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Research skills in the first-year biology practical - Are they there?

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Abstract

Laboratory practicals engage students in complex thinking to build their scientific knowledge and understanding. Surprisingly few studies connect the development of students' cognitive and metacognitive skills for learning in the laboratory practical with foundational skills for researching. Librarians strive to establish teaching partnerships with academics to contextualise research skills within curriculum content. However, pedagogical models to make research skills explicit and guide library-faculty collaborations are lacking. This study explores the Research Skill Development (RSD) framework (Willison & O'Regan 2006/2018; see the first article in this issue) to extrapolate students' research skills in a first-year biology practical unit. A qualitative research design was applied to identify research skills in the unit's laboratory manual and in descriptive observations of students in five laboratory practicals. Results show students engaged in the research skills articulated by the RSD, yet these skills were implied rather than explicitly taught. Implications suggest that fundamental research skills which enable student preparedness for research can be overlooked in practical curricula. Research skills remaining unrecognised impacts learning and teaching, including the contribution librarians could make in this context. Findings demonstrated that the RSD is a useful theoretical construct and *a priori* framework to make research skills visible to educators.

Keywords

Research skills, laboratory practicals, first year science education, first year biology, library-faculty collaboration, student-teacher interactions, learner autonomy

Introduction

Students' research skill development in undergraduate coursework is discussed by a substantial body of literature, and, to a large extent, it describes higher education curriculum initiatives designed to equip students with thinking skills and processes for research (Healey & Jenkins 2009; Brew 2006, 2012; 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 1998; Jenkins & Healey 2009). The emphasis placed on students attaining research skills towards the end of their undergraduate studies, however, overlooks potential for the explicit and progressive cultivation of research skills within regular undergraduate coursework.

Academic librarians are strongly present in the literature, exploring ways to strategically align their research skill expertise with skill development initiatives in their institutions (Bruce 2001). To enable a stronger alignment, librarians have sought ways 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; Smith 2011; Moselen & Wang 2014). The fostering of collaborative teaching partnerships by librarians with discipline academics has become the accepted model to achieve this aim (Peacock 2011).

The study described in this paper focused on identifying students' research skills in a first-year biology practical unit. The study was prompted by the challenges faced by librarians in establishing library-faculty teaching partnerships to connect their research skill expertise to science practical curricula. A collaborative teaching model is dependent on a number of factors and includes, a common understanding among educators as to what research skills might entail in the laboratory 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 aims to contribute to the understanding of these factors.

The Research Skill Development (RSD) framework (Willison & O'Regan 2006/2018; see the first article in this issue), a conceptual, flexible and adaptable model for developing students' research skills, was considered a suitable instrument to underpin this study. The RSD framework 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 and O'Regan 2007, pp. 404). The RSD framework was applied to this study so that its usefulness as a construct through which to identify and extrapolate on the research skills developed by students in one first-year biology practical unit could be considered.

Rationale

Science coursework practicals integrate content knowledge with students' scientific skill development (Luckie, Aubry, Marengo, Rivkin, Foos & Maleszewski 2012). Skill-related discussion in the literature is largely centred on students gaining proficiency with manipulative and technical skills, with less emphasis placed on higher-order thinking skills related to researching (Di Trapani & Clarke 2012; Loveys, Kaiser, McDonald, Kravchuk, Gilliham, Tyerman & Able 2014). Therefore, students' foundational skills for research within undergraduate practical coursework generally appear to be an overlooked outcome of learning (Di Trapani & Clarke 2012), which offers an explanation for their absence in the literature (Bradley 2013). Gaining clarity as to what such skills entail in a first-year practical biology unit may be the first step required to open a new conversation amongst librarians and science academics to make research skills explicit in this challenging learning context.

The underlying research question was:

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?

Research Skill Development in Undergraduate Science Curricula

Undergraduate science students at many universities are generally introduced to research skills through Undergraduate Research Experiences (UREs) or capstone units (Seymour, Laursen, Higgins & DeAntoni 2004; Healey & Jenkins 2009; Corwin, Runyon, Robinson & Dolan 2015). The URE model is a 'research internship' where the undergraduate student engages in meaningful research under the guidance of a faculty mentor (Kardash 2000). Although proponents of UREs claim benefits to student learning such as the development of critical thinking and problem-solving skills, an evaluation of published UREs undertaken by Howitt, Wilson and Wilson (2010), claims that the efficacy of such course-based approaches for inculcating students' research skills is scant. The authors note that "the evidence on which assertions are based, is at best anecdotal and at worst absent" (2010, pp. 406). Studies undertaken by Kardash (2000) and Russell, Hancock and McCullough (2007) conclude that benefits of the URE are limited to developing students' confidence with certain basic skills; however, the development of higher-order thinking skills associated with researching is less apparent due to the lack of standardized measures to evaluate benefits of the model:

> *"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).

A further limitation of the URE model for developing undergraduate students' research skills more broadly across the student cohort is that the URE is generally offered to high achieving students. This suggests that a more equitable model may be required to cultivate, nurture and develop the research skills of all students in science programs of study, not only those undertaking competitive and elite co-curricular research units. Placing value on research skills within the context of final year research-oriented units suggests a limited interpretation of what research skills might encompass, including how and where such skills are developed. For research skills to become integrated into everyday learning, Willison and O'Regan (2007, pp. 394) advise that a new understanding of "research skills as both a product and a process of university education needs to transpire" among educators, together with a reconceptualisation of what research skills may encompass in the undergraduate years. This raises the question, 'When does an undergraduate student suddenly begin to research?'

Willison and O'Regan (2007) offer an explanation, suggesting that research can be perceived by university educators as "an entity separate from and unrelated to student coursework" (Willison & O'Regan 2007, pp. 398). Willison and O'Regan posit that 'research' tends to be conceptualised within a hierarchy of terms. It is associated with the formal activity of academic or professional research performed by a researcher, rather than a skill set that is ideally developed and practiced progressively as part of an undergraduate's learning journey (Willison & O'Regan 2007, pp. 398). Therefore, the development of research skills as an explicit and coherent element of learning which is incrementally developed remains aspirational, poorly understood and difficult to realise (Willison & O'Regan 2007).

Challenges in Conceptualising Students' Research Skills

A laboratory-based program consisting of coursework practicals is considered a "cornerstone of most science degrees because it provides students with an opportunity to develop critical thinking skills needed to become a scientist" (Barrie et al. 2015, pp. 1810). The literature focuses on the importance of science students developing practical and generic skills that include higher-order 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, pp. 353). Yet conventional recipe-driven practicals tend to overlook the potential of this learning environment to draw explicit connections between the higher-order thinking skills students engage with in the practical, and the skills necessary for research proficiency (Peirce, Ricci, Lee & Willison 2009; Gregory 2013).

A study undertaken by Wilson, Howitt and Higgins (2015) identified the difficulty faced by educators in articulating research skills as learning outcome statements for coursework practicals, which may indicate a reduced focus on research skills in this learning context. This study noted the different ways in which skills were generally categorised by educators participating in the study. For example, skills were either "outcomes based, positioned as extensions of conventional learning or qualitatively different and inherently entangled in the process of becoming a researcher" (Wilson, Howitt & Higgins 2015, pp. 4.)

