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Learning-Led Disciplinary Literacy in Science Education

by

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CONTENTS

List of Figures iv
List of Tables vii
Acronyms and Symbols ix
Declaration x
Acknowledgements xi
Abstract xiii
Prologue 1
Lived Experiences 1
Learning-Led Research 8
Evolution of the Artefacts 11
The Role of the Artefacts in Research 14
The Audience 19
Introduction: Framing Expertise 22
Context 24
Why these problems exist 26
Research questions 32
Scope 34
Original contribution to knowledge 34
Chapter structure and outlines 35
Chapter 1 : Conflicting Agendas 37
1.1 The Role of Universities in Preparing Graduates for the Workplace 37
1.2 Why Science Communication Matters 44
1.3 Communication Theory 51
1.4 Science Communication Education Research 52
1.5 Communication Education in Practice 59
1.6 Multiliteracy 61
1.7 Multimodality 64
1.8 Knowledge Processes for Modern Educational Paradigms 68
1.9 Discourse 72
1.10 Disciplinary Literacy 74
1.11 Approaches 77
1.12 Genre 78
1.13 Scholarship of Teaching and Learning 80
1.14 Self-Efficacy and Student Engagement 83
1.15 Authenticity: Writing in Context 85

1.16 Questions and Answers 89
Chapter 2 : The Importance of Disciplinary Knowledge 93
2.1 Learner Identity 93
2.2 Disciplinary Literacy 96
2.3 Epistemic Practices 100
2.4 Literacy Development 101
2.5 Metacognition 104
2.6 Writing is Thinking and Learning 104
2.7 Historical Context of Science 108
2.8 Information Literacy in Science 111
2.9 The Role of Mathematics 112
2.10 The Role of Language in Science 114
2.11 The Deficit Model of Communication 116
Chapter 3 : The Language of Science 121
3.1 Ontology and Epistemology 121
3.2 A note to the reader: the selection of a lens 123
3.3 Study Design 124
3.4 Experimental Elements 126
3.4.1 Undergraduate Data Collection 126
3.4.2 Postgraduate Data Collection 127
3.4.3 Mapping Topic Content 129
3.4.4 Data Analysis 130
3.4.5 Digital Learning Platforms 130
3.4.6 Genre 131
3.4.7 Alignment to Research Questions 132
3.5 Current Assessment Practices 134
3.5.1 Introduction 134
3.5.2 Methodologies 135
3.5.3 Method 136
3.5.4 Results 138
3.5.5 Discussion 149
3.6 Student Resourcing 151
3.6.1 Introduction 151
3.6.2 Methodology 155
3.6.3 Methods 155
3.6.4 Results 157
3.6.5 Discussion 161

3.7 E-Learning Modules 170
3.7.1 Introduction 170
3.7.2 Methodology 175
3.7.3 Pedagogy 175
3.7.4 Method 177
3.7.5 Results 181
3.7.6 Discussion 207
3.7.7 Limitations 211
3.7.8 Future Development 212
3.8 Translating the Language of Science 213
Chapter 4 : Framing Disciplinary Literacy 214
4.1 The Learner's Experience 214
4.2 The Educator's Experience 219
4.3 Theory, Lenses and Disciplines 222
4.4 Literacy studies 231
4.5 Universal design 233
4.6 Developing a theoretical model 234
4.7 A theoretical model of the learning process 235
4.8 A theoretical model of the teaching process 250
4.8.1 Practice-based teaching 252
4.8.2 Practice-led teaching 254
4.8.3 Learning-led teaching 255
4.9 Theory in Teaching Practice 256
Conclusion: Towards Expertise 259
Research Interrupted: The Value of Developing and Deploying Expertise in Challenging Times 272
Limitations and Future Directions 274
The Future of Science Education 275
References 280
Appendix A : The Artefacts 300
What are the Artefacts? 300
Key design elements 300
Accessing the Artefacts 308
Appendix B : The Language of Science Additional Data 309
Detailed data analysis for section 3.5 Current Assessment Practices 309
Detailed data analysis for section 3.6 Student Resourcing 313
Detailed data analysis for section 3.7 E-learning Modules 315

Scientific Writing Assignment Analysis 315
Scientific Writing Assignment Analysis – E-learning through a pandemic 322
Discussion Paper Assignment Analysis 330
Impact of e-Learning Modules on Student Confidence 334
Appendix C : Assignment rubrics analysed in this study 341
Appendix D : Undergraduate student survey 346
Appendix E : Postgraduate student survey 352

LIST OF FIGURES

Figure 1.1. Employment status of BSc graduates in Australia. (created using data sourced from Palmer et al. (2018) based on 2011 Australian census data). . 51
Figure 1.2. Image of a woman participating in the March for Science (Science Alert, 2018). 67
Figure 1.3. Mapping the original Multiliteracies pedagogy against the ‘Knowledge Processes’. Adapted from Cope and Kalantzis (2015). 69
Figure 2.1 An excerpt from the Scientific Writing Assignment artefact depicting the e-guide linking the importance of scientific reading and writing. 107
Figure 2.2 An excerpt from the Impact Statement artefact depicting the e-guide presenting an authentic example of scientific literature in the genre students are learning.. 107
Figure 3.1. Methodological elements of the research project. 125
Figure 3.2. Mode of assessment tasks in first year communication assessment items.. 139
Figure 3.3. Intended audience of written assessment tasks in first year communication assessment items.. 140
Figure 3.4. Proportion of written communication assessment tasks and the intended audience they target in sub-disciplines of science within the College of Science and Engineering.. 142
Figure 3.5. Proportion of written communication assessment tasks reported by undergraduate students.. 143
Figure 3.6. Proportion of written communication assessment tasks undertaken during undergraduate degree programs. Items marked with * indicates statistically significant difference between cohorts.. 145

Figure 3.7. Resources identified by students as most useful in learning to write scientifically. 157
Figure 3.8. Resources identified by postgraduate students as most useful in learning to write scientifically. 161
Figure 3.9 An excerpt from the Scientific Writing Assignment e-learning module depicting an activity to orient students in reading and interpreting texts within the discipline. 172
Figure 3.10 An excerpt from the Scientific Writing Assignment e-learning module depicting an activity with embedded examples to orient reading and writing of disciplinary texts. 172
Figure 3.11. Median scores of Scientific Writing Assignment between 2018 and 2019.. 183
Figure 3.12. Mean scores characterised by assessment criteria of section headings in the Scientific Writing Assignment. 186
Figure 3.13. Median grades between cohorts in 2018, 2019 and 2020.. 188
Figure 3.14. Median grades between students that did not use the e-learning module and students that used the e-learning module. 190
Figure 3.15 Mean scores characterised by assessment criteria of section headings in the Scientific Writing Assignment in 2020. 193
Figure 3.16. Mean scores of Discussion Paper.. 195
Figure 3.17. Mean scores characterised by section headings in the Discussion Paper. 197
Figure 3.18. Proportion of students confident in scientific writing assessments. 199
Figure 3.19. Survey responses regarding confidence in ability to write an assignment in the format of an impact statement in their specific field. 200
Figure 3.20. Proportion of students confident in scientific writing assessment. 203
Figure 4.1. The relationship between the three central elements of student learning. 237
Figure 4.2. The increasing specialization that accompanies literacy development. 239
Figure 4.3. Theoretical model of disciplinary literacy development. 241
Figure 4.4. Model of student learning with the inclusion of multimodal assessment practices. 243
Figure 4.5. The relationship between the three central elements employed in the artefacts that promote student learning. 246

Figure 4.6. Representation of the engagement of a student whose expectations and context are not closely aligned. 249
Figure 4.7. Representation of the opportunity for engagement of a student whose expectations and context are closely aligned. 250
Figure 4.8. Relationships and outcomes of practice-based teaching experiences. 253
Figure A.1 Excerpt of the introductory section of the impact statement module..... 302
Figure A.2 Excerpt of the impact statement module depicting an example of authentic writing from an expert in the discipline. 303
Figure A.3 An excerpt of the SWA module describing experimental methods. 304
Figure A.4 An excerpt from the discussion paper module reminding students of the overall structure of the text. 305
Figure A.5 An excerpt from the SWA module prompting students to draft a response. 306
Figure A.6 An excerpt from the SWA module providing a comparison of an expert interpretation.. 306
Figure A.7 An excerpt from the discussion paper module depicting the introduction to genre. 307

LIST OF TABLES

Table 3.1 Descriptors and examples of categorisation of assessment activities.. .. 137
Table 3.2 Descriptive statistics of the differences between proportion of students completing assessment item Lab Report. 147
Table 3.3 Descriptive statistics of the differences between proportion of students completing assessment item Journal Article. 147
Table 3.4 Descriptive statistics of the differences between proportion of students completing assessment item Literature Review. 148
Table 3.5 Descriptive statistics of the differences between proportion of students reporting to use Rubrics as a resource in learning to write scientifically. 159
Table 3.6 Descriptive statistics of the differences between proportion of students reporting to use Assignment Examples as a resource in learning to write scientifically. 160
Table 3.7 Descriptive statistics of the differences between reported confidence of students undertaking an assessment in the form of an Impact Statement. . 202
Table 3.8 Descriptive statistics of respondents reporting agreement in confidence undertaking an assessment in the form of an Impact Statement.. 205
Table 3.9 Proportion of respondents that indicated high confidence in performing various scientific writing tasks.. 205
Table B.1 Descriptive statistics and results of Fisher's Exact test of the differences between proportion of students completing assessment items during an undergraduate degree program. 310
Table B.2 Descriptive statistics and Chi-square test statistics of the differences between proportion of students reporting using various learning resource to develop writing skills. 313
Table B.3 Descriptive statistics and Mann-Whitney U test statistic of student grades for the scientific writing assignment. 315
Table B.4 Descriptive statistics and Mann-Whitney U test statistic of student grades for each assessment criteria of the scientific writing assignment................. 316
Table B.5 Descriptive statistics and Mann-Whitney U test statistic of student grades for the final exam in 2018 and 2019. 321
Table B.6 Descriptive statistics and Mann-Whitney U test statistic of student grades for the scientific writing assignment across three years. 322

Table B.7 Descriptive statistics and Mann-Whitney U test statistic of student grades for the scientific writing assignment in 2020 between groups that had/had not completed the e-learning module. 323
Table B.8 Descriptive statistics and Mann-Whitney U test statistic of student grades for each assessment criteria of the scientific writing assignment in 2020. ... 324
Table B.9 Descriptive statistics and Mann-Whitney U test statistic of student grades for the mid-semester exam in 2020. 329
Table B.10 Descriptive statistics and independent samples t-test statistic of student grades for the discussion paper assignment between years. 330
Table B.11 Descriptive statistics and independent samples t-test statistic of student grades for each assessment criteria of the discussion paper. 331
Table B.12 Descriptive statistics and Chi-square test statistics of the differences between proportion of students reported confidence in assessment tasks.. 335

ACRONYMS AND SYMBOLS

Acronyms	
CLA	Collegiate Learning Assessment
DP	Discussion Paper
FTE	Full time equivalent
LMS	Learning Management System
SAM	Statement of Assessment Methods
SD	Standard Deviation
SoTL	Scholarship of Teaching and Learning
SPSS	Statistical Package for the Social Sciences
STEM	Science, Technology, Engineering and Maths
SWA	Scientific Writing Assignment
S1	Semester One
S2	Semester Two
PG	Postgraduate
UG	Undergraduate

Symbols	
+/-	A single standard deviation of data points around a mean score
df	Degrees of Freedom
M	Median
n	Sample size
p	P value sample statistic
σ	Standard deviation
t	Independent samples t-test statistic
U	Mann-Whitney U test statistic
X^2	Chi-square test of independence statistic
$\bar{x}$	Mean

DECLARATION

I certify that this thesis does not incorporate without acknowledgment any material previously submitted for a degree or diploma in any university; and that to the best of my knowledge and belief it does not contain any material previously published or written by another person except where due reference is made in the text.

