in Physiology Education, 36*(4), 325-335. doi:10.1152/advan.00017.2012

Luckie, D. B., Maleszewski, J. J., Loznak, S. D., & Krha, M. (2004). Infusion of collaborative inquiry throughout a biology curriculum increases student learning: a four-year study of "Teams and Streams". *AJP: Advances in Physiology Education, 28*(4), 199-209. doi:10.1152/advan.00025.2004

Menke, C. (2013), Streamlining program learning objective assessment with targeted activities and descriptive rubrics. Retrieved from: http://assessment.ucmerced.edu/sites/assessment.ucmerced.edu/files/page/documents/menkec-presentation.pptx.pdf

Monash University Handbook (2014.) Retrieved from: http://www.monash.edu/pubs/2014handbooks/

Monash University Library (2012). Strategic Plan 2012-2015. Retrieved from: https://www.monash.edu/library/researchdata/about/strategy

Monash University, Biology II-BIO1022 Practical Manual (2014). School of Biological Sciences.

Moselen, C., & Wang, L. (2014). Integrating Information Literacy into Academic Curricula: A Professional Development Programme for Librarians at the University of Auckland. *The Journal of academic librarianship, 40*(2), 116-123. doi:http://dx.doi.org/10.1016/j.acalib.2014.02.002

Munns, S., & Chilton, L. (2014). *Demand evidence and think critically: Building research excellence in tomorrow's scientists.* Paper presented at the Proceedings of the Australian Conference on Science and Mathematics Education, University of Sydney.

Oliver, B. L., Ferns, S. J., Whelan, B. A., & Lilly, T. (2010). *Mapping the curriculum for quality enhancement: Refining a tool and processes for the purpose of curriculum renewal*. Paper presented at the AuQF2010, Gold Coast.

Osborn, J. (2012). The national year of reading: celebrating the role of literature in an academic culture. *Australian Library Journal*, 61(4), 281-288.

Peacock, J. (2001). Teaching Skills for Teaching Librarians: Postcards from the Edge of the Educational Paradigm. *Australian Academic & Research Libraries, 32*(1), 26-42. doi:10.1080/00048623.2001.10755141

Peirce, E., Ricci, M., Lee, I., & Willison, J. (2009). *First-year Human Biology students in the ivory tower.* Paper presented at the UniServe Science University of Adelaide.

Petrella, J. K., & Jung, A. P. (2008). Undergraduate Research: Importance, Benefits, and Challenges. *International Journal of Exercise Science, 1*(3), 91-95.

Pretorius, L., Bailey, C., & Miles, M. (2013). Constructive Alignment and the Research Skills Development Framework: Using Theory to Practically Align Graduate Attributes, Learning Experiences, and Assessment Tasks in undergraduate

Midwifery. *International Journal of Teaching and Learning in Higher Education, 25(3), 378-387*.

Rayner, G., Charlton-Robb, K., Thompson, C., & Hughes, T. (2013). Interdisciplinary Collaboration to Integrate Inquiry-Oriented Learning in Undergraduate Science Practicals. *International Journal of Innovation in Science and Mathematics Education, 21*(5), 1-11.

Rayner, G., Familari, M., Blanksby, T., Young, J., & Burke da Silva, K. (2012). *Assessing first year biology student practical skills: Benchmarking across the landscape*. Paper presented at the International First Year in Higher Education Conference, Brisbane.

Rayner, G. M., Charlton-Robb, K., Thompson, C. D., & Hughes, T. (2013). Interdisciplinary collaboration to integrate inquiry-oriented learning in undergraduate science practicals. *International Journal of Innovation in Science and Mathematics Education [E], 21*(5), 1-11. Retrieved from: http://ojs-prod.library.usyd.edu.au/index.php/CAL/article/view/7301

Rice, J. W., Thomas, S., M., & O'Toole, P. (2009). *Tertiary Science education in the 21st century*. Australia: Australian Learning and Teaching Council.