A further incongruence noted by the authors was the emphasis placed by educators on the product of learning rather than the process itself. The authors stated that "such assessment implies that successful learning in a research project is best measured by the results obtained, rather than the thinking processes and understanding developed in obtaining them" (Wilson et al. 2015, p. 5).

The many conceptualisations and terms in current usage to describe research skills present a significant obstacle when librarians endeavour to explain how their research skill expertise might benefit student learning. This raises important questions about how research skills are perceived, conceptualised and understood by science educators and librarians alike, and what might be required to develop students' skills for researching as a shared responsibility. 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 acknowledged outcomes of learning compounds this challenge.

Teaching Approaches in the Practical

Science educators have debated the benefits of pre-determined experimental laboratory activities that use sequenced instructional learning approaches with predetermined outcomes. Chaplin (2003) emphasises 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 continues to report a lack of opportunity in recipe-driven laboratory practicals for students to become cognisant of the skills and processes involved in laboratory activities, as the focus is on completing the final 'product' and covering disciplinary content (Rice, Tomas & O'Toole 2009; White et al. 2013). Recognising the deficiencies of recipe-driven instruction, the literature explores ways to invigorate undergraduate science curricula through innovative teaching methods such as Inquiry-Oriented Learning approaches (IOL; Rayner, Charlton-Robb, Thompson & Hughes 2013).

Research Context

This study was undertaken in a research-intensive university. The purpose of the study was to identify which research skills were being developed by first-year students in a second-semester biology practical unit. The unit incorporated two instructional approaches delivered by two different Teaching Associates (TAs). Practicals 1 to 3 were designed as conventional 'recipe-driven' practicals (delivered by TA1), while Practicals 4 and 5 were IOL (Inquiry Oriented Learning)-inspired practicals (delivered by TA2) and badged as IDEA (Idea-Design-Explore-Answer) experiments (Rayner, Charlton-Robb, Thompson & Hughes 2013). Conventional 'recipe-driven' Practicals 1 to 3 explored a different topic in each practical. IDEA Practicals 4 and 5 investigated a topic over two practical sessions. Comparing and contrasting different teaching styles of the TAs offered unexpected insights into what might be needed to enable students to become more autonomous in developing and applying research skills in laboratory settings.

Students enrolled in this unit were required to complete all six coursework practicals to meet unit requirements. However, Practical 6 was omitted from this study as it involved students presenting a group assignment where the preparation made by students for this task was unable to be observed.

Methodology and Methods

This study was informed by a qualitative research design underpinned by social constructivist epistemology (Vygotsky 1978). Interpretive analysis (Strauss & Corbin 1998) of the data sources; descriptive observations of students engaged in five consecutive laboratory practicals, and content of the unit's laboratory manual (School of Biological Sciences 2014) was undertaken. The interactions between students and their TAs in the learning context of each practical, and the instructional content of the practical manual were analysed for students' cognitive skills and processes related to researching. Skills emerging from the data were thematically categorised in alignment with the elements of the RSD framework: the vertical axis delineating the facets of research and the horizontal axis explicating the scope of autonomy (Willison & O'Regan 2006/2018). The intention of this study was not to arrive at a definitive or conclusive 'truth' about students' skill development, but to gain a clearer picture of this phenomenon in the learning setting of one first-year, second-semester biology practical unit.

Data Collection and Analysis

Data was collected by taking detailed descriptive observations (Spradley 1980) of a laboratory bench of eight students in a laboratory classroom setting. The same eight students were observed in five consecutive practicals. To add rigor and enhance reliability, data was triangulated with a content analysis of the instructional components of each practical in the laboratory manual.

Coding categories (nodes) based on the RSD framework's Facets of Research and Scope for Student Autonomy were created in NVivo qualitative analysis software. In this way, the RSD framework served as the schema through which research skills and their development were interpreted. Identifying research skills in the data sources involved processes associated with interpretive and iterative analysis techniques (Strauss & Corbin 1998).

The process of analysis revealed subskills in the data sources related to the facets of research. The analytical approach applied acknowledges that in the search for meaning in complex relationships, words may be analysed quantitatively, coded, categorised and expressed in numerical form (Lofland & Lofland 1995). To enhance reliability and reduce personal subjectivity, coding decisions were reviewed by a category challenger who reviewed coding decisions. Coding was undertaken over two iterations before coming to final coding conclusions.

Results

Learning Aims

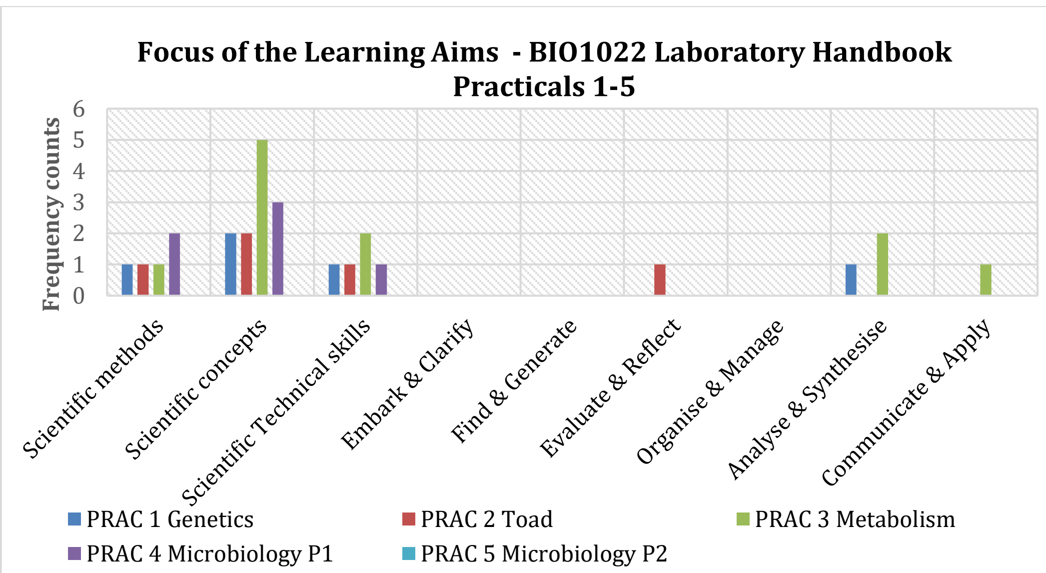

Figure 1. Analysis of BIO1022 learning aims from the laboratory handbook for each of the five practicals examined.

Figure 1 presents analysis of the learning aims for Practicals 1 to 5 (Appendix A). Each learning aim was thematically interpreted for learning emphasis in alignment with the RSD framework's facets of research. Results show that the acquisition of scientific methods, scientific concepts and scientific technical skills appears recurrently in the learning aims, in contrast with the lack of emphasis placed on skills and processes for research.

Learning aims related to research skill development in the laboratory manual do not articulate specific skills. Rather, reference to skill development in the learning aims is stated in broad terms, for example, 'To develop skills' (Practical 2), and 'To further develop skills' (Practical 3). Learning aims expressing research-related terminology only occur in Practical 2, for example; 'To interpret', 'To identify' and 'To investigate'. Practical 4 (Part 1: Microbiology) and 5 (Part 2: Microbiology), designed as IDEA practicals, do not articulate skill development in the learning aims.