Signed ………………………………………………………………..

Date ………………………………………………………………..

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ABSTRACT

This doctoral research investigates how expertise is framed within a discipline, developed in a learner, and communicated to a variety of audiences. In a time where expertise is undervalued in governmental and industry contexts, this PhD seeks to replace ridicule with understanding, aligning language between experts and non-experts, to produce a shared understanding in a time of climate-change denial, antivaccination rhetoric and general distrust in science and scientists.

The original contribution to knowledge offered in this doctoral research is the creation of an innovative gauze through which to view disciplinary literacy in the sciences. This way of thinking and way of seeing provides a framework through which educators can further develop disciplinary literacy programs by understanding how learners develop literacy within a discipline. The exegesis component of this thesis contributes original knowledge to the field of Science Education by investigating why disciplinary literacy is integral to addressing the access of science to the broader community. This originality is modelled through an e-learning tool which form the artefacts of this thesis. The combination of artefacts and exegesis – e-learning tool and interrogative research in disciplinary literacy – creates a transformative model for reading, writing, thinking and translating knowledge.

The use of writing within the curriculum is summoned and amplified to promote deeper understanding of topic content and helping students to make connections with intricate concepts. This research explores how writing develops in undergraduate science students, with the framing research literature suggesting that through the process of writing itself scientists develop a greater understanding of scientific processes as they interpret and make meaning of data. The results presented here indicate that students

only access a narrow set of learning skills and resources available to them, resulting in little improvement in writing skills throughout their degree program.

Additionally, educators are not providing the variety of writing experiences to undergraduate students to prepare them for their future needs. Focusing on communication between experts within a discipline, students graduate without being able to effectively communicate with a wider audience. This lack effectively limits employment opportunities and the reach of their research.

Without the wider frame afforded by reading and writing across a range of genre, students are limited to communicating their understanding of a concept using language and genre specific to the field in which they are situated and learning writing skills without wider reflection on the context and consequences of that dissemination. Instead of scientific writing forming a part of undergraduate education, it is most commonly developed during post-graduate or doctoral studies through an apprenticeship model by co-authorship, imitation, feedback from advisors and peer review. These apprenticeship models are successful through postgraduate education in part due to smaller cohorts and the ability of supervisors to invest more time with an individual student. But because of limitations in scope and scale, this model is not feasible for large undergraduate cohorts. Large undergraduate topics not only have many students, but each has a varied background in writing experience. Therefore, I chose an innovative and creative approach and mode to develop a solution to this problem, allowing students an opportunity to model the types of writing performed by scientists in the workplace.

Through digitization, the ability to incorporate interactive e-learning tools that focus on writing is now achievable. Within the scope of this project, I developed interactive e-learning tools to teach undergraduate science students how to write within the scientific genres of Scientific Journal Article, Impact Statement and Discussion Paper. Providing opportunity for students to use a combination of explicit and interactive teaching methods, students were guided in writing development and afforded an opportunity to practise in a low risk setting, while receiving feedback. Based on the model of apprenticeship, examples of writing were sourced from biology academics at Flinders University, providing real world examples of scientific writing performed in the workplace. Results indicate small gains in scientific language, improvements in structure and increased confidence in writing ability from previous cohorts. With approximately 94% student engagement with the e-learning modules and over 10,000 views, students were encouraged to attempt e-learning modules several times to assist in the development of assignments.

The research presented in this doctorate has resulted in the development of a theoretical model that describes how learners move from novice to expert. Linking student learning strategies and behaviour to assessment outcomes, educators are enabled to design appropriately scaffolded curricula to support students as they develop a disciplinary identity. Importantly, encouraging transdisciplinary learning makes a transfer of communication skills possible, resulting in the improved accessibility of science.

PROLOGUE

Lived Experiences

This is my second bite at the PhD apple. My first - investigating the evolutionary history of parasites in Allodapine bees in Australia and South Africa and after spending much time in a research laboratory - ended in disarray. While my supervisor tried to help, the system was just not cut out to deal with a young woman that struggled to fit into a masculine scientific environment. At the time, I could not articulate what I needed to succeed. Now I can. With the experience I have since gained in Science Education, I can now see what was missing and how the system failed me. My experiences of the academic culture in Australia were sadly not unique. Many young women find themselves leaving a PhD incomplete. Through this research, I hope to enact change in the way learners and teachers approach the development of disciplinary literacy to enable wider participation and prevent my experience being repeated among other minorities poorly represented in the sciences.

After leaving Science research, I discovered a passion for education, completing a Bachelor of Education with the intention of teaching high school science. However, finding a passion for Science Education led me right back to academia with a short-term, part-time position at Flinders University. I found a way to combine both my love of Biology and people. This seems to be a common thread among many women in science. While women now comprise around 44% of the university workforce within Australia (Winchester & Browning, 2015) the proportion of women in senior academic roles is considerably less than men (Bell, Yates, May, & Nguyen, 2015; Broadbent, Strachan, & May, 2017; Lipton, 2017). This is reflected in a variety of disciplines, including medicine where “In Australia, women make up more than half of medical graduates but only 28% of medical school deans, 29% of governing board or committee members of medical colleges, and 12.5% of chief executives of hospitals larger than 1000 beds" (Kuhlmann et al., 2017, p. 2). As a level B lecturer in the Australian university system, I am all too aware of the ceiling that many women experience and that is reflected in employment statistics. The proportion of women in Australian Level A and B lectureship positions in the sciences has changed little since 2001, holding relatively stable at 40% and 45% respectively (Bell et al., 2015). Alarmingly, across the broad disciplines of science between 2001-2011 only small gains were made in the proportion of women employed at level C (senior lecturer) and D (associate professor), in the order of 1% per year increasing from approximately 10% to 20%, significantly lower than in non-science disciplines (Bell et al., 2015). The natural and physical sciences show an even more disturbing trend with women representing approximately 12% of level E academic positions (Bell et al., 2015).

Little has changed in the last decade since Dever et al. (2008) analysed gender differences in Australian Universities and found that female PhD graduates were employed more often in academic teaching, advising or mentoring students, while male graduates more often worked in research, managing, and supervisory positions. Heijstra, Steinthorsdóttir, and Einarsdóttir (2017) describe this combination of roles including teaching and other student focused activities as 'academic housework', chores that chalk up little value of academic credential. With a perception that women are more suited to these roles, tertiary institutions seem to be contributing to this gendered issue, rather than providing opportunities for women to develop their research career (Guarino & Borden, 2017; Lipton, 2017).

By spending more time on these academic 'chores,' women in science are afforded fewer opportunities to develop their research careers. White (2015) argues that due to the current model of grant funding in scientific research, with most funding coming from the National Health and Medical Research Council, and requiring an intensive application process from senior research scientists, women are limited in opportunities due to the very nature of the organisation they are part of, with funding often awarded on the basis of the researchers track record, including past success at securing that funding. Compounding this issue women are more likely to be encouraged and accept accommodations to their role such as working part-time or moving into internally-facing roles which may disrupt their careers (Ely & Padavic, 2020). It seems that the opinions expressed by Lawrence Summers in 2005, then the President of Harvard University (Chapple & Ziebland, 2018) regarding the reasons why women are fewer in science still persist in the scientific community, including a lack of willingness to put in effort, a lack of aptitude and discrimination or stereotyping preventing them from performing in senior scientific positions.

As a relatively young white female, my experience of being an academic is not unusual. As I think of my colleagues in the field, I see myself reflected in their lives and experiences. What is less clear are the challenges faced every day, the seemingly little things that impact the ability for women to perform their jobs in a male-dominated environment. An environment that is set up to see women like me fail even before they begin. Even though we have seen a shift in the representation of women in science, and young children are more often depicting female scientists than ever before (Miller, Nolla, Eagly, & Uttal, 2018), this does not appear to last into adulthood. The idea that I could see myself as a successful scientist was easily shaken by what was to come.

My first experience of the challenges that women face in academia began early. At the very beginning of my career, employed on a short-term contract, I was tasked with the redevelopment of the first year Biology curriculum and improving student retention.

The unit was the largest in the University, important to the financial sustainability of the institution and had the potential to significantly impact student retention into later years. Eager to impress, I threw myself headlong into making significant changes. Burning the midnight oil regularly to ensure the student experience was of high quality, the changes I made translated into increased student performance and retention. A weekend rarely went by without a tower of books to be marked on my dining table. As a trainee scientist, the importance of research had been driven into me, so using these skills I prepared data to show how effective my curriculum changes were. I was excited. Student attitudes were positive, and my data showed that the changes had worked by increasing engagement and assessment results.

Towards the end of this contract, heavily pregnant with my first child, I raised with my supervisor the enormous amount of time that I was spending simply doing my job, yet it was not included in my workload. I dared utter the words that “marking should be part of an academic’s workload”. Their response stunned me, “Being an academic is a lifestyle choice” with a glance at my swollen belly, “And your contract is coming to an end anyway”. Suddenly it occurred to me that my decision to become a parent had more impact on whether my contract would be renewed than the impressive data I had gathered. Would a male colleague have been met with this same remark in my position?