Roberts, R. (2001). Procedural understanding in biology: the 'thinking behind the doing'. *Journal of Biological Education, 35*(3), 113-117. doi:10.1080/00219266.2001.9655758

Ross, P., Taylor, C., & Jones, S. (2013). *Biology Standards Statement*. Sydney, N.S.W.: Office for Learning and Teaching. Department of Industry, Innovation, Climate Change,

Science, Research and Tertiary Education. VIBEnet Vision and Innovation in Biology Education. Retrieved from: https://www.researchgate.net/profile/Susan_Jones8/publication/273886879_Biolog y Standards_Statement/links/550f90790cf21287416b8cf8/Biology-StandardsStatement.pdf.

Roth, W. M. (1996). Teacher Questioning in an Open-Inquiry Learning Environment: Interactions of Context, Content, and Student Responses. *Journal of Research in Science Teaching, 33*(7), 709-736. doi: 10.1002/(SICI)1098-2736(199609)33:73.0.CO2R

Rudestam, K. E., & Newton, R. R. (2015). *Surviving your dissertation: a comprehensive guide to content and process* (4th ed.): Thousand Oaks, California Sage Publication.

Russell, S. H., Hancock, M. P., McCullough, J., & of, P. (2007). Benefits of undergraduate research experiences: surveys indicate that undergraduate research opportunities help clarify students' interest in research and encourage students who hadn't anticipated graduate studies to alter direction toward a Ph.D. *Science, 316(5824)*, 548-549.

Sadler, T. D., & McKinney, L. (2010). Scientific research for undergraduate students: a review of the literature. *Journal of College Science Teaching, 39*(5), 43.

Schofield, J.W. (2002). Understanding and validity in qualitative research. In A.M. Huberman & M.B. Miles (Eds.), *The Qualitative Researcher's Companion* (pp. 171-203). Thousand Oaks: Sage.

Seymour, E., Hunter, A. B., Laursen, S., & DeAntoni, T. (2004). Establishing the benefits of Research experiences for Undergraduate studnts in the sciences: First findings from a Three-Year Study. *Science Education, 88*(4), 493-534.

Shepardson, D. (1997). The nature of student thinking in life science laboratories. *School Science and Mathematics, 97*(1), 37-44.

Silverman, D. (2006). *Interpreting qualitative data: methods for analysing, talk, text and interaction* (3rd ed.). London: Sage.

Silverman, D. (2014). *Interpreting qualitative data / David Silverman* (5th ed.). London: SAGE.

Smith, C. (2011). Evaluating the quality of work-integrated learning curricula: a comprehensive framework. *Higher Education Research & Development, 31*(2), 247-262. doi:10.1080/07294360.2011.558072

Smith, L. (2011). Monash University Library: A New Paradigm for a New Age. *Australian Academic and Research Libraries, 42*(3), 246-264.

Snape, & Spencer, D. (2011). The foundations of qualitative research. In *Qualitative research practice, guide for social science students and researchers* (pp. 2-23). London: Sage.

Snelling, C., & Karanicolas, S. (2008). *Why Wikis Work: Assessing group work in an on-line environment.* Paper presented at the ATN assessment conference, University of South Australia, 20-21 November 2008.

Spradley, J. P. (1980). *Participant observation*. New York: Holt, Rinehart and Winston.

Spronken-Smith, R. (2010). Undergraduate research and inquiry-based learning: is there a difference? Insights from research in New Zealand. *Council on Undergraduate Research Quarterly, 30*(4), 28-35.

Spronken-Smith, R., Walker, R., Batchelor, J., O'Steen, B., & Angelo, T. (2010). Evaluating student perceptions of learning processes and intended learning outcomes under inquiry approaches. *Assessment & Evaluation in Higher Education, 37*(1), 57-72. doi:10.1080/02602938.2010.496531

Stamatoplos, A. (2009). The role of academic libraries in mentored undergraduate research: a model of engagement in the academic community. *College & Research Libraries, 70*(3), 235-249. doi:10.5860/crl.70.3.235

Stewart, P., Styles, K., Torres, L., & Horne, D. (2012). *Skill mapping an undergraduate Pharmacy degree*. Paper presented at the International Pharmaceutical Federation (FIP) World Centennial Congress of Pharmacy and Pharmaceutical Sciences, International Conference, Amsterdam, October 2012

Strauss, A., & Corbin, J. (1998). *Basics of qualitative research*. Thousand Oaks, California: Sage.

Sumsion, J., & Goodfellow, J. (2004). Identifying Generic Skills through Curriculum Mapping: A Critical Evaluation. *Higher Education Research and Development, 23*(3), 329-346.