Facets of Research and Extent of Student Autonomy from the RSD Framework Identified Across Practicals

Figures 2 and 3 below present results from analysing the content of the laboratory manual (Figure 2) and student observations at the unit level (Figure 3). The results show the emphasis placed in each practical experience proportionate to each RSD framework facet and extent of student autonomy across the unit.

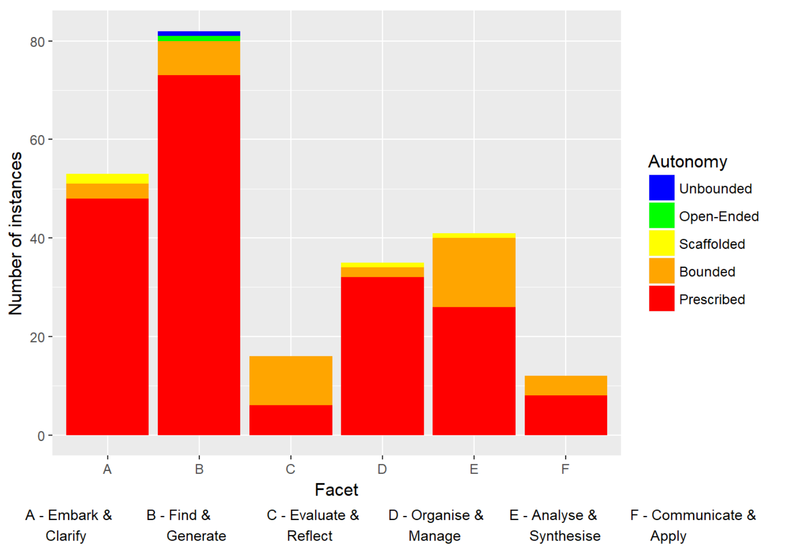

Figure 2. Number of instances each facet of research and level of student autonomy was identified in the instructional content of the laboratory manual.

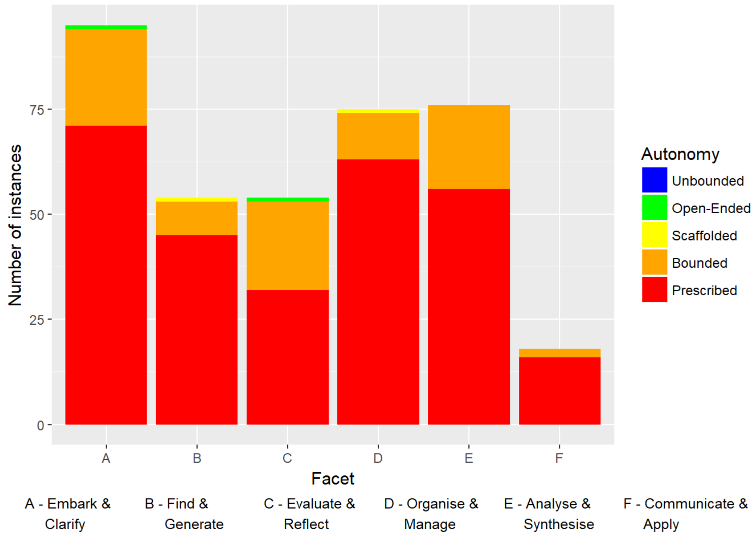

Figure 3. Number of instances and the level of student autonomy for each facet of research observed in each practical.

Results in Figures 2 and 3 above show that the unit engages students with all research skills described by the RSD framework, to varying frequencies and autonomy levels. Prescribed autonomy dominated both the instructional content in the manual and the practical experience itself, in conformity with the transmissive nature of highly guided 'recipe-driven' instructional approaches. For example, Figure 2 captures Facet B: *find & generate* at the Prescribed level as the most frequently occurring skill in the manual across all practicals. This is not surprising, given the manual provides students with procedural instructions for undertaking experimental processes that involve the generation of data. In contrast, Figure 3 shows that Facet A: *embark & clarify* was the most frequently observed facet across all the practicals, suggesting that students needed considerable clarification before commencing the experiment, and guidance to this effect from the TA.

Results in Figure 2 show that although instructional content was largely Prescribed, the manual content also conveyed instructions that corresponded with higher autonomy. Figure 2 shows that Scaffolded skills occurred in the laboratory manual in relation to Facets A: *embark & clarify*, Facet D: *organise & manage* and Facet E: *analyse & synthesise*. An instance of Open-ended research was identified in the manual (Figure 2) for *find & generate*; however, observational data (Figure 3) captures Open-ended research for *embark & clarify* and *evaluate & reflect*.

A single instance of Unbounded Research was noted in the laboratory manual for Practical 2 (Figure 2) for *find & generate*. The relevant directive instructed students to do their own research using information resources other than their textbook. This prompt towards increased autonomy implies an expectation that students have previously acquired and honed skills to undertake sophisticated literature-based activities, yet there is no indication in the manual of students having previously practiced these skills through literature-based research activities to complete the task to the degree of autonomy expected.

Although Facet C: *evaluate & reflect* and Facet E: *analyse & synthesise* occurred less frequently in the manual (Figure 2), these skills were captured at significantly higher levels of autonomy than other Research Skill facets. Yet, observational data (Figure 3) shows that across the unit, students needed considerable guidance from the TAs to perform the skills of evaluation, reflection, analysis and synthesis, as occurrences of Prescribed autonomy increased for these skills in the practical. Hence, when students *were* guided to evaluate, reflect, analyse and synthesise through the instructional content of the manual, autonomy for these skills increased proportionately in comparison to other facets when they were applied in the learning context of the practical (Figure 3).

Results for Facet F: *communicate & apply* (Figure 3) capture instructional content in the practical manual where students were directed to communicate scientific understandings. Facet F (Figure 3) 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 2 and 3 show that Facet F is the most underrepresented skill range across the unit. The low occurrence of communication skills may reflect a limitation of this study and will be discussed later in this paper.

The following graphs (Figures 4 and 5) provide a picture of students' research skills within each practical experience.

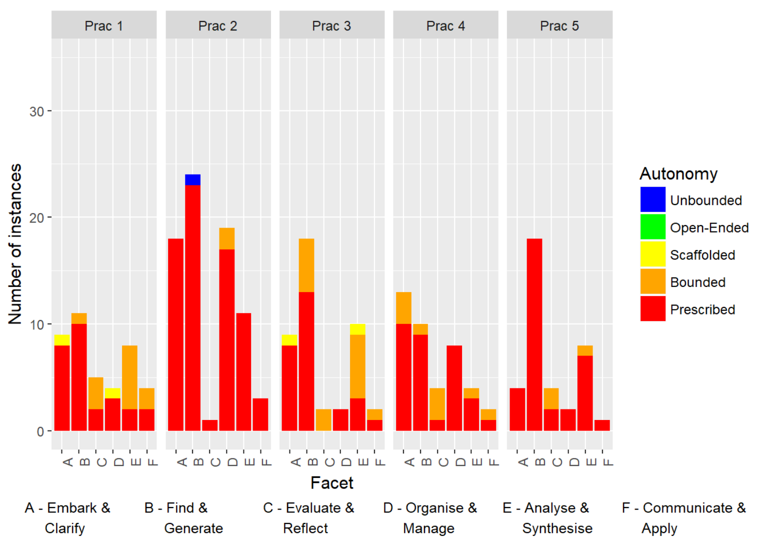

Figure 4. Number of instances of each facet of research and the corresponding level of student autonomy in the laboratory manual for each practical.