At this point, I left academia for a short period, working part time in science communication while raising my children. The opportunity to return to an academic position arose several years later and I was keen to try again. I applied for and won a permanent position as an Education Focused academic, with 20% of my time spent on education research. The catch was also clear. I was employed in a part-time position, just 0.4FTE. This meant that just three hours per week to spend on research into Science Education.

That was six years ago now. An institutional restructure has seen me offered a package to leave or accept a position as Teaching Specialist, with no workload allocated towards Education Research. That three hours per week now seems privileged. Furthermore, upon asking what would happen if I undertook research in my own time, I was strongly discouraged. The reasoning behind this determination was to limit the impact of publications in 'lower ranking' journals, common in the Science Education research space compared to traditional scientific publications located in the disciplines. However, the point was made, if my research cured cancer, the university would of course expect the credit. The general attitude of the institution appears to be to use teaching specialist academics as workhorses, fodder for running large and admin heavy topics, particularly focused on first year where the academic rigour of the curriculum is deemed less important than in later years. Sadly, this is not unusual in the Australian University system, where funding models are often linked to publishing in high-impact scientific journals, limiting the participation of women in research even further (White, 2015).

These issues are compounded with junior female academics regularly experiencing appalling behaviour by more senior male academics, making the path to success far more challenging. On several occasions, male academics have clearly exhibited a lack of respect towards myself and other female colleagues and undermined the ability and potential of these academics, even though they have a similar track record of scientific research and multiple teaching awards. On a recent occasion, one male academic became particularly aggressive and threatening towards me when I simply asked him to include a content warning in future presentations after a stream of students attended my office in tears, overwhelmed by a graphic image shown in a lecture. I have rarely seen this type of behaviour directed towards men in any workplace. I had to work hard to earn a place amongst my colleagues. I would expect nothing less. My experiences along the way have shaped who I am and my vision of Science Education, as I am sure it has for many others. However, I wonder what is it about this field that attracts so many women in Biology Education, including myself?

The reason I share this story is to provide a view of the personal and professional history that led me to begin a PhD in Science Education. In the words of Guy Sebastian and Lupe Fiasco "These battle scars, don't look like they're fading" (Sebastian et al., 2012 ,track 3). My love of science and education are shaped by my experiences. Part of me just wants to prove that I can complete a PhD. Part of my identity is tied to successful research and a PhD is the naturalized pathway to this achievement. As an academic, I require this qualification to progress any further in my career in its current trajectory, without it I am not able to progress beyond a Level B regardless of any amount of further credentials, teaching excellence or research success. I also really enjoy and have much to offer to the field of Science Education research, which is currently missing from my tenured position.

The field of Science Education is broad and differs from other fields of educational research in a very important way that is often ignored. In addition to many Science Educational researchers being women, many have not started their career in education, instead have had an indirect pathway through a scientific discipline resulting in a different perspective of educational research. So strong is this background in Science that it is tied to our identity as educators. I still consider myself a Biologist, even though I have not been involved in traditional scientific research for over 10 years and believe this is one of the strongest factors influencing my approach to Education Research. With a strong foundation of scientific methods, many Science Education researchers focus on the importance of rigorous quantitative analysis of research evidence. There is a drive amongst these researchers to convince colleagues of the quality and importance of educational research and justify their existence. Many science educators are limited in the relationships they form with other academics, often becoming siloed with like-minded academics. This can be problematic as it can intensify the aforementioned issues in the narrative that commenced this prologue. Science educators have developed their own silo in the form of Science Education conferences in which they can discuss the issues specific to Science Education. While attending a recent conference for Science Educators, ACSME (Australian Conference on Science and Maths Education) many presentations discussed the challenges faced by the Science Education community yet did not consider how these issues could be addressed. Little was discussed about how to increase the profile of Science Education research or improve opportunities for researchers in this field. Many discussions focused on how to communicate Educational Research results with a scientific audience in order to influence their teaching practices, using the language of data that we know scientists typically value. In order to truly value Science Education research the language and discourse around the field must change. We need to address the issues that lead to dead-end, low research opportunity positions, disproportionately held by women in this field. The value of this area of research is not in its scientific merit (although it has plenty) but in improving the quality of the educational experience for students regardless of gender. By improving the experience of women in Science Education and extending opportunities for quality research, both academics and students will benefit.

Instead of relying on well-developed educational methods, many Science Education researchers attempt to apply strict scientific methods in a setting that quite simply has none of the characteristics of a controlled scientific setting. This is where my expertise is valuable. As both a scientist and experienced educator, I can link these two fields together. Relying on proven methods from both disciplines, my research has the potential to be truly cross-disciplinary. My experiences shaped the way that I understand the relationships between teachers and learners, teaching and learning. This research project is the culmination of many years of reflection on both processes and how we can impact meaningful change in both.

Learning-Led Research

Brew (2006, p. 3) summarized my hopes for the future of research, teaching and learning in higher education institutions when she wrote the following statement about the complex relationship between teaching and research: “I shall explore a vision of higher education institutions as places where academics work collaboratively in partnership with students as members of inclusive scholarly knowledge-building communities; where teaching and research are integrated, and where both students and academics are engaged in the challenging process of coming to understand the world through systematic investigation and collaborative decision-making in the light of evidence”. It is this relational goal that has defined this project in many ways, linking research, teaching and learning in such a way to highlight the importance of integrating them in higher education institutions.

Quite rightly, research-led teaching has gained prominence amongst educators in the higher education sphere and is recognised as valuable in providing real world context and engagement for students. Healey and Jenkins (2009, p. 3) argue that “all undergraduate students in all higher education institutions should experience learning through, and about, research and inquiry". The link between research and teaching is clearly valuable, productive and powerful, but especially in the development of a genuine understanding of research in our students as well as strengthening the links between teaching and research, which in modern times has been used as leverage to increase the perceived value of teaching in research institutions. This link is predominantly viewed as unidirectional, with the benefit being vastly in the favour of teaching. Much less focus is placed on learning-led research, where "undergraduate curriculum and teaching are designed and executed in such a way as to develop the teacher's disciplinary research" (Harland, 2016, p. 461). From my experience as a researcher and educator it is clear to me that design of higher education curriculum and teaching practices can and should also support research. This is particularly evident in the field of Science Education but need not be limited to other areas of education research. In a time where teaching and research are being driven apart, the need to draw them together once more has enabled me to consider the needs of the learner, teacher and researcher together and develop innovative curriculum to meet these needs, transforming wider thinking and practice in higher education.

A great deal of work exists in the Science Education research space, particularly in the Biology discipline, with well over 47,000 items listed in this field in a literature search this year to date (Google Scholar, 2020). This research space is expanding. The energy, momentum and credibility it wields amongst science educators is expanding. However, for the most part this research is focused on investigating classroom practices and problems that are specific to the science disciplines. While I am deeply interested in what goes on in our science classrooms, I also recognise that the issues that arise there are more widespread. Therefore, while my context is within my discipline of Biology, the observations and understanding described in this exegesis can transcend beyond a single discipline into the sciences more generally.

Importantly my own experiences during this PhD have influenced my understanding and participation with learning-led research as well. I was privileged to begin this PhD journey under the guidance of two highly accomplished researchers in the field of Science Education, Associate Professor Lisa Schmidt and Professor Martin Westwell, who generously shared their experience and expertise to contribute towards my research design. However, this privilege came with consequences. Their expertise being highly valued meant they were both highly sought after by other institutions and within months of one another they had accepted positions elsewhere. This turn of events happened to be one of the greatest influences in the structure of the research and thesis that is presented here and has deeply affected my approach to learning-led research. With a change in supervision I was forced to re-evaluate my initial project and reflect on the most appropriate way to communicate the research therein. Initially I had intended to submit a traditional thesis, focussing on the educational outcomes of students undertaking the e-learning modules that are now presented here as the artefacts. However, when reflecting upon the development of these artefacts what was clear was the importance of the journey that students (and myself) undertook through the process, rather than simply the product. By reflecting on my own experience performing this research I have developed perspective that has allowed me to understand the processes involved in developing disciplinary literacy. By using my own experiences of moving from novice to expertise within a discipline, I have been able form a theoretical understanding of the process that can be applied to students more widely. Therefore, as the e-learning modules were integral in this process it seems appropriate that they are afforded the prominence that they deserve.

Evolution of the Artefacts

Educators around the globe, regardless of their discipline, relate to the frustrations of reading a student assessment in which the student has not engaged with the supporting materials that have been meticulously curated for them. Over the past decade little has changed regarding the expectations of written assessment for science undergraduates with most courses including some form of written report or journal article style assessment. However, during that time student performance has not increased with the growing availability of resources and support, rather it seems to have declined (Bellamy, 2017; Carter & Harper, 2013; Thomas, 2019). The artefacts presented here were in part, borne out of frustration from reading the same mistakes in hundreds, if not thousands of student assessments over the last decade. With class sizes ever increasing, it is difficult to provide individualised support to each student to help improve their writing. However, what I noticed were distinct patterns that indicated certain behaviours behind the problems that existed. The patterns of errors were concentrated in ways that indicated a lack of understanding of genre. When students wrote a journal article they had clearly read and referred to published journal articles in their work. Yet, when they were asked to include a figure that described their data and incorporate a descriptive title and legend they struggled to do so, even though they had read many examples. They had difficulty determining the differences between a journal article structure and a lab report that they had completed in secondary school, often producing something more like a lab report in style. Rather than making the connections to the published journal articles that I was asking them to model their work on, they slipped into familiar styles of writing, failing to develop new skills.

Thoroughly frustrated and seeking alternate ways to support students, I developed Q&A sessions to assist students in improving their writing by addressing the assessment requirements. This format enabled larger groups to share the discussion that was traditionally held one-on-one in my office. During these sessions teaching staff would provide clarification of the instructions and rubric of the assessment task and assist students with data interpretation. It was during one of these sessions that a student asked me "how am I supposed to know this" in relation to how to format a journal article. I paused, surprised at the question. The student had clearly read journal articles, she understood how to incorporate the knowledge from literature into her assignment, yet she did not recognise that what she was reading was an example of what she was being asked to write. She could not see the similarities that were so clear to me. This conversation led me to ponder how to better support students to see the connections that were so obvious to me, in a way that could be shared by hundreds of students without adding to an already bulging workload. Additionally, it made me reflect on how and when I had made those connections myself. Simply telling students to model their writing on published literature was not working. I began to think more deeply about how those texts are formed and how they are read by the disciplinary community. This was the catalyst for the PhD project presented here. Each disciplinary community has a specialised way of reading and interpreting disciplinary texts. I had been asking students to write these texts before they knew how to read them. Therefore, I set out to understand how to develop these skills in my students.