Taib, A., & Holden, J. (2013). 'Third generation' conversations - A partnership approach to embedding research and learning skills development in the first year. A Practice Report. *The International Journal of the First Year in Higher Education, 4*(2), 131-136. doi:http://dx.doi.org/10.5204/intjfyhe.v4i2.178

Talgar, C. P., & Goodey, N. M. (2015). Views from academia and industry on skills needed for the modern research environment. *Biochemistry and Molecular Biology Education, 43*(5), 324-332. doi:10.1002/bmb.20883

Thompson, Rayner, Barratt, Hughes, & Kirkup. (2014). *Cognitive skills and processes associated with researching are often dispersed across these pedagogical categorisation*. Sydney, NSW: Office of Learning and Teaching, Department of Industry, Innovation, Science, research and tertiary Education.

Thomson, E. A., Auhl, G., Hicks, K., McPherson, K., Robinson, C., & Wood, D. (2017). Course design as a collaborative enterprise: Incorporating interdisciplinarity into a backward mapping systems approach to course design in Higher Education. In R. G. Walker & S. B. Bedford (Eds.), *Research and Development in Higher Education: Curriculum Transformation,* (Vol. 40 pp. 356-367). Sydney, Australia 27–30 June 2017.

Torres, L., & Jansen, S. (2016). Working from the same page: catalysing university-wide library-faculty partnerships to enhance students' research skill development. *Council for Undergraduate Research (CUR) Quarterly., 37*(1), 26-33. Retrieved from: doi:10.18833/curq/37/1/9

Venning, J., & Buisman-Pijlman, F. (August 2011). The development of an assessment matrix to promote student learning in postgraduate multidisciplinary research projects. *ERGO The Journal of the Education Research Group of Adelaide, 2*(2), 37-44.

Vygotsky, L. S. (1978). *Mind in society: The development of higher psychological processes*. Cambridge: Harvard University Press.

Wass, R., & Golding, C. (2014). Sharpening a tool for teaching: the zone of proximal development. *Teaching in Higher Education, 19*(6), 671-684. doi:10.1080/13562517.2014.901958

Wei, C. A., & Woodin, T. (2011). Undergraduate Research Experiences in Biology: Alternatives to the Apprenticeship Model. *CBE-Life Sciences Education, 10*(2), 123-131. doi:10.1187/cbe.11-03-0028

White, H. B., Benore, M. A., Sumter, T. F., Caldwell, B. D., & Bell, E. (2013). What skills should students of undergraduate biochemistry and molecular biology programs have upon graduation? *Biochemistry and Molecular Biology Education, 41*(5), 297-301.doi:10.1002/bmb.20729

Willison, J. (2013). Inquiring ape? *Higher Education Research & Development, 32*(5), 861-865. doi: 10.1080/07294360.2013.806043

Willison, J. (2012). When academics integrate research skill development in the curriculum. *Higher Education Research and Development, 31*(6), 905-919. doi:10.1080/07294360.2012.658760

Willison, J., & Buisman-Pijlman, F. (2016). Ph.D. Prepared: Research Skill Development Across the Undergraduate Years. *International Journal for Researcher Development, 7*(1), 63-83. doi:http://dx.doi.org/10.1108/IJRD-07-2015-0018

Willison, J., & O'Regan, K. (2006). Research Skill Development Framework. Retrieved from http://www.adelaide.edu.au/rsd/ Accessed on 25 April, 2013

Willison, J., & O'Regan, K. (2006, 2013). Research Skill Development Framework. Retrieved from http://www.adelaide.edu.au/rsd/

Willison, J., & O'Regan, K. (2007). Commonly known, commonly not known, totally unknown: A framework for students becoming researchers. *Higher Education Research & Development, 26*(4), 393-409.