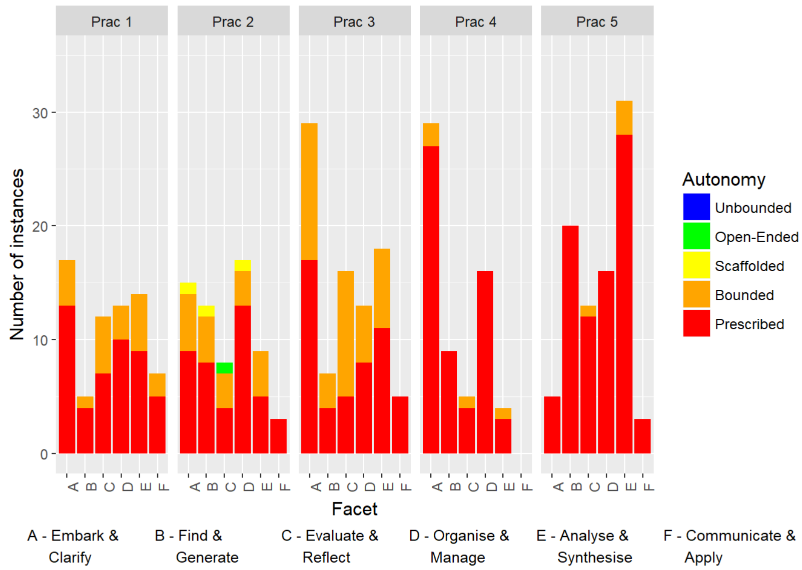

Figure 5. Number of instances each facet of research and corresponding level of student autonomy was observed in each practical.

Figure 4 above shows the emphasis placed on each facet of research in the laboratory manual and the level of autonomy attributed to each facet in each practical experience. Figure 5 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 1, exploring genetics, showed that the instructional content of the laboratory manual (Figure 4) was predominantly Prescribed, particularly for Facet B: *find & generate*. Facet A: *embark & clarify* also occurred mostly at the Prescribed level of autonomy; however, Facet A (Figure 4) jumped to Scaffolded instruction, as did Facet E: *analyse & synthesise*. There was also an expectation that students would have the skills to work beyond Prescribed levels and into the Bounded level of autonomy for Facet C: *evaluate & reflect* and Facet F: *communicate & apply* (Figure 4). In contrast, results from the observations (Figure 5) show that students needed close and Prescribed guidance to perform all facets of research, particularly Facet C: *evaluate & reflect* and Facet D: *analyse & synthesise*.

Practical 2, involving a toad dissection, was highly guided in the instructional content of the laboratory manual (Figure 4), particularly in relation to Facet A: *embark & clarify* and Facet B: *find & generate*. The only occurrence of Unbounded Research in the laboratory manual was noted in association with Facet B. The instruction related to Facet B: *find & generate*, appeared unexpectedly and was discussed earlier (Figure 2). Facet C: *evaluate & reflect*, scarcely appeared in the manual (Figure 2); however, guidance from TA1 in Practicals 1 to 3 (Figure 3) enabled students to apply this skill with increased autonomy. Facet D: *organise & manage* appeared with similar frequency to Facets A and B. Practical 2 recorded the highest occurrences in the manual (Figure 3) of Facet D: *organise & manage* across the unit, possibly due to the delicate processes involved in dissection requiring more involvement with this skill range. The manual (Figure 4) also provided Prescribed direction for Facet E: *analyse & synthesise* and students were able to move to Bounded levels of autonomy in practice for this facet (Figure 5).

Practical 3 shows that instructional content in the manual (Figure 3) for Facet C: *evaluate & reflect* only provides instruction at Bounded levels of autonomy. Figure 5 captures students observed working at both Prescribed and Bounded levels for this facet. Instructional content from the manual (Figure 4) suggests that students are able to use the skills of analysis and synthesis with greater autonomy, as Facet D captures both Bounded and Scaffolded instructional content. However, the observational data (Figure 5) shows that students required guidance from TA1 in the practical in order to be able to apply evaluation, reflection, analysis and synthesis skills, and were underprepared to work at the Scaffolded levels which were expected. Practical 3 (Figure 5) also shows students engaging proportionately more with all facets except for Facet F: *communicate & apply*.

Despite the IOL intentions of IDEA Practicals 4 and 5, these practicals were highly prescriptive and restrictive in both the instructional content of the manual (Figure 4) and the practical itself (Figure 5). In addition, the highly guided teaching methods used by TA2 in Practicals 4 and 5 provided little opportunity for students to progress along the autonomy continuum. There was an expectation in the manual instruction (Figure 4) that students would be able to work at a Bounded level of autonomy for Facets A, B, C, E and F in Practical 4; however, observations (Figure 5) show that prescriptive guidance increased in the classroom during this practical. In Practical 5, students did not move beyond Prescribed levels for Facet A: *embark & clarify*, Facet B: *find & generate* and Facet D: *organise & manage* (Figure 5).

Figure 5 above shows that IDEA Practical 5 had the highest frequency counts for Facet B: *find & generate*, Facet C: *evaluate & reflect* and Facet E: *analyse & synthesise*, albeit at the Prescribed level. This might suggest that an experimental topic that is allocated more time (i.e., over two practical sessions) provides more opportunity for students to engage in a range of research skills regardless of the teaching style of the TA.

Subskills Emergent in the Data

The process of analysing and interpreting the data sources for the research skills that aligned with the facets of research in the RSD framework revealed a range of subskills relating to each RSD facet. The articulation of subskills identified in the descriptive observations and within the content of the laboratory manual contributed a deeper understanding of which skills are encompassed in this learning context. Figures 6 to 12 present these findings.

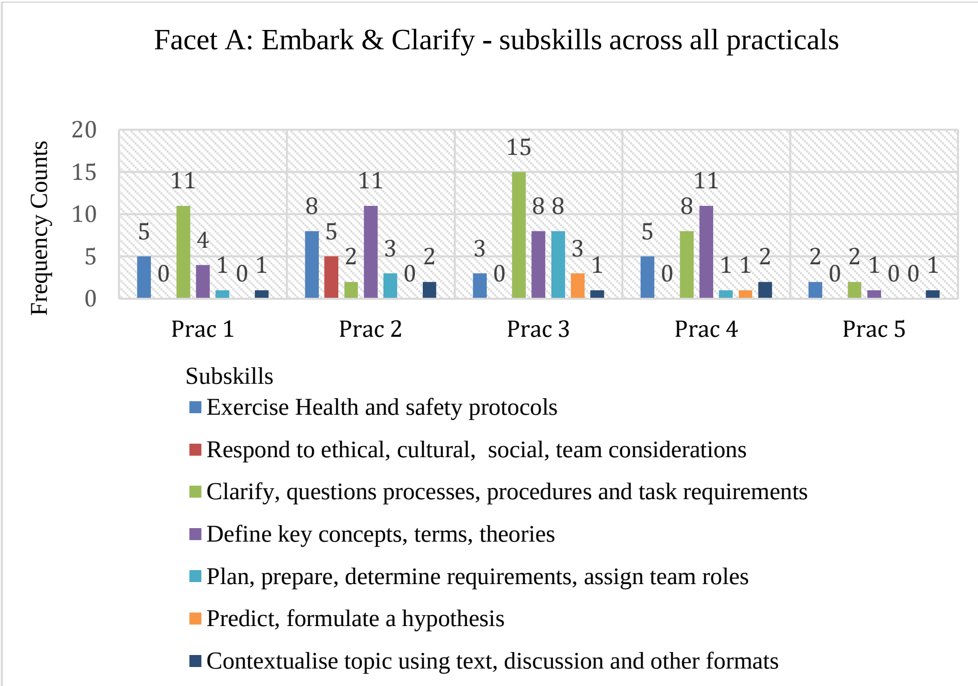

Figure 6. Subskills relating to Facet A: *embark & clarify*.