Large classes of up to 1000 students meant that whatever the resources looked like, they would need to be flexible and - once designed - require minimal educator input. Thus, I investigated a range of existing e-learning platforms to find out what practices were in place internationally at other higher education institutions. I discovered several wonderful resources for developing scientific writing but noticed that all focussed on developing those skills in a narrow range of genre, the scientific laboratory report and the journal article. This puzzled me as there are many other forms of writing that are performed by scientists and are important for students to learn yet are not a prominent part of the curricula. This led me to develop the second aspect of my research investigating the various forms of scientific writing in which scientists engage within the discipline. The more I searched the more I noticed that scientific writing is viewed as a narrow genre within undergraduate education and I began to wonder about the contributions of this to the development of how graduates perceive their discipline and develop their identity as part of the disciplinary culture. The artefacts presented here have been used to address the gap that I perceived in the current practices in science education regarding writing instruction. They are designed to introduce students to scientific reading and writing by making explicit the way that disciplinary experts perform these skills. The e-learning modules break down the disciplinary understanding that is well-developed in experts, enabling students to access these skills and begin developing them at an earlier stage whilst they are orienting themselves within the discipline. The modules are designed for two-fold impact, for educators and students. Educators can use the choices of genre expressed in modules to reflect on the types of writing skills they would like to develop in their students, prompting them to consider the variety of scientific texts available and build these into their curricula. While the modules are intended for students to develop entry level skills of reading and writing within disciplinary contexts, modelling how experts carry out these tasks and providing a starting point to engage with disciplinary texts. The incorporation of a feedback process in this model is important to support student engagement with learning. Students seek instructive feedback to develop their writing and find feedback most useful when it provides suggestions for improvement (Voelkel, Varga-Atkins, & Mello, 2020). Thus, the feedback incorporated into the e-learning modules included key elements and terminology that were being assessed and included clear examples. The e-learning tools allowed a large cohort of students to develop and apply their technical skills based on real-world examples, incorporating interactive tasks to facilitate engagement and provide additional instruction where and when it was needed.The artefacts have been provided in their original form as presented to students and educators in Appendix A and are accompanied by supplementary information to help orient educators and students in using and accessing them.

The Role of the Artefacts in Research

While the mode of artefact and exegesis thesis exists in a range of disciplines such as creative writing, design and performance, they are uncommon in the natural sciences. My research combines creative-led inquiry and social science research, applied to the field of natural sciences. This unusual approach allows me to address the problem of accessibility of the discipline using a disciplinary literacy framework. E-learning modules are the artefacts of my thesis creation and will be supported by a thorough analysis of the impact on student learning and confidence in developing disciplinary literacy skills within Biology, bringing together design, education and scientific research. Through the artefacts and analysis, I configure an original contribution to knowledge, revealing the process of disciplinary literacy development in the natural sciences. The exegesis component of my thesis will contribute original knowledge to the field of Science Education and investigate why disciplinary literacy is integral to addressing the access of science to the broader community using the e-learning artefacts as a model. Three e-learning modules form the artefacts and, along with this exegesis, are the objects of examination. These artefacts embody the theoretical ideas presented throughout this doctoral thesis.

Throughout the research process, I have taken the opportunity to reflect on my own learning and uncovered a striking similarity in my experiences to those that I describe in my students. The research process has been a journey of discovery in my own learning, enabling me to have an atypicalinsight into the learning process as I perform learning through my own writing. Integral to the leaning-led basis of my research are the artefacts that form part of this doctoral research. These artefacts were initially designed and developed in response to a growing need to provide support to students in their written assessment tasks. As a teaching specialist academic, I regularly encounter circumstances where students are not afforded the support they need to develop written communication and the necessary literacy skills to connect with other scientists and the broader community. At the commencement of this research project the artefacts that were generated to support my teaching practice were not anticipated to be as integral to the overall story as they have come to be. However, what was discovered during the exploratory phase to inform the design of the artefacts led to a wider scope and the project that is ultimately described here. The artefacts are now not only an integral part of this story, but my hope is that they enable wider participation in the sciences for a range of students by disrupting the status quo of teaching practice in science education, bringing research, teaching and learning together in a more meaningful way.

Undergraduate students lack the perspective of an experienced researcher and without this research frame, students are limited to communicating their understanding of a concept using language and genre specific to the field in which they are situated and learning writing skills without wider reflection on the context and consequences of that dissemination. Instead of forming a part of undergraduate education, scientific writing is most commonly developed during postgraduate or doctoral studies through an apprenticeship model by co-authorship, imitation, feedback from advisors and peer review (Emerson, 2017; Kamler, 2008; Maher, Timmerman, Feldon, & Strickland, 2013). Apprenticeship models are successful during postgraduate education in part due to smaller cohorts and the ability of supervisors to invest more time with an individual student. Creative and bespoke learning practices are encouraged in this environment, such as the use of audio recordings to document research discussions (Voelkel, Mello, & Varga-Atkins, 2018) and public podcasts to disseminate research (Brabazon, 2019). Because of requirements for scope and scale apprenticeship models are not feasible for a large undergraduate cohort, yet it is precisely this group that need to be introduced to a wide range of communication literacies. Large undergraduate topics not only have many students, but each has a diversity of background in writing experience. Therefore, I chose an innovative and creative approach towards developing a solution to this problem, allowing students an opportunity to experience models of the types of writing performed by scientists in the workplace.

The artefacts that underpin parts of this thesis have been designed to enable students to model not just one type of scientific writing, but three. Within the scope of this project, I developed interactive e-learning tools to teach undergraduate science students how to write within the scientific genres of *Scientific Journal Articles, Impact Statements* and *Discussion Papers*. These establish a foundation to diversify the types of scientific communication that scientists learn. Providing opportunity for students to use a combination of explicit and interactive teaching methods, students are guided in writing development and afforded an opportunity to practise in a low risk setting, while receiving feedback. The e-learning tools allow a large cohort of students to develop and apply their technical skills within the context of real-world examples, incorporating interactive tasks to facilitate engagement and provide additional instruction where and when it is needed. Based on the model of apprenticeship, genuine examples of writing were sourced from biology academics, providing real world examples of scientific writing performed in the workplace.

The decision to invite research and teaching active academics to contribute content for the development of the e-learning modules was made to foster connections between academics and students. By including authentic examples of research activity from within their own institution I aimed to make both the research and the researchers more visible to students, and to demonstrate the diversity of the academic writing in the workplace. Additionally, this would enable research to be linked to known identities that were already familiar to students in a teaching context. Therefore, increasing the profile of research and researchers by linking to existing knowledge that students already possessed.

The focus of the artefacts in the context of this project is their use within an undergraduate unit to facilitate the inclusion of a variety of written communication genres, i.e. to enable higher education educators to include more relevant and varied written communication assessment without increasing ever bulging workloads. Integral to this model is versatility and cost effectiveness. An educational tool that is unable to be utilised on a variety of platforms or is very expensive will be limited in its impact, thus the platform was designed using *Articulate Storyline 3* software, which is low cost and compatible with most learning management systems currently used in higher education institutions. Educators must keep abreast of new research and technologies in their content areas, and consideration must be given to the level of expertise and experience academics typically have in the field of written communication and literacy education, where many describe feeling ill-equipped to teach writing (Emerson, 2017). Thus, it was also important to consider the ease of use for educators, limiting how much of the underlying technology that they would need to understand in order to be confident to include it in their curriculum. I made a carefully considered decision to keep the technology components as simple as possible such that expertise was not needed to use the tools, instead freeing educators to focus on the important aspects of the pedagogy and assessment in their course/unit, enabling the technological tools to act as scaffolds for high quality teaching and learning.

As the design of the artefacts is integral to my research, it is fitting that they form a key part of this thesis. They are not 'examples.' They are not an 'illustration.' Instead, the exegesis loops from the artefacts, summoning the relevant research literature, and then proceeds to loop once more into the artefacts for new insights. To change metaphors, they are the well of this research into which I dive. Thus, I have chosen to present my research in the form of artefacts and exegesis. This mode of thesis is unusual in the field of Science Education and I am acutely aware that many of the educators that I need to reach with this research may be deterred by its form. However, the future of Science Education, if it is to evolve and retain relevancy in future generations, lies not in enacting activities in the same old ways that they have always been done. We need to explore new ways of teaching and learning in higher education and embracing alternate methodologies must form part of the approach. Nonetheless, to ensure that the scientific community is included in this conversation and continues to be a co-contributor in the education space I have also included (as every good scientist would expect) an analysis of quantitative and qualitative data on the impact of the e-learning tools in undergraduate Biology cohorts, because we must (of course!)

always remember our audience if we want our message to reach them. This exegesis serves as companion to the e-learning modules that investigate the development of disciplinary literacy in undergraduate students. The artefacts produced for examination include the three e-learning modules that were produced for and trialled in first year Biology units. The artefacts are presented exactly as they were delivered to the students, to allow you as the reader to view and consider the learning support configured for the students in their most authentic contexts. These are learning objects that resonate with this exegesis. Together, the artefacts and exegesis demonstrate how disciplinary literacy is developed in learners and why this is important for science education.

The mode and form of these artefacts will become obsolete over time, with history showing that new modes and forms will appear on the educational landscape rendering e-learning very different from what we see today. However, this exegesis provides an original contribution to knowledge that will inform the development of future educational modes, providing a longevity to the research. The exegesis provides a critical examination and explanation of what is observed through the artefacts and the way their use influences educators, learners and science education in general. Direct links to the artefacts in their full form are provided in Appendix A, along with brief explanations to help orient the reader in their design and implementation within first year biology classes.

The Audience

A doctoral thesis is written for examination and dissemination of research. Thus, it is constructed in a form and consistent with a style that develops from within the discipline. Yet, what if the research is transdisciplinary and those disciplines are divergent in their way of thinking and engaging in research? What if those disciplines do not speak the same language? In this instance the challenge of bringing together two disciplines with vastly differing forms and styles has resulted in an uncommon blend, one that does not sit comfortably in either research space, but rather in the gap between.