Willison, J., Sabir, F., & Thomas, J. (2016). Shifting dimensions of autonomy in students' research and employment. *Higher Education Research & Development*, 36(2), 1-14.
doi:10.1080/07294360.2016.1178216

Willison, J., Schapper, J., & Teo, E. (2009). *Multiple methods of improvement of research skills in business ethics and business law*. Paper presented at QATLHEBEC conference, University of Melbourne, 6 February 2009.
http://www.adelaide.edu.au/rsd/evidence/relatedarticles/Willison_Schapper_Teo.pdf

Wilson, A., Howitt, S., & Higgins, D. (2015). A fundamental misalignment: intended learning and assessment practices in undergraduate science research projects. *Assessment & Evaluation in Higher Education*, 41(6), 1-16.
doi:10.1080/02602938.2015.1048505

Yacoubian, H. A., & BouJaoude, S. (2010). The effect of reflective discussions following inquiry-based laboratory activities on students' views of nature of science. *Journal of Research in Science Teaching, 47*(10), 1229-1252. doi:10.1002/tea.20380

Appendices

List of Tables

List of Figures

Appendix A

Research Skill Development Framework

www.rsd.edu.au

A conceptual framework for the explicit, coherent, incremental and cyclic development of the skills associated with researching, problem solving and critical thinking

RSD

Extent of Students' Autonomy

What characterises the difference between 'search' and research? More searching and more data generation is just a 'bigger search'! Research is when students...		Level 1 (Prescribed Research)	Level 2 (Bounded Research)	Level 3 (Scaffolded Research)	Level 4 (Student-initiated Research)	Level 5 (Open Research)
		Highly structured directions and modelling from educator prompt student research	Boundaries set by and limited directions from educator channel student research	Scaffolds placed by educator shape student independent research	Students initiate the research and this is guided by the educator	Students research within self-determined guidelines that are in accord with discipline or context
a. Embark & Clarify Respond to or initiate research and clarify or determine what knowledge is required, heeding ethical/cultural and social/team considerations.	Curious	Respond to questions/tasks arising explicitly from a closed inquiry. Use a provided structured approach to clarify questions, terms, requirements and expectations.	Respond to questions/tasks required by and implicit in a closed inquiry. Choose from several provided structures to clarify questions, terms, requirements and expectations.	Respond to questions/tasks generated from a closed inquiry. Choose from a range of provided structures or approaches to clarify questions, terms, requirements and expectations.	*Generate questions/aims/ hypotheses framed within structured guidelines*	*Generate questions/aims/ hypotheses based on experience, expertise and literature*
b. Find & Generate Find and generate needed information/data using appropriate methodology.	Determined	Collect and record required information or data using a prescribed methodology from a prescribed source in which the information/data is clearly evident.	Collect and record required information/data using a prescribed methodology from prescribed source/s in which the information/ data is not clearly evident.	Collect and record required information/data from self-selected sources using one of several prescribed methodologies.	Collect and record self-determined information/ data from self-selected sources, choosing an appropriate methodology based on structured guidelines.	Collect and record self-determined information/data from self-selected sources, choosing or devising an appropriate methodology with self-structured guidelines.
c. Evaluate & Reflect Determine and critique the degree of credibility of selected sources, information and of data generated and reflect on the research processes used.	Discerning	Evaluate information/data and reflects on inquiry process using simple prescribed criteria.	Evaluate information/data and reflect on the inquiry process using given criteria.	Evaluate information/data and inquiry process using criteria related to the aims of the inquiry. Reflect insightfully to improve own processes used.	Evaluate information/data and the inquiry process comprehensively using self-determined criteria developed within structured guidelines. Reflect insightfully to refine others' processes.	Evaluate information/data and inquiry process rigorously using self-generated criteria based on experience, expertise and the literature. Reflect insightfully to renew others' processes.
d. Organise & Manage Organise information and data to reveal patterns and themes, and manage teams and research processes.	Harmonising	Organise information/data using prescribed structure. Manage linear process provided.	Organise information/data using a choice of given structures. Manage a process which has alternative pathways.	Organise information/data using recommended structures. Manage self-determined processes with multiple possible pathways.	Organise information/data using student-determined structures, and manage the processes, within the parameters set by the guidelines.	Organise information/data using student-determined structures and management of processes.
e. Analyse & Synthesise Analyse information/data critically and synthesise new knowledge to produce coherent individual/team understandings.	Creative	Analyse and synthesise information/data to reproduce existing knowledge in prescribed formats. *"Ask emergent questions of clarification/curiosity"*	Analyse and synthesise information/data to reorganize existing knowledge in standard formats. *"Ask relevant, researchable questions emerging from the research"*	Analyse and synthesise information/data to construct emergent knowledge. *"Ask rigorous, researchable questions based on new understandings"*	Analyse and create information/data to fill knowledge gaps stated by others.	Analyse and create information/data to fill student-identified gaps or extend knowledge.
f. Communicate & Apply ethically Write, present and perform the processes, understandings and applications of the research, and respond to feedback, accounting for ethical, social and cultural (ESC) issues.	Constructive	Use mainly lay language and prescribed genre to demonstrate understanding for lecturer/ teacher as audience. Apply to a similar context the knowledge developed. Follow prompts on ESC issues.	Use some discipline-specific language and prescribed genre to demonstrate understanding from a stated perspective and for a specified audience. Apply to different contexts the knowledge developed. Specify ESC issues.	Use discipline-specific language and genres to demonstrate scholarly understanding for a specified audience. Apply the knowledge developed to diverse contexts. Specify ESC issues in initiating, conducting and communicating.	Use discipline-specific language and genres to address gaps of a self-selected audience. Apply innovatively the knowledge developed to a different context. Probe and specify ESC issues in each relevant context.	Use appropriate language and genre to extend the knowledge of a range of audiences. Apply innovatively the knowledge developed to multiple contexts. Probe and specify ESC issues that emerge broadly.
...spiral through the facets, adding degrees of rigour and discernment as they delve.		Research Skill Development (RSD), a conceptual framework for Primary school to PhD, developed by John Willison and Kerry O'Regan ©, October, 2006/November, 2012, with much trialling by Eleanor Peirce and Mario Ricci. Facets based on: ANZIIL (2004) Standards & Bloom's et al (1956) Taxonomy. * *Framing researchable questions often requires a high degree of guidance and modelling for students and, initially, may need to be scaffolded as an outcome of the researching process (Facet E, Levels 1-3). After development, more students are able to initiate research (Facet A, Levels 4 & 5)*. The perpendicular font reflects the drivers and emotions of research. Framework, resources, learning modules and references available at http://www.rsd.edu.au. For information: john.willison@adelaide.edu.au				