Subskills related to Facet A: *embark & clarify* (Figure 6) 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 2: 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 TA1 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 TA1 introduces the topic. The students waited to ask a question"* (Practical 3: Metabolism, Observations).

Practical 3 was the only practical that provided students with formal instructions to formulate a hypothesis based on readings. Guided questioning from TA1 in Practical 3, however, prompted students to predict what would happen in the experiment. Students' application of planning skills associated with Facet A was mostly noted in Practical 3. Planning skills were not apparent in observational data gathered from Practicals 4 and 5, possibly due to the highly-guided teaching style of TA2.

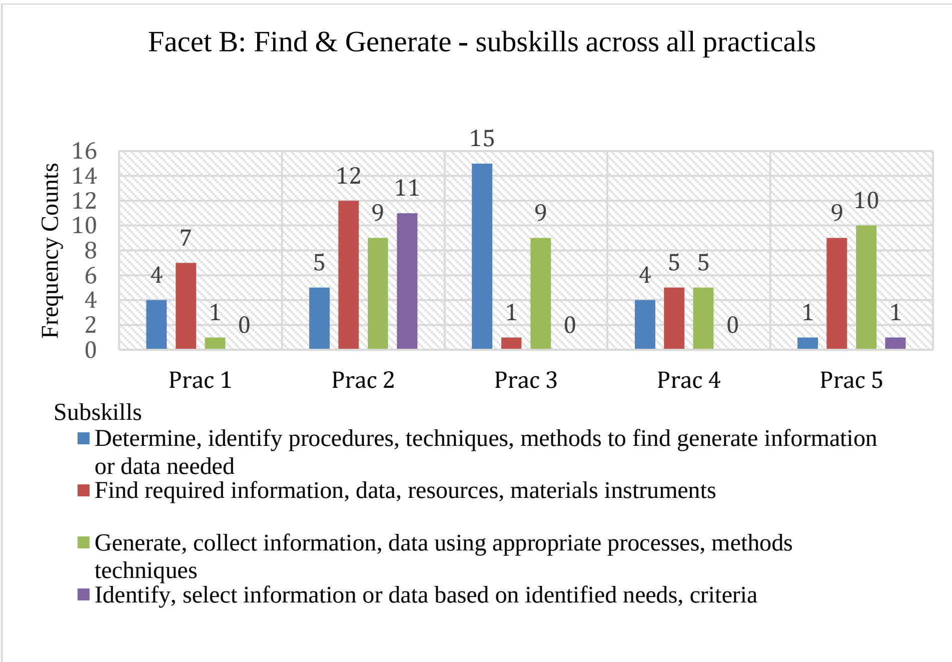

Figure 7. Subskills relating to Facet B: *find & generate*.

Subskills related to Facet B: *find & generate* (Figure 7) involved processes related to gathering information, scientific instruments, or generating data as part of the process of conducting experiments. Practical 2 shows students engaging with this skill range more frequently than other practicals, possibly due to the complex nature of the toad dissection. Practicals 1 and 4 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 3 showed the highest occurrence of students applying procedures and techniques to *find & 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 2: 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 1: 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).

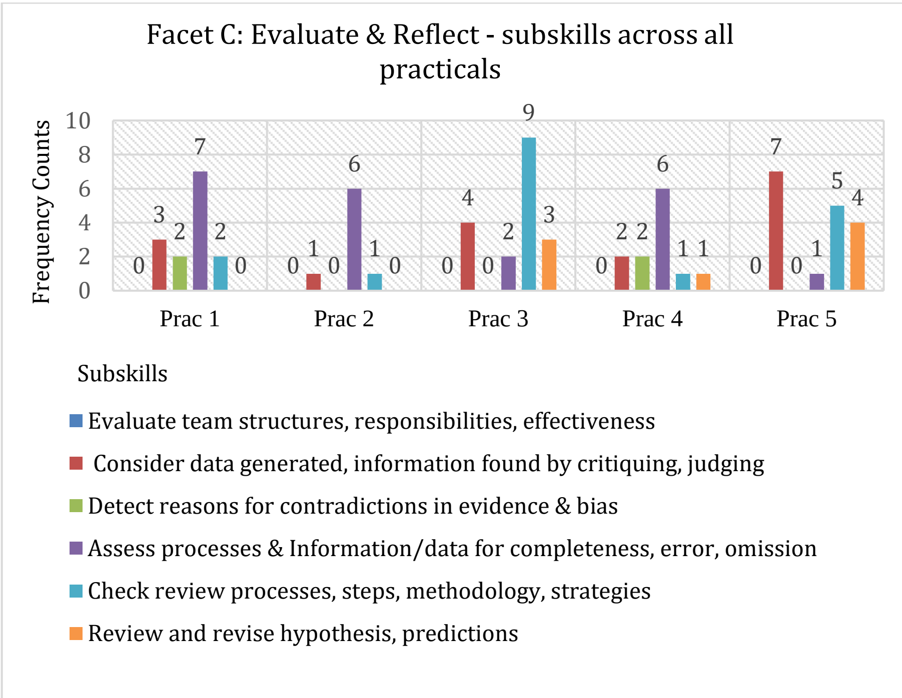

Figure 8. Subskills relating to Facet C: *evaluate & reflect*.

Subskills related to Facet C: *evaluate & reflect* (Figure 8) were identified less often in the instructional content of the laboratory manual than subskills related to other facets. Questioning from TA1 in Practicals 1 to 3 enabled students to apply these skills at increased autonomy levels. Sophisticated questioning appeared to be paramount for activating evaluation and reflection skills and prompting students' thinking, thus moving students from the Prescribed to the Bounded level of autonomy. This was particularly evident in Practical 3:

> *"TA1 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?" TA1 persists with questions. One student turns excitedly to her partner. "I know!" she says and explains to her partner what could happen when…"* (Practical 3: Metabolism, Observations).

A single instance of students evaluating team structures, responsibilities and effectiveness was noted across practicals. This event occurred in Practical 2 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 Open-ended 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 2: Toad Dissection, Observations).

During Practical 2, sophisticated examples of students 'evaluating team effectiveness' were 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.