I ask you – the reader, the scholar, the researcher, the citizen - to view the following work understanding the intention and purpose with which it is written, including the choice of style and form. As a scientist, I understand the value that each discipline places on scientific methods and empirical data in research. I have based research methods and data collection on scientific methodology where possible and have been sure to include a data driven section in the thesis. While this is no less important in Educational research the methods applied often involve more theory driven analyses, which I have endeavoured to incorporate as well. Throughout my research I speak of engagement in learners. I recognise that a major component of engagement with challenging material is familiarity to it. Without a hook engagement is unlikely. I hope to catch a few scientists using a hook that they are familiar with, data.

The purpose of the research presented here is to make a change in the behaviour of scientists generally, not just science educators. Thus, given the theoretical framework that I present on disciplinary literacy I feel that an important aspect of making this research accessible to scientific audiences is to present it in a mode in which they are familiar. However, I have stretched the boundaries of traditional scientific genres by meshing with a more educational speak where I have felt it is necessary. This is especially evident where I have included direct quotes from literature. While I could have chosen to paraphrase, ensuring that I stayed within scientific writing norms I felt that in the context of writing to learn, the words and the form matter. I have chosen to include direct quotation even if it may make the scientific audience somewhat uncomfortable, it highlights that how ideas are conveyed is important. In an effort to show that content and form are both important, I have pushed the boundaries of form and ask that you read between the lines presented here. I am both a scientist and an educator, my identity is now strongly tied to both disciplines not just one. By moving between modes, the content that is developed and understood in one discipline can be transferred, translated and transformed to the other, a skill – nay literacy - that I hope this research will help to develop in future scientists.

INTRODUCTION: FRAMING EXPERTISE

Knowledge forms the basis of society, replacing the traditional measures of productivity of land, labour and capital (Stehr & Grundmann, 2011). In a society built upon knowledge, the role of experts is vital in mediating that knowledge, moving science into the realm of politics. Expertise is vital to ensure that knowledge is translated appropriately and used to inform public policy and decision making, with disciplinary literacy enabling translation between one discipline and another. Experts are not born; rather they develop through their learning environment and experiences. Thus, it follows that educators must facilitate the development of expertise by scaffolding appropriate learning opportunities. In this context scaffolding refers to the provision of tools or structures that are provided to students in order to break up the learning into manageable components. Educators facilitate the development of mastery in increments, guiding students by gradually removing the scaffolding to allow the student to become an independent learner (Hogan & Pressley, 1997). By leading learners towards expertise in their discipline the benefits to society can be realised through improved translation of scientific knowledge.

This thesis probes and demonstrates how expertise is framed within a discipline, developed in the learner, and communicated to a variety of audiences. In a time where expertise is undervalued and replaced with a search engine (Brabazon, 2002, 2016a, 2016b) this research seeks to return value to expertise, repositioning it through aligning language between experts and non-experts to produce a shared understanding in a time of climate-change denial, anti-vaccination rhetoric and diminishing trust in science and scientists (Herrando-Pérez, Bradshaw, Lewandowsky, & Vieites, 2019; Lander & Ragusa, 2020).

The communication of science is integral to its broader uptake and understanding amongst the general population. The current education model seen within universities around the world facilitates undergraduate science students learning to communicate science from scientists (Baram-Tsabari & Lewenstein, 2012) which has resulted in a community of scientific experts that are not well prepared to communicate their research with those outside of their field and limits access to only those who understand this specialised language. In the context of scientific innovation and advancement, communication is crucial as the understanding between scientists and the diversity of industries in which graduates are employed is hampered due to differences in communication styles and expectations (Gilliland et al., 2016; Meissner, Cottler, & Michener, 2020). So, while we may have the greatest scientists solving the world's most challenging problems, if they are unable to communicate effectively, there is little hope for the science to be implemented, or indeed understood. This has economic, social and political consequences.

A scientist's career hinges on the ability to write and effectively communicate to other scientists and stakeholders. Success as a research scientist is often tied to the ability to frequently publish journal articles and secure grant funding commonly referred to as 'publish or perish' (Devine, 1998), while scientists outside of research rely on communication between a range of fields such as health, farming, engineering and industry to name just a few (Emerson, 2017). Currently, where the public are bombarded with such a variety of information, we can no longer expect the science to speak for itself, the ability of scientists to communicate their knowledge with others is more important than ever before (Bernhardt, 2004). In the words of Randy Olsen (2009, p. 9) "communication is not just one element in the struggle to make science relevant. It is the central element".

Context

The art and craft of teaching science students the importance of writing for learning and communicating is not new and has been revisited time and again in high school and undergraduate classrooms the world over (Carlisle, 1978; Rice, 1998). However, the way in which we view the context of the problem is critical to finding a solution. The artefacts that accompany this thesis (Appendix A) seek to close the gap between scientists and their audiences. Providing science students opportunities to develop communication skills that are tied to the context in which they occur.

Communication between individuals is highly specific to the context in which they are situated. As scientists, we develop a specific set of language and literacy that enable the sharing of ideas between like-minded scientists. The shared understanding of the discipline more broadly and the common language of science enables ideas and knowledge to be transmitted well within a discipline. The notion of *disciplinary literacy* has been investigated by Shanahan and Shanahan (2008) and others (Moje, 2015; Porter, 2018; Shanahan & Shanahan, 2012) and posits that the context of the discipline is integral in the way we think and communicate content. Disciplinary literacy refers to the social and cognitive skills associated with expertise within a discipline. Disciplinary literacy therefore is the combination of multiple literacies and is tied to disciplinary knowledge related to both content and context which develop from the history of the discipline and are expressed in the way practitioners of the discipline think, read, write and act as a member of their discipline. It is only through the development of disciplinary literacy that individuals can move from novice to expert within a discipline, and part of this is the ability to communicate successfully to those outside of the discipline. When we consider that many scientists are not often trained in communicating with anyone outside of their discipline it becomes evident that this may negatively impact the uptake of their scientific output, as well as impact the inclusion of non-scientists in many important aspects. Only through developing disciplinary expertise and the communication skills to move information between disciplines can we hope to understand how different disciplines interact. Robinson and Bawden (2014, p. 122) consider these differences between disciplines as “discontinuities in understanding which make it difficult to understand whether the ‘information’ being spoken of in different contexts is in any way ‘the same thing’, or at least ‘the same sort of thing’’ which embodies the challenges in moving knowledge across disciplinary boundaries without shared context.

The Integrative Pedagogy Model developed by (Tynjälä, 2008) describes the elements of the learning environment that are required to develop expertise, including theoretical knowledge, practical skills and self-regulation and the artefacts that accompany this exegesis act as a mediator between these elements. In this way learners use writing to draw upon theoretical knowledge and apply this to the practical skill of communication while reflecting on how they perform this within the discipline of science, both with experts in the field and with the public. The artefacts have been developed to bring about change in the way that science students are taught to communicate, embedded in assessment activities to demonstrate the value of communication to a variety of audiences. The e-learning modules map to three of the key areas of science communication performed by scientists in the workplace, modelling authentic and contextually rich experiences of writing. This is crucial as science graduates are not afforded adequate opportunities to develop literacy skills to communicate their research effectively to a range of stakeholders. Therefore we see a mismatch of skills required by employers that contributes to the underemployment of graduates (Sarkar, Overton, Thompson, & Rayner, 2016). A report from the Office of the Chief Scientist in Australia highlighted that employers were particularly concerned with inadequate level of workplace experience (Prinsley & Baranyai, 2015; Sarkar et al., 2016). While employers recognise the importance of communication skills, they also note that they are lacking or under-developed in many graduates (McInnes, Hartley, & Anderson, 2000) and that the training received by graduates does not adequately prepare them for the workplace (F. E. Gray, Emerson, & MacKay, 2005; McInnes et al., 2000). The following sections serve to create a path through which the reader can navigate recent history of the higher education system. This provides the reader context for understanding the framing of the main questions and scope of this PhD research.

Why these problems exist

The last two decades have seen significant changes to the way we gather and value information, with the rise of the “Google Effect” (Brabazon, 2006) resulting in the devaluing of expertise. Search tools such as Google have changed the way we access information, more profoundly than shifting from paper to screen. Learners have shifted from being “passive consumers to active participants” (Welbourne & Grant, 2016, p. 706) with user generated content models becoming increasingly popular. In and of itself active participation is not a bad model but combined with low levels of information literacy and a diminishing value of expertise the result is dangerous in terms of the way information is misperceived and incorrectly utilised. With a plethora of information at our fingertips “the concern is the lack of literacy skills and strategies to sort the trash from the relevant” (Brabazon, 2006, p. 157). “A scholarly monograph can be found as easily as an Instagram ‘influencer’” (Brabazon & Redhead, in press). Online communities and media outlets are increasingly being sought out to provide information that would previously have been the realm of professionals (Lutkenhaus, Jansz, & Bouman, 2019), with more people than ever before relying on “Dr Google” for health information (Van Riel, Auwerx, Debbaut, Van Hees, & Schoenmakers, 2017).

The digital revolution has insidiously swept through the higher education sector under the guise of reducing staff workloads and ease of accessibility, promising greater reach to ever growing and diversified student cohorts. We would be hard-pressed today to find a tertiary institution that does not rely on a centralised learning management system to deliver information to students. This change has had a significant impact on the way teaching and learning takes place. However, rather than lamenting for the return of traditional chalk board teaching methods and library card catalogues to restore information literacy to teaching and learning I have chosen to embrace this electronic age which is expressed in the mode of e-learning modules in the artefacts of this thesis, enabling the movement of the artefacts beyond the time and space of an individual teaching unit or institution. In this way connections are formed between the artefacts and existing academic literature addressing the issue of reduced information literacy in students, perpetuated by educators under the pretext of streamlining content. Tara Brabazon (2014, p. 192) describes the experience of sessional staff filtering and synthesising materials for online courses run via one such system as “students simply downloaded already scanned articles. It was like a vending machine for research. There was no need or initiative to search widely or read expansively.” Such spoon-feeding of information does not encourage the development of information literacy skills that are crucial to learning, instead promoting a culture of fast food information with little thought given to the process.