Facets of Research

Appendix B

Bachelor of Science, Monash University Learning Outcomes

1. Demonstrate broad knowledge and technical skills in at least one area of science, and a basic understanding of science disciplines other than those in which [they] major
2. Develop, apply, integrate and generate scientific knowledge in professional contexts to analyse challenges and to develop effective solutions
3. Demonstrate understanding of the importance of science to the human endeavour
4. Collect, organise, analyse and interpret data meaningfully, using mathematical and statistical tools as appropriate to the discipline of a major(s)
5. Convey ideas and results effectively to diverse audiences and in a variety of formats
6. Work and learn both independently and collaboratively to encompass diverse abilities and perspectives
7. Exercise personal, professional and social responsibility as a global citizen (Monash University Handbook, 2016)

Appendix C

Learning outcomes for BIO1022, 2014

On completion of this unit students will be able to:

1. Understand and comprehend concepts and processes related to molecular genetics, genetic engineering and the biochemistry and physiology of organ systems, including homeostasis, nervous and muscular-skeletal systems, animal reproduction and development and nutrition;
2. Understand the nature of microbial diversity, in particular how it relates to human health and disease;
3. Demonstrate competency in laboratory procedures and techniques, including Gram staining, aseptic techniques, gel electrophoresis, and spectrophotometry;
4. Demonstrate competency in designing experiments, gathering data and analysing and presenting summative data in meaningful and accurate ways;
5. Communicate scientific principles and information underlying biology-related topics in written or oral formats and using appropriate conventions for scientific attribution;
6. Utilise skills in the use of library catalogues and databases to locate published information and synthesize such into essays and practical reports

(Source: http://www.monash.edu/pubs/2014handbooks/units/BIO1022.html)

Appendix D

Learning Aims of BIO1022 Practicals 1-5 (Practical Manual)

Practical 1. Genetics (Regular practical)

- To understand the operon concept as a mechanism for controlling gene expression in bacteria at the level of gene transcription;
- To gain experience in the measurement of enzyme activity;
- To gain understanding in the analysis of experimental results;
- To gain understanding of the effects of mutations on protein function.