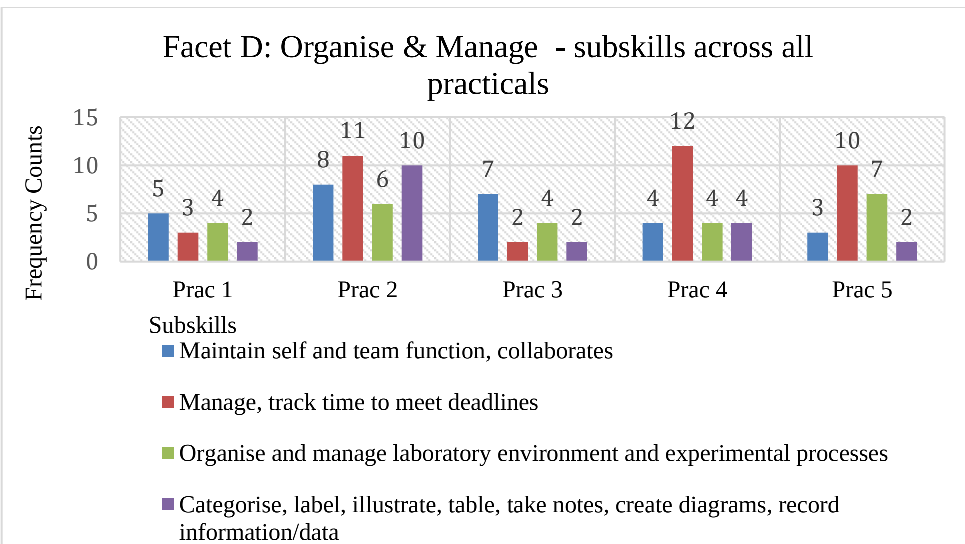

Figure 9. Subskills relating to Facet D: *organise & manage*.

Subskills related to Facet D: *organise & manage* (Figure 9) were captured more frequently in Practical 2, which involved the toad dissection. The nature of the experiment in Practical 2 required students to work very collaboratively in pairs according to their self-assigned roles. Practicals 2, 4 and 5 also showed that students were using the skill 'Manage time to meet deadlines' more frequently than other skills associated with Facet D, possibly due to the TA's close guidance, involving time and sequencing prompts throughout the experiment.

In Practicals 4 and 5, students fell into a pattern of waiting for instructions from the TA. Hence, the TA's teaching approach reduced opportunities for students to self-manage, maintain team function and manage the experimental procedure themselves. The following example demonstrates that close guidance to this degree from TA2 was time-consuming and detrimental to students' ability to complete the experiment as instructed in the manual.

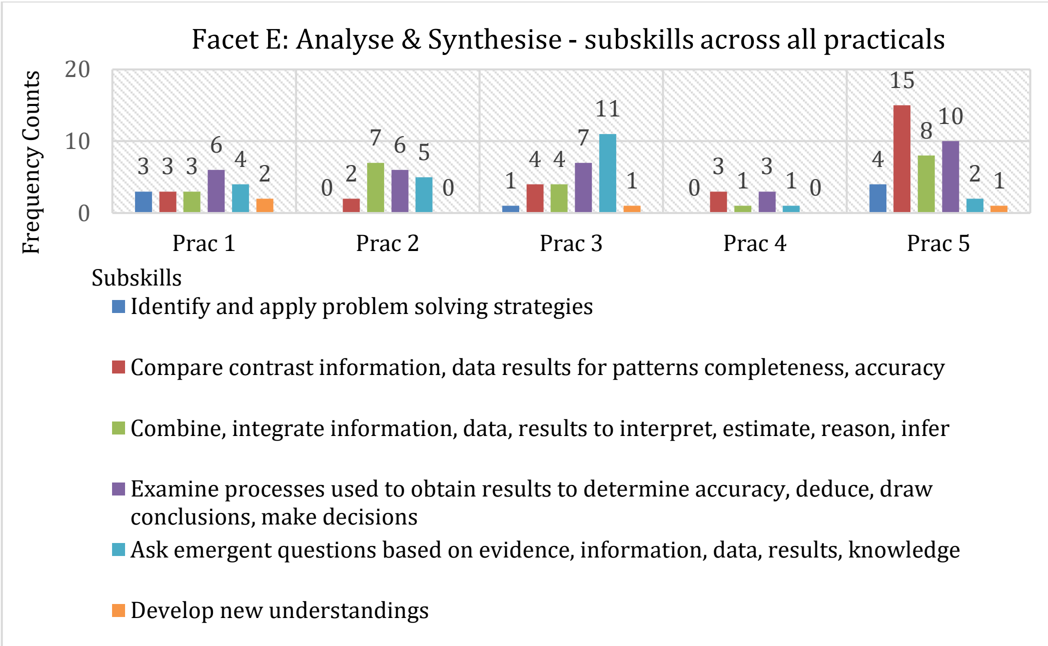

Figure 10. Subskills relating to Facet E: *analyse & synthesise*.

Subskills related to Facet E: *analyse & synthesise* (Figure 10) primarily occurred through questioning and examining processes for accuracy. Comparing data and information also occurred relatively frequently, particularly in Practicals 2 and 5. The event captured below from Practical 1 demonstrates the adept teaching style of TA1 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. TA1 suggests that they have a chat to another pair of students about their results to compare"* (Practical 1: Genetics, Observations).

The advantage of having time to *analyse & synthesise* was highlighted in Practical 5, 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 5: Microbiology part 2).

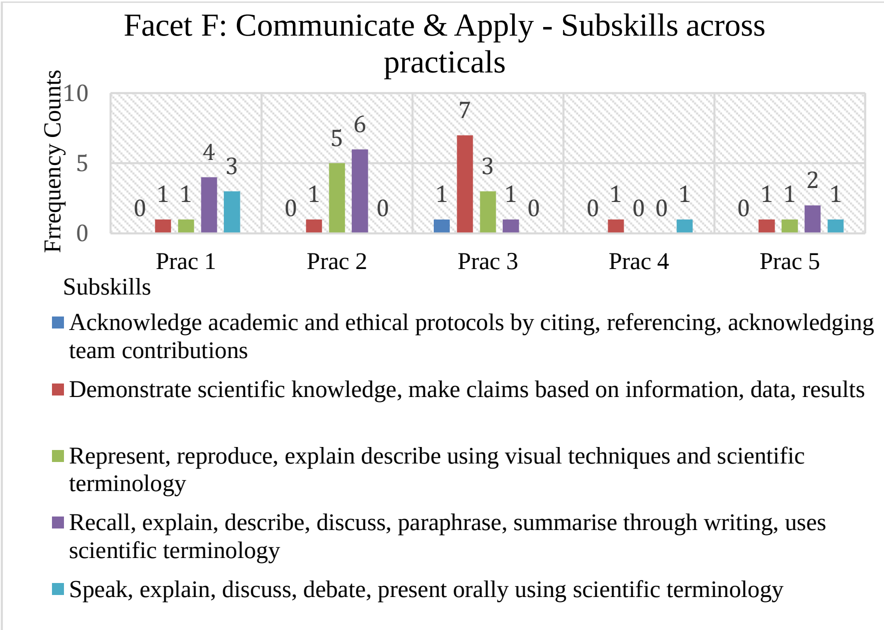

Figure 11. Subskills relating to Facet F: *communicate & apply*.

Subskills related to Facet F: *communicate & apply* (Figure 11) were the most underrepresented skill range. This finding may point to limitations of this study. Facet F was confined to representation in the laboratory manual and from observing students in the practicals.