Similarly, the emergence and development of social media services like Facebook and Twitter increasingly used as sources of daily news (Ju, Jeong, & Chyi, 2014) operate using algorithms that are shaping what we see (Usher-Layser, 2016) optimising content to ensure that we are provided with the information that will keep us on our devices for longer and encourages us to express our feelings and opinions regardless of whether we have anything of merit to say. The value of the thoughts and feelings of a novice become equal to an expert in such a flattened information landscape. With the likelihood of users seeking information that support existing beliefs, described as confirmation bias (Nickerson, 1998) leading to "unsubstantiated or untruthful rumo[u]rs reverberat[ing] on social media, contributing to the alarming phenomenon of misinformation" (Zollo & Quattrociocchi, 2018, p. 177) exacerbating the situation even further.

The disintermediation of information has resulted in increased accessibility but is not without draw backs. No longer is information carefully crafted and presented by valued experts, instead all text is given equal footing, regardless of expertise. YouTube and TikTok are replacing experts. The opinions of Instagram 'influencers' are held with as much regard, considered reliable and trustworthy (Gashi, 2017). The cacophony of user-generated content is drowning out the expert voice, resulting in a "flattening of culture that is blurring the lines between traditional audience and author, creator and consumer, expert and amateur" (Keen, 2011, p. 1). How can we encourage dialogue without reducing the rigour of content? The answer lies in teaching students to understand the value of language and genre and the role this plays within a discipline. With thoughtful choices, experts can reach audiences in ways to increase opportunities for meaningful dialogue whilst maintaining academic rigour. By carefully scaffolding the way educators expect students to gather and engage with information, guiding and supporting them to locate high quality academic sources information literacy will develop. This is demonstrated in the artefacts by scaffolding student reading, guiding them to appropriate resources of high intellectual and disciplinary value and suitability to their assessment and learning. These resources are not easy to grasp at an undergraduate level, in fact they are challenging to many scientific experts outside the narrow field of expertise, however by introducing these types of literature early and establishing how to engage with them students are supported in their development of skills required to understand and interpret this type of academic information. Students do not have innate knowledge of where to find suitable academic resources, thus educators must scaffold their use and importance to demonstrate how they contribute to the understanding and broader conversations within a discipline. In the broader community this involves academics understanding their audience, engaging with them through varied platforms whilst retaining the same standards of fact checking and information literacy expected elsewhere. Only by showing students the value of scholarly texts and driving engagement with them through assessment practices (Pecorari, Shaw, Irvine, Malmström, & Mežek, 2012) will we begin to see changes in behaviour in how information is created and shared. “In creating barriers – spaces – between texts and consumers, opportunities are opened for thoughtful dissemination, rather than endless ‘shares’ and reflection on ideas through verification and argument, rather than assumptions of accuracy” (Brabazon & Redhead, in press). The digital era is not going away. Scientists must embrace new modes of communication if we are to be a part of the conversation instead of limiting output to outdated modes. Reaching an audience of only a few experts (Carrigan, 2017) is not sustainable.

Compounding issues of increasing digitisation and flattening of culture, internationally we are experiencing a significant change to the labour market, with increasing privatisation, employers are shifting the burden of risk to employees. Careers that were once considered stable and included non-wage forms of remuneration such as paid leave entitlements, medical and retrenchment benefits are now commonly the realm of "'flexible' labor contracts; temporary jobs; labor as casuals, part timers…. labor brokers or employment agencies" (Standing, 2014, p. 10). These precarious occupations have been disproportionately taken up by women (Standing, 2011) and are increasingly common amongst university graduates. Standing (2014, p. 10) describes this group as The Precariat: "the first working class in history that, as a norm, is expected to have a level of education that is greater than the labo[u]r they are expected to perform or expect to obtain…. Few in the precariat use their full educational qualifications in the jobs they have". In this insecure and unstable job market, graduates need to be able to respond quickly to labour market needs, demonstrating flexibility, innovation and transferability of skills.

The suitability of graduates to the workplace encompasses a broad range of skills including communication and is highly dependent on generic or 'soft' skills, more recently referred to as 21st Century skills (The Foundation for Young Australians, 2017). Graduates that are overlooked for employment due to perceived skill deficits are unlikely to gain access to opportunities that enable innovative developments and relationships with successful enterprises and social mobility. It is my assertion that the focus placed on developing "a broader and more holistic set of key generic skills required by the conditions of the information-based new economy, the mounting pressures for lifelong learning and maintaining employability in the workforce, and for creating a culture that supports learning, enterprise, innovation and creativity" (P. Kearns, 2001, p. 2) limits undergraduates ability to focus on specific skills necessary to communicate effectively in their specific fields of employment. With a focus on producing graduates who are well-rounded and have generalised capabilities, I believe that graduates are missing the importance of field-specific experience. Expertise within a discipline is valuable as without context-specific skills, there is little opportunity to link disciplinary knowledge to other areas. While a graduate may be innovative and creative, this becomes almost worthless without the ability to communicate these ideas successfully to those within and outside of the discipline. The need of employers for multidisciplinary skills has come at the expense of disciplinary experience, de-emphasising the discipline in favour of 21st century skills. The consequence is that the discipline is no longer the point of focus, and without focus the content and context is unclear. While multidisciplinarity is necessary, disciplinary literacy is the answer to combat the 'watering down' effect. Developing these skills in graduates does not require additional time. Instead as can be seen in the artefacts that accompany this thesis, they can be developed by incorporating opportunities for students to practise their field specialist knowledge by communicating with a variety of audiences. By demonstrating the importance of being able to communicate content knowledge equally to an expert as to the public graduates will be better prepared for working within their discipline.

The current model of tertiary science education emphasises the importance of content or discipline specific knowledge, thus the focus is placed upon scientific content in the form of information and data. There is less focus on science as a way of thinking, understanding and interpreting the world and how scientific writing is involved in this process (Yore, Bisanz, & Hand, 2003). For science graduates to be well prepared for employment opportunities it is the responsibility of science educators to provide them with the disciplinary literacy skills they require.

Science education experiences low levels of engagement among women and minority groups (UNESCO, 2017) due to a variety of factors, including historical, social, cultural, political and ideological barriers. Research in the United States indicates that Minority groups, including women, undertake STEM majors at University at similar rates as white males, yet do not graduate at the same rate (Estrada et al., 2016). Similar experiences are observed in Australia with research suggesting "low self-efficacy and limited access to role models are key factors preventing retention of female STEM students enrolled in university degrees" (Roemer et al., 2020). Whilst programs exist to tackle this disparity (Windsor et al., 2015) I suggest that a more comprehensive and holistic approach is needed to make STEM inclusive for all.

Research questions

Several questions arise around the use of a Disciplinary Literacy framework to develop first-class communication skills in undergraduate students, and more importantly improve the accessibility of science education to minority groups.

1. ***How can Disciplinary Literacy be applied to provide a framework to support the inclusion of a variety of communication skills?*** The breadth of genres students are exposed to is very limited with the majority of assessment focussing on developing communication skills that will be used to communicate with other scientists within the discipline (Stevens, Mills, & Kuchel, 2019), ignoring the fact that the majority of science graduates will not be employed in this field (Palmer, Campbell, Johnson, & West, 2018). The artefacts that form part of this thesis will be used to investigate and understand how the inclusion of varied forms of communication-based assessment may influence the development of Disciplinary Literacy in undergraduate science students.
2. ***How does Disciplinary Literacy develop during an undergraduate science degree program?*** Teaching staff report confidence in delivering

and assessing science communication skills (Ferns, 2012) however graduates are not demonstrating proficiency either during their undergraduate education or during early employment.

3. ***How can the application of a Disciplinary Literacy framework be used to address factors limiting the inclusion of minority groups in Science Education?*** Broader community engagement with science requires a shift, not only in how scientists communicate, but their views of who can provide meaningful contributions to scientific discussion.

In answering these questions, the focus is deeply seated within a scientific context to understand the specific barriers that exist in science education. However, the disciplines of science and education bring different lenses with which to view the outcomes. Therefore, it will be important that a trans-disciplinary approach is used to enable a clear view of the learning experience, which may offer broader understanding beyond the confines of the sciences.

Disciplinary literacy and expertise are entwinned. To develop expertise one must have well-developed disciplinary literacy. Therefore, this research seeks to understand the relationship of disciplinary literacy in building expertise and will develop principles based on research in the field of both expertise and disciplinary literacy. However, the focus will be on disciplinary literacy and its role in developing expertise. The characteristics of expertise development presented throughout this thesis are based upon research by Alexander (2003) and Alexander, Sperl, Buehl, Fives, and Chiu (2004) which investigated the behaviours exhibited by learners moving through an undergraduate degree program in Special Education.

Scope

The purpose of this study is to determine how students develop disciplinary literacy in the hopes of creating a more accessible culture in Science Education. The research focusses on the experiences of undergraduate students from within an Australian University, located in Adelaide South Australia. A small cohort of postgraduate research doctorate students are also included in order to understand how disciplinary literacy develops. The study spans 3 years including the development of resources and collecting data, beginning in 2017.

Original contribution to knowledge

The original contribution of my doctoral research to world knowledge is the creation of a new gauze through which to view disciplinary literacy development within the sciences. This provides a framework in which educators can scaffold effective disciplinary literacy programs through understanding how science learners develop their own literacies within their discipline. Upon completion of this research, the artefacts as e-learning modules will be available for use in undergraduate teaching programs within the discipline of Biology but will encourage a broader range of literacy development within the sciences. Through adoption of such methods, each graduate's disciplinary literacy capacity will be enhanced and their ability to break down language barriers to interface with non-scientists will improve. Thus, science will be rendered more accessible to the broader community. By applying the lens of Disciplinary Literacy Development to Science Educational design and praxes, this project will establish and provide a theoretical framework that underpins the future development of course material in these teaching and learning spaces.

Chapter structure and outlines

The following section provides an overview of the thesis structure and outlines the content of each chapter therein. This research thesis consists of two initial chapters that explore the history and theories that have shaped science communication education and science education more broadly (chapters 1 and 2). This is followed by an experimental chapter in which the specifics of three main aspects of the experimental research are described, including current assessment practices, student resourcing and e-learning modules (chapter 3). A final chapter is included that brings together previous theoretical understanding and the experimental findings to describe a new theoretical model on of the teaching process (chapter 4).

Chapter 1: Conflicting Agendas – This chapter contains a review of the literature around science communication in higher education. It is focussed on understanding the relationship between institutional structures and how these have influenced student experiences in the sciences. This chapter frames the questions for the research in subsequent chapters.

Chapter 2: The Importance of Disciplinary Knowledge – This chapter investigates the role of disciplinary literacy in how both teachers and learners approach the learning environment. It provides a lens through which to view practices in science education that are second nature to science educators.