Practical 2: Toad dissection (Regular practical)

- To develop skills in dissecting a vertebrate;
- To identify anatomical structures and develop an understanding of the interrelationships between these structures;
- To reinforce understanding of the links between structure and function of vertebrate organ systems;
- To develop skills in peer assessment.

Practical 3: Metabolism (Regular practical)

- To investigate metabolic processes in a living organism by extracting an active enzyme and using it to catalyse a specific biochemical reaction;
- To investigate the relationship between enzyme activity and metabolic function during different life stages of a living organism;
- To use scientific methods to make and test predictions regarding the product of an enzyme-catalysed-reaction;
- To identify maltose as the product of starch hydrolysis by amylase;
- To interpret results in terms of the metabolic role of amylase during plant development;
- To further develop report writing skills in biology.

Practical 4 & 5: Microbiology 1 & 2 (Inquiry Oriented Learning (IOL))

- You should understand the biochemical basis of the differential Gram Stain and the importance of its role as a first stage identification test for unknown microorganisms.
- You should be able to derive, transfer and row pure cultures of microorganisms using aseptic techniques
- You should be familiar with tests and differential stains used to identify bacterial structures including flagella, spores and capsules, and the production of enzymes such as haemolysin and catalase.

Practical 6: Animal feeding and nutrition (Student Investigation and joint presentations)

- To become familiar with different forms and sources of the organic material on which animals feed.
- To recognise different classifications of feeding types among animals and the main body structures and plans that are associated with each.
- To examine and report on the diversity of morphological and behavioural adaptations for feeding that have evolved among animals.
- To further develop teamwork and peer learning.
- To further develop science research and oral communication skills.

Appendix E

Observational Data Sheet Template

Criteria adopted from Spradley, J.P. (1980) Participant Observation. Holt, Rinehardt and Wilson, New York.

Date	Time	#Students	#TAs	Ohers	Setting description and physical objects
	Start Finish				

Lab Activities Students/TA/Others		**Questions/Comments/Insights/ Follow-up**
Events Students/TA/Others		

Acts Students/TA/Others		

Feelings Emotions felt/expressed		
Language Talk/Vocabularies		
Other		

Appendix F

Subskills identified in the data sources related to the RSD Facets of Research

- EMBARK & CLARIFY
  - Exercises health and safety protocols
  - Responds to ethical, social and team considerations
  - Define key concepts, terms, theories
  - Clarifies, questions processes, procedures and task requirements
  - Contextualises topic using text, visuals, diagrams, discussion
  - Plans, prepares, determines requirements, assigns team roles
  - Predicts, formulates a hypothesis
- FIND & GENERATE
  - Applies procedures, techniques, methods to find generate information or data needed
  - Finds, Identifies required information, data, resources, materials instruments
  - Generates, collects information, data using appropriate processes, methods techniques
  - Distinguishes, selects information or data based on identified needs, criteria
- EVALUATE & REFLECT
  - Evaluates team structures, responsibilities, effectiveness
  - Considers data generated, information found by critiquing, judging
  - Detects reasons for contradictions in evidence, bias
  - Assesses processes, completeness, adequacy, errors, omission of information, data
  - Checks review processes, steps, methodology, strategies
  - Reviews and revise hypothesis, predictions
- ORGANISE & MANAGE
  - Collaborates, maintains team function
  - Manages, tracks time to meet deadlines
  - Organises and manages laboratory environment and experimental processes
  - Categories, labels, illustrates, tables, takes notes and creates diagrams
- ANAYLSE & SYNTHESISE
  - Identifies and apply problem solving strategies
  - Compares contrast information, data results for patterns completeness, accuracy
  - Combines, integrate information, data, results to interpret, estimate, reason, infer
  - Examines processes used to obtain results for accuracy, to deduce, draw conclusions, make decisions
  - Asks emergent questions based on evidence, information, data, results, knowledge
  - Develops new understandings and learnings
- COMMUNICATE & APPLY
  - Acknowledges academic and ethical protocols by citing, referencing, acknowledging team contributions
  - Demonstrates scientific knowledge, make claims based on information, data, results
  - Represents, reproduce, explain describe using visual techniques and scientific terminology
  - Recalls, explains, describes, discusses, paraphrases, summarises through writing, uses scientific terminology
  - Speaks, recalls, explains, discusses, debates, presents orally using scientific terminology