An example where TA1 guided the students through questioning to communicate their results follows:

> *"'How did you go? Did you change anything?' asks TA1. The students explain their results before writing anything further. Another student overhears and joins the discussion, explaining what he interpreted from the results. TA1 listens and slowly moves away, leaving the students to share their results amongst themselves"* (Practical 3: Metabolism, Observations).

The underrepresentation of this skill set is concerning, as it suggests that students lacked the opportunity to discuss the outcome of experiments and to hone skills in communicating using discipline-specific language and research skill terms. The removal of the post-lab wrap-up from this unit suggests a lost opportunity for students to apply a range of communication skills.

Discussion

Making Research Skills Visible

Science educators are challenged to articulate what research skills encompass, as these skills tend to be hidden in a proliferation of nomenclature and pedagogical initiatives arising from science practical curriculum reform (Healey & Jenkins 2009). This impacts student learning and is particularly evident in this study as demonstrated by the lack of skill-related vocabulary used in the laboratory manual, learning aims and one of the observed TA's teaching practices. This study shows that students do engage with foundational skills for researching in this unit, although the considered development of research skills in the context of this study is generally implied, not explicit, and largely overlooked as a pre-determined outcome of learning.

Findings related to analysis of the learning aims of this unit (Figure 1) correspond with studies in science education literature which show that students' technical skill competencies for the laboratory are emphasised by educators over higher-order thinking skills related to research (Trapani & Clarke 2012). In addition, the lack of skill-related learning aims in this unit reflects the discussion in the literature identifying the fact that science educators lack the ability to articulate what research skills encompass in undergraduate science (Wilson, Howitt & Higgins 2015).

The Influence of TA-Student Interactions on Skill Development and Autonomy

The literature highlights the difficulty of prompting students' awareness of thinking processes within laboratory content (Shepardson 1997). This difficulty includes providing students with teachers who are consistent in their knowledge of how to facilitate students' thinking in a laboratory context, as TAs often have variable levels of teaching experience and backgrounds (Rice et al. 2009; Schmid & Read 2010). This study strongly indicated that quality teaching methods, and not curriculum alone, influenced students' ability to apply research skills with increasing autonomy. Therefore, a shared pedagogy of the right design may help to equalise variations in the experience and quality of individual teachers.

Although the RSD framework skill facets generally aligned with the Prescribed range of autonomy in the laboratory manual and observations, when students responded to instructional content in the practical, they typically did so at increased levels of autonomy, particularly in Practicals 1 to 3. Results indicated that students needed the intervention of TA1 to activate research skills in practice through modelling, questioning and appropriate guidance, as students were not yet prepared to work at the Bounded level of autonomy required in the laboratory manual. For example, prompting by TA1 (Figure 5) increased students' ability to apply evaluation and reflection skills at the Open-ended range of autonomy. This finding related to students developing discipline-related research skills is supported by Willison, Sabir and Thomas (2016, p. 4), who note that:

> *"In Prescribed Research, academics and tutors may closely model appropriate ways of engaging with information and data in the discipline; this modelling is core for students to understand how to proceed in discipline-appropriate ways and, indeed, how to add rigour to the process."*

It is concerning that the IDEA practicals designed to encourage greater learner autonomy did not achieve this intention, as the restrictive over-guidance of TA2 observed facilitating Practicals 4 and 5 stifled students' ability to become more autonomous. This demonstrates the importance of educators being more aware of the sophisticated nuances and pivotal role of autonomy in learning, and adapting their teaching methods and levels of guidance as appropriate.

Results from observing Practicals 1 to 3 indicated that sophisticated questioning in TA-student interactions was pivotal to increasing student autonomy in the practicals. Questioning is a recognised, sophisticated, complex teaching method, integral to student learning (Roth 1996). This study suggests that science educators would benefit from targeted professional development in using questioning as a teaching strategy. The explicit inclusion of research skill terminology when framing questions in such TA-student interactions would also benefit students by bringing these terms closer to the student vernacular.

Developing Underrepresented Skills

Communication skills were poorly represented in the manual and in the observations of the studied unit, and although there was an expectation that students would be able to apply the skills of evaluation and reflection with a degree of autonomy in the instructional content of the laboratory manual (Figure 2), students needed guidance from TA1 to be able to apply these skills beyond Prescribed levels of autonomy in the practical itself (Figure 3). What may have contributed to these skills being less apparent was the removal of the post-lab wrap-up. The removal of the wrap-up resulted in a reduced opportunity for students to metacognitively evaluate, reflect and discuss experimental processes, outcomes and research skills. Yacoubian and BouJaoude (2010) emphasised the importance of reflective discussions following laboratory activities to enhance students' understandings. Reinstating the post-lab wrap-up could open an opportunity to involve librarians at the end of the practical and contribute to enhancing the development of students' research skills, which 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 could contribute to making research skills visible to students and support the teaching partnership between librarians and science educators.

Additionally, the design of this unit incorporated a practical spanning two sessions. Findings from this study highlighted that additional time to explore a topic enabled students to engage more frequently in under-represented skills than single session practicals, despite the prescriptive teaching style of the TA. This provides support for the idea of designing practical units that provide time for students to practice, hone and apply research skills with increasing self-reliance. The RSD could be used either from the outset, to inform curriculum design and the progressive and explicit development of research skills, or retrospectively, to identify skill gaps and duplications in the existing curriculum.

This study signals that the RSD has potential to equalise variations in the experience and quality of individual teachers, inform curriculum design and enable a common language amongst educators to facilitate students' research skill development as a shared endeavour.

Limitations

Limitations of this study include the influencing factors outside the educators' control such as the variables associated with students' prior knowledge, acquired skills and experience of studying science. Additionally, observational methods were deliberately limited to a narrow segment of students (n=8), as it proved difficult to observe and listen to more than one bay of eight students at one time. In making this decision based on practicalities, the results may not be representative of the broader student cohort undertaking this unit. A further potential source of error concerns the different teaching styles of each TA and the contrasting structure of Practicals 1 to 3, and Practicals 4 and 5. The products of assessment were not included in the data set, which may have influenced the results, as this would have reduced the capture of data relating to Facet F:

communicate & apply.

Although the variables above could threaten the reliability of the findings, educational settings often share similar and comparable conditions. For example, TAs may possess 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.

Further Research

Further exploration of the nuances of autonomy through TA-student interactions - inclusive of the student perspective - would contribute to understandings of how these interactions influence the development of students' research skills in the practical. Evaluating the benefits and challenges of using the RSD to underpin library-faculty collaboration in this context would inform how the RSD could support teaching partnerships as a shared response towards students' research skill development in science practicals.

Conclusion

This study was guided by the postulation that preparing scientifically research-literate students requires educators to understand what 'foundational research skills' encompass.

The key findings were that:

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 implicit nature of students' research skill development in the design and teaching of this practical unit suggests that science educators are challenged when it comes to conceptualising and articulating what foundational skills for research involve in first-year practical curricula. Although research skills were largely hidden and disconnected from learning how to research in the laboratory manual and in teaching practices of this unit, the RSD framework assisted in demonstrating that the thinking processes foundational for researching are embedded in this unit. Of significance were findings related to teaching methods and curriculum design, which impacted students' ability to develop autonomy as learners and reduced students' ability to engage deeply with research skills.