Chapter 3: The Language of Science – This chapter is so named to represent the experimental stage of this PhD research and the deeper connection it has to traditional scientific representation. This chapter outlines the study design and experimental elements and includes sections examining current assessment practices, student resourcing and e-learning modules that are presented as the Artefacts that form part of this thesis.

Chapter 4: Framing Disciplinary Literacy – This chapter offers a theoretical view of how learners develop disciplinary literacy through a theoretical model of the learning process. By bringing together existing disciplinary literacy literature in combination with the data presented in chapter 3, this theoretical model provides educators an opportunity to scaffold curricula to enhance the learning experience of students and promote the development of disciplinary literacy.

Conclusion: Towards Expertise – The conclusion revisits the key findings and draws together the most important aspects of this research, highlighting the original contributions to knowledge. It provides educators with a perspective into incorporating disciplinary literacy into teaching practices, clarifying the value of science education as an inclusive and accessible discipline.

CHAPTER 1 : CONFLICTING AGENDAS

1.1 The Role of Universities in Preparing Graduates for the Workplace

In September of 2016, I attended the symposium *From the Margins to the Centre: The Future of University Literacy Support & Writing across the Curriculum* in Adelaide, South Australia. My expectations of the event were quite simple. I was hoping for strategies that I could use to apply to my own students to help them improve their writing skills, which I perceived to be lacking. However, this was to be a transformative experience and perhaps the most influential in the direction that this PhD research has taken. Hearing the experiences shared by Professor Lisa Emerson, from Massey University in New Zealand, while she investigated the relationship that science academics have with writing provided not only the inspiration for this PhD, but a way for me to understand what I was seeing in the undergraduate students that I teach. From her perspective outside the discipline of science, Professor Emerson was able to translate the transformational experience that occurs through writing and articulate the importance of this process to the way scientists think. Furthermore, Professor Emerson challenged the notion that scientists were poor writers, instead sharing examples of chemists, physicists and mathematicians who are both prolific and engaging writers in a variety of genre. By sharing the stories of successful scientific writers, Professor Emerson provided a much-needed voice to elevate the role of scientific writing in how we understand the development of scientific literacy. This became a pivotal point at which I would reflect on the purpose of higher education, the expectations of students and my responsibilities as an educator. The cross-disciplinary engagement embodied through the symposium informing my future practice (Vered, Thomas, & Emerson).

The importance of preparing graduates for the workplace has also been a key area of interest from the outset of my research proposal. Many students expect improved employability through higher education experiences (Bennett, Knight, Divan, & Bell, 2019; Nilsson & Ripmeester, 2016) and I was determined to help graduates develop the necessary skills to translate their research in a way that would be more accessible to industry. I was troubled by the lack of translation of research from bench to industry and my perceptions were that this hampered the ability of graduates to find meaningful employment, preventing them from advancing their careers as research scientists. However, upon delving deeper into how to support graduates to develop these skills it became apparent that this was the tip of the iceberg in terms of preparing students to become active members of the scientific discipline. Inspired by the work of Professor Emerson I began to understand the crucial role that writing plays in the development of scientists, and my goal became to clarify this relationship and provide a scaffolded way for educators to develop writing skills in their students. The literature review presented in this chapter demonstrates not only how my research questions were honed through gaps emerging in the literature, but also provides context for the development of the artefacts that accompany this exegesis. The artefacts represent the way higher education can address the disciplinary needs of students and have been designed in response to the educational theories presented here, laying the foundation for investigating how learning is shaped by disciplinary experiences. By understanding how literacies are developed within a discipline and applying this knowledge to science education, it will enable graduates to improve their communication skills while developing a deep connection with their discipline. The expertise that graduates develop empowers them to translate their skills, knowledge and research beyond the bench, aligning the needs of students, higher education and industry. This is not a reification of 'university and industry partnerships.' It is a commitment that students have a right to work and contribute to citizenship.

With the massification of university education and the widening participation agenda that strives for 40% of all Australians 25-34 years of age to complete a Bachelor degree by 2025, universities have transformed their role in society (Tight, 2019). With an increasingly diverse student population and lower academic standards (Altbach, Reisberg, & Rumbley, 2019) the focus of higher education is increasingly on the employability of students with the qualities, skills and understandings that are desirable for their profession and as a citizen (Boden & Nedeva, 2010). However, upholding these standards without standardising curriculum that often excludes minority groups is challenging (L. L. Kearns, 2016). Universities perform many roles within society, one of these being to produce graduates who are capable and suited to the workplace. The suitability of graduates to the workplace encompasses a broad range of skills including communication and is highly dependent on generic, global or 21st century skills, traditionally referred to as 'soft' skills that are not based on the acquisition of technical content (The Foundation for Young Australians, 2017). Graduates that are overlooked for employment due to perceived skill deficits are unlikely to gain access to opportunities that enable innovative developments and relationships with successful enterprises. Therefore, higher education is tasked with improving these skills in graduates. However, meeting the increasing diversity for literacy support will require institutional change (Vered et al.) in order to value writing as integral across disciplines. It is my assertion that the focus placed on developing "a broader and more holistic set of key generic skills required by the conditions of the information-based new economy" (P. Kearns, 2001, p. 2) limits undergraduates ability to focus on specific skills necessary to communicate effectively in their specific fields of employment. Generic skills or competencies are words and phrases that fill university strategic plans, vision statements and industry engagement statements. Arguing against them is akin to arguing against motherhood or public health. However, creating space for specific skills and framed competencies that operate within disciplines first, to – if appropriate – move beyond them provides opportunities for skills to develop in a meaningful context. Rather than the model suggested by Malenczyk, Miller-Cochran, Wardle, and Yancey (2018) where writing is positioned as its own discipline perhaps there is greater value in retaining writing skills within the context of the discipline they are performed. By focussing on producing graduates who are well rounded and have generalised capabilities, it appears that universities are missing the importance of field specific experience. Therefore, a graduate may be innovative and creative, but this becomes almost worthless without the ability to communicate these ideas successfully beyond their discipline.

In this chapter, I explore the divergent and conflicting responsibilities that universities have in preparing graduates for the workplace demonstrating that these needs can be aligned. During a debate in April 2018 hosted by the Centre for Industry Engagement at Pearson College London, academics and industry leaders discussed the purpose of universities (Allan, 2018). The opening statement made by the panel chair Ben Hughes, Vice Principal at Pearson College London, highlights the juxtaposition that exists in the current state of play in tertiary institutions "The purpose of a university is to be the guardian of reason, inquiry and philosophical openness, preserving pure inquiry from dominant public opinions. [And] the purpose of the university has changed to a focus on social mobility. University allows more people to transform their lives, if necessary, at the expense of some academic rigour" (Allan, 2018 para. 3). While traditionally perceived as a place to develop scholarly practice, an academic mindset and be cognitively challenged, the role of universities in society has shifted. Significant change has occurred in higher education over the last 40 years, with a greater focus on economic capital (Marginson & Considine, 2000) and increased involvement of industry (Etzkowitz, Webster, Gebhardt, & Terra, 2000; Turner, 2019) which has led to an increase in focus on preparing graduates for the workplace. In Australia this shift in focus has been highlighted by the *Review of Australian Higher Education* recommendation to place greater emphasis on employability skills such as communication (Bradley, Noonan, Nugent, & Scales, 2008). Subsequent reviews have reduced research funding and increased the focus on application and innovation with industry (Gonski et al., 2018; Gonski et al., 2011) and more recently proposed changes to funding models specifically designed to produce job-ready graduates (Department of Education Skills and Employment, 2020) further demonstrates this shift. Has increased access really come at the expense of academic rigour? Rather than increased access driving down quality, we need to look closely at the influence of industry in determining the content and value placed on university qualifications. The wants of industry are often considered to be misaligned with formal education, however this need not be the case. The skills of inquiry and philosophical openness are essential to building a strong and resilient workforce, capable of withstanding challenging environments like the ones we see today. By re-engaging the public with scientific exploration there is hope for the traditional values of fundamental research to once again be appreciated more widely without devaluing the process to simply a tool for industry. By generating a space where the public can co-contribute, share and engage with scientific information a stronger scientific community can be developed. In much the same way as fans contribute to a rich media culture (Price & Robinson, 2017) so too can the wider public strengthen scientific culture. We can have both intellectualisation and societal appreciation of the knowledge it creates. However, society can only appreciate the significance of knowledge creation if it is appropriately communicated and they are engaged with meaningful discussion, which relies on experts being able to apply ‘soft’ or 21st century skills of communication (Christlieb & Wijayatunga, 2019).

The ideology that 21st century skills may be transferrable is contentious, with debate considering whether skills developed in one context can really be transferred to another (Botke, Jansen, Khapova, & Tims, 2018; Eertwegh, Dulmen, Dalen, Scherpbier, & Vleuten, 2013). Educational researchers cannot assume that once a student has developed a particular skill in one context that they can translate it to other contexts. It is therefore crucial that undergraduate students are provided the opportunity to develop these skills in appropriate contexts with relevance to their field, enhancing the opportunity for transfer to occur (Botke et al., 2018). The artefacts that form part of this thesis provide an example of how this contextual link can be developed. Based within existing disciplinary contexts students develop writing skills around existing content knowledge. In conjunction with traditional teaching methods where students conduct lab and field-based experiments, students are provided a scaffolded learning experience to develop their writing and thought processes to communicate with others both within and outside of their field. Importantly, the types of writing students are asked to undertake are based on authentic examples required of graduates in the workplace and are framed by exemplars from their own academic staff. By incorporating opportunities to develop communication skills in a way that is contextually rich and relevant ensures that students demonstrate not only proficiency with content but develop skills to use that content in a meaningful way.

Science graduates themselves have identified that both oral and written communication skills are important to their employment and development of both were lacking during their undergraduate studies and this notion is echoed amongst employers (Moore & Morton, 2017; O'Byrne, Mendez, Sharma, Kirkup, & Scott, 2008; Sarkar et al., 2016). The mismatch between employer needs and graduate qualities seems clear. Yet, this may be the result of employers focussing on the importance of content knowledge rather than the development of critical, thoughtful and engaged graduates. Disturbingly, research by Arum and Roksa (2011, p. 54) indicates that "undergraduates are barely improving their [Collegiate Learning Assessment] CLA-measured skills in critical thinking, complex reasoning, and writing during their first two years of college … almost half are demonstrating no appreciable gain in these skills between the beginning of their freshman year and the end of their sophomore year". This would indicate that neither proposed function of the university is being deployed here, with little improvement in these skills students are unlikely to develop an inquiring mindset or one that enables them to mobilise upwards socially. Neither society nor industry gains in this circumstance, and without learning taking place students are left with nothing more than debt. However, this does not have to be the case. These skills can be developed as I will demonstrate throughout this research, and linked to academic, social and industry improvements.