This study offers reconceptualised methods for clarity around what research skills encompass in undergraduate science practicals, since the relevance of this knowledge for student learning and the failure to apply this knowledge remains an ongoing challenge (Smith 2011). This study demonstrates the significance of the RSD framework in offering a conceptual model to support the development of students' research skills in the first-year practical experience by offering a means to identify and articulate what such skills encompass. 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.

Given that current approaches used by librarians to establish partnerships with academics have demonstrated limited success, a reconceptualised approach for fostering library-faculty teaching partnerships may be warranted. Arriving at a shared understanding of what skills for research encompass across disciplines may be critical for harnessing the collaborative potential of library-faculty teaching partnerships. Underpinning such teaching collaborations with the RSD would enable new understanding of how librarians could contribute to the development of students' research skills in the practical experience. Since research skills also encompass the skills of evaluation, reflection, analysis and synthesis – skills traditionally taught by librarians in the context of information seeking, librarians have expertise and knowledge that would contribute to the development of these research-related skills which were generally underrepresented across practicals.

Furthermore, a new interpretation of traditional library understandings of what 'information finding' skills' involve through the application of the RSD would be transformative for librarians, offering new opportunities to connect library research skill development agendas directly to skill sets specifically required in laboratory contexts. Therefore, the RSD offers a way to transcend traditional library definitions and interpretations of 'information finding' skills, where students are consumers of information, to a reconceptualised interpretation where students generate data as information producers.

This study demonstrated that the RSD framework was a suitable construct through which to identity students' research skills in a first-year biology practical unit, with potential for broader application to other disciplinary contexts. The RSD framework is well placed to offer science educators and library staff a new paradigm to move forward with skill agendas in undergraduate science practicals based on pedagogically sound approaches and empirical methods. 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

Barrie, SC, Bucat, RB, Buntine, MA, Burke da Silva, K, Crisp, GT, George, AV, Jamie, IM, Kable, SH, Lim, KF, Pyke, SM, Read, JR, Sharma, MD & 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*, vol. 37, no. 11, pp. 1795-1814.

Bradley, C 2013, 'Information literacy articles in science pedagogy journals', *Evidence Based Library and Information Practice*, vol. 8, no. 4, pp. 78-92.

Brew, A 2013, 'Understanding the scope of undergraduate research: A framework for curricular and pedagogical decision-making', *Higher Education*, vol. 66 no. 5, pp. 603-618.

Bruce, C 2001, 'Faculty-librarian partnerships in Australian higher education: Critical dimensions', *Reference Services Review*, vol. 29, no. 2, pp. 106-115.

Callan, P, Peacock, J, Poirier, J & Tweedale, R 2001, 'Practice makes information literacy perfect: Models of educational collaboration at QUT', in J Frylock (ed.), *Partners in learning and research: Changing roles for Australian technology network libraries*, University of South Australia Library, Adelaide, pp. 1-18.

Chaplin, S 2003, ‘Guided development of independent inquiry in an anatomy/physiology laboratory’, *Advances in Physiology Education*, vol. 27, no. 4, pp. 230-240.

Corwin, L, Runyon, C, Robinson, A & Dolan, E 2015, ‘The laboratory course assessment survey: A tool to measure three dimensions of research-course design,’ *CBE-Life Sciences Education*, vol. 14, no. 4, ar37.

Di Trapani, G & Clarke, F 2012, ‘Biotechniques laboratory: An enabling course in the biological sciences’, *Biochemistry and Molecular Biology Education*, vol. 40, no. 1, pp. 29-36.

Goldey, E, Abercrombie, Ivy, T, Kusher, D, Moeller, J, Rayner, G, Smith, F & Spivey, N 2012, ‘Biological inquiry: A new course and assessment plan in response to the call to transform undergraduate biology’, *CBE-Life Sciences Education*, vol. 11, no. 4, pp. 353-363.

Gregory, K, 2013, ‘Laboratory logistics: Strategies for integrating information literacy instruction into science laboratory classes’, *Issues in Science and Technology Librarianship*, no. 74.

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*, vol. 29, no. 4, pp. 405-420.

Kardash, C 2000, ‘Evaluation of an undergraduate research experience: Perceptions of under-graduate interns and their faculty mentors’, *Journal of Educational Psychology*, vol. 92, no. 1, pp. 191-201.

Lofland, J & Lofland, LH 1995, *Analyzing social settings: A guide to qualitative observation and analysis*, 3rd edn, Wadsworth, Belmont, California.

Loveys, B, Kaiser, 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*, vol. 22, no. 3, pp. 15-25.

Luckie, DB, Maleszewski, JJ, Loznak, SD & Krha, M 2004, 'Infusion of collaborative inquiry throughout a biology curriculum increases student learning: A four-year study of "Teams and Streams"', *Advances in Physiology Education*, vol. 28, no. 4, pp. 199-209.

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*, vol. 40, no. 2, pp. 116-123.

Peirce, E, Ricci, M, Lee, I & Willison, J 2009, ‘First-year human biology students in the ivory tower’, paper presented at the Motivating Science Undergraduates: Ideas and Interventions Conference, University of Adelaide, 1-2 October, viewed 23 April 2018, <http://hdl.handle.net/2440/58183>.

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*, vol. 21, no. 5, pp. 1-11.

Rice, J, Thomas, S & O'Toole, P 2009, *Tertiary science education in the 21st century*, The Australian Learning and Teaching Council, Australia.

Russell, S, Hancock, M & McCullough, J 2007, 'Benefits of undergraduate research experiences', *Science*, vol. 316, no. 5824, pp. 548-549.

School of Biological Sciences 2014, *Biology II-BIO1022 practical manual*, Monash University, Australia.

Seymour, E, Hunter, A, Laursen, S & DeAntoni, T 2004, 'Establishing the benefits of research experiences for undergraduate students in the sciences: First findings from a three-year study', *Science Education*, vol. 88, no. 4, pp. 493-534.

Shepardson, D 1997, 'The nature of student thinking in life science laboratories', *School Science and Mathematics*, vol. 97, no. 1, pp. 37-44.

Smith, L 2011, 'Monash University Library: A new paradigm for a new age', *Australian Academic and Research Libraries*, vol. 42, no. 3, pp. 246-264.

Spradley, JP 1980, *Participant observation*, Holt, Rinehart and Winston, New York.

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

White, HB, Benore, MA, Sumter, TF, Caldwell, BD & Bell, E 2013, 'What skills should students of undergraduate biochemistry and molecular biology programs have upon graduation?' *Biochemistry and Molecular Biology Education*, vol. 41, no. 5, pp. 297-301.

Willison, J, Sabir, F & Thomas, J 2016, 'Shifting dimensions of autonomy in students' research and employment', *Higher Education Research & Development*, vol. 36, no. 2, pp. 430-443.

Willison, J & O'Regan, K 2007, 'Commonly known, commonly not known, totally unknown: a framework for Students becoming researchers', *Higher Education Research & Development*, vol. 26, no. 4, pp. 393-409.

Willison, J & O'Regan, K 2006/2018, *Research Skill Development Framework*, viewed 14 June 2018, <www.adelaide.edu.au/rsd>.

Yacoubian, HA & 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*, vol. 47, no. 10, pp. 1229-1252.

Appendix A: Learning Outcomes

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 (IDEA Practicals)

- 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 haemolysis and catalase.