The following review of literature was undertaken in order to orient the research that follows. To identify which literature should be included in the review I began by identifying key search terms that were relevant to the overarching aims, which were later refined based on the evidence presented in the literature review. Key terms were expanded and adjusted with the assistance of Flinders University librarians, who offered an invaluable perspective. Once initial primary sources were identified, an outline of the key components was created. Further sources were identified using a combination of approaches including examining the references included in the primary sources for relevant publications and authors.

1.2 Why Science Communication Matters

Investment in scientific research is central to the advancement of society (Meirmans et al., 2019; OECD, 2018) and is often only possible due to publicly funded resourcing. Therefore, an expectation that research is published in ways which are accessible to the public is not unreasonable and is desirable if graduates are to make meaningful connections with industry partners. Yet we have been aware for decades that “research papers are written for specialists. This style means that authors can be explicit in their referencing and economical with space. But whereas the approach produces succinct papers for editors and referees, it makes tough reading for nonspecialists” (Hayes, 1992, p. 1). Most research funded via public investment is still presented in academic texts which are inaccessible to most audiences, and attract on average an audience of between three and eight readers, resulting in little social or academic impact (Carrigan, 2017). This is not surprising considering that “most journals are difficult to access and [are] prohibitively expensive for anyone outside of academia” (Biswas & Kirchherr, 2015 para. 10). Heleta (2016) attributes this in part to academics lacking training in how to write for a wider audience. A broader audience might be reached via the employment of a wider range of communication modes such as sonic media, video/film, plain language reports, social media and newspaper articles that most academics do not regularly contribute to as part of the communication of their research. The notion that academics only perform a narrow spectrum of communication activities aligned with my own experiences, thus part of this investigation was designed to collect information about the assessment practices used in higher education as an indicator of the value academics place on the forms of communication they think students should develop. This was also an important consideration in the development of the artefacts and the specific choices made as to which modes and genres of communication to include. To increase opportunities for students to develop literacy skills to communicate with an audience beyond other academics two of the three artefacts were designed to target non-scientific audiences including the general public and non-scientist professionals such as politicians, scaffolding development of appropriate structure and terminology to suit an audience without a scientific background or understanding in the specific field. Without explicit guidance in these types of communication graduates are ill-prepared to communicate with the variety of people they will work and communicate with in the workplace.

Academic communication practices impact the way research is used to inform policy decision-making. Research suggests that "academic research, while valued and considered relevant, is not being used by the majority of staff in policy decision-making" with staff indicating that "academic research is not available when needed, is difficult to access, or is not being translated in a user-friendly form for policy-makers" (Ferguson, Head, Cherney, & Boreham, 2014 para. 5). The decision to broaden the research focus to communication beyond industry was driven by the plethora of literature noting the general lack of communication skills among scientists. By making research outcomes accessible and employing policy makers' preferred modes of communication we may hope to achieve greater impact. As can be seen in the artefacts presented with this thesis, communication directly with funding bodies is an important part of this discourse. The inclusion of the scientific genre of impact statements as an artefact was carefully considered to ensure students could connect their research to funding opportunities, highlighting the importance and relevance of translating scientific research into outcomes that can be used to inform funding and policy decisions. While the communication of science is integral to the broader uptake of scientific knowledge amongst the general population, initially this was not the focus of this research. However, the current education model seen within universities around the world facilitates undergraduate science students learning to communicate science from scientists (Baram-Tsabari & Lewenstein, 2012) who typically focus on narrow forms of communication with other experts. This has resulted in a community of scientific experts that are not well prepared to communicate their research with those outside of their field. In the context of scientific innovation and advancement, communication is crucial as the understanding between scientists and industry can be hampered due to differences in communication styles and expectations. While we may have the greatest scientists solving the world's most challenging problems, if they are unable to communicate with industry there is little hope for the science to be implemented. If scientists are unable to communicate with policy makers or with the public then we are likely to see little impact of the incredible advancements being made. Therefore, the entire project and artefact design was directed not towards communication with industry alone but towards developing communication skills that crossed the boundaries of disciplines and became transdisciplinary, enabling science graduates to move with confidence between disciplines to apply their knowledge using contextually appropriate language to communicate.

Research into translational communication indicates that the use of highly technical language and jargon remains common in scientific communications written for the public (Sharon & Baram-Tsabari, 2014) continuing to include high levels of obscure terms and phrases. Yet the literature is clear, showing that the use of highly scientific terminology negatively impacts understanding (Krieger & Gallois, 2017; Shulman, Dixon, Bullock, & Colón Amill, 2020) and the ability of non-experts to engage with scientific content (Shulman et al., 2020). However, a scientist's career hinges on their ability to write and effectively communicate with other scientists and stakeholders, while scientists outside of research rely on communication between a range of fields such as health, farming, engineering and industry to name just a few (Emerson, 2017) and it is likely that this impacts the choices made regarding assessment of student writing, with those tasks that are considered valuable by the academic also being the focus of their teaching.

In an information-rich age, where citizens confront a diversity of modes and interfaces, science can no longer speak for itself. Scientists must communicate their knowledge with an awareness of the audiences beyond the disciplines of science (Bernhardt, 2004). This is not to say that communication between experts is less important than between other groups and there is much to be gained from communication between experts in the development of disciplinary literacy, but this is just one of the suite of communication tools that scientists will need in their toolkit in order to overcome the barriers to the uptake of science among the wider community. In the words of Olsen (2009, p. 9) "communication is not just one element in the struggle to make science relevant. It is the central element". As such the focus of the artefacts is on communicating scientific content to three key groups, experts within the discipline, non-specialists outside of the discipline and the general public. With emphasis on avoiding the use of jargon associated with the field in the latter two groups. In making science relevant to the community graduates will need to develop strong communication skills in a variety of modes and genres capable of crossing boundaries of disciplinary knowledge. In each instance the artefacts have been designed to scaffold the development of writing skills to enable clear communication with a range of audiences, allowing the reach of science to expand beyond those within the discipline. Additionally, through the process of writing, students and scientists develop a greater understanding of scientific processes as they interpret and make meaning of their research (Emerson, 2012; Poe, Lerner, & Craig, 2010), thus the benefits are two-fold, with writing expertise in a discipline associated with communication across discipline boundaries (Bazerman, 1988). The development of rhetorical knowledge, the ability to analyse and adjust communication to suit context amongst our scientific community is invaluable to the future of science, and ensures that scientists have the necessary language and understanding to communicate their research to a range of audiences in varied contexts (Poe et al., 2010).

Whilst educational researchers can recognise the importance of these skills as educators, there still exists a mismatch of skills required by employers and those possessed by undergraduate students and this contributes to the underemployment of graduates (Dobbs et al., 2012; Sarkar et al., 2016). A report from the Office of the Chief Scientist in Australia highlighted that employers were particularly concerned with graduates unsatisfactory understanding of workplace practices (Prinsley & Baranyai, 2015; Sarkar et al., 2016), while internationally employers recognise the importance of communication skills and note that they are either lacking or under-developed in many graduates (McInnes et al., 2000) and that the training graduates receive does not adequately prepare them for the workplace (F. E. Gray et al., 2005; McInnes et al., 2000; Mourshed, Farrell, & Barton, 2013). With many employers noting that a skill deficit in graduates directly impacted effective recruitment into STEM related industries (Consult Australia, 2011; Dobbs et al., 2012). The Foundation for Young Australians (2017) forecast that by 2030 Australian employees will spend 2 hours more each week on average communicating in written forms than they do today. With research indicating a relationship between associated skills such as handwriting contributing to the broader academic success of students (McCarroll & Fletcher, 2017), instead of reducing the amount of explicit instruction in these areas as has occurred over the past decade (Dolin, 2016; Graham & Perin, 2007) more attention is required to support the development of these skills than ever before. “Whichever way we look, written language is not going away. It is just becoming more closely intertwined with the other modes” (Cope & Kalantzis, 2009, p. 182) and in order to be able to effectively engage with the range of modes in which writing will be integral, graduates will require well developed literacies to effectively participate. In fact generic skills such as communication may even be considered more important than disciplinary knowledge by employers (Ferns, 2012; The Foundation for Young Australians, 2017) and educators alike highlighting an increasing need for written communication skills to be highly developed. In order to equip graduates with these skills educators must demand more of themselves and of their students, encouraging wide reading and engagement with a variety of texts (Brabazon, 2016a) to prepare them to communicate widely in the workplace and beyond. However, even presented with vast evidence that varied forms of communication are important for graduate employment this has not been enough to change educational practices in higher education, highlighting the importance of a new approach based within disciplines.

Lowrey and Venkatesan (2008, p. 254) point out that “because scientists tend to direct their communicative activities to other scientists, even well-educated but not scientifically trained people would not comprehend the methods of science on a rational basis” indicating that semiotic analysis of science communication may hold the key to understanding and improving the accessibility of science to the wider public.

Ultimately, science is a social activity with the outcomes of research often tied to addressing issues of public interest. Therefore, the communication of such research must be accessible to all, not just those with privileged understanding of the discipline. However, for such a communication system to be implemented, complex and intricate translational work is required. Here the artefacts will provide the scaffolded learning needed to prepare science graduates to communicate using appropriate language and form. Providing an avenue for greater uptake of science to the wider community, graduates will be able to connect scientific research to everyday problems, not only increasing the uptake of the knowledge, but increasing the impact of research. This is relevant to both scientists and society to ensure that publicly funded research results in the best outcomes possible. How higher education prepares science graduates to communicate with each other and with the wider community is highly relevant to their future employment, with less than 18% of Bachelor of Science graduates in Australia finding employment within a scientific field as depicted in Figure 1.1 (Palmer et al., 2018). Internationally the situation reflects a similar proportion of STEM graduates finding employment in STEM focussed jobs (Smith & White, 2019) with markedly higher proportions of Engineering graduates finding employment in the field. Thus, one aspect of the broader problem is that we are only preparing our graduates to perform a small fraction of the work they will go on to do as most graduates are employed in other disciplines. In fact, approximately 34% of science graduates surveyed five years after graduating were employed in the Education sector, a proportion second only to education graduates (Coates & Edwards, 2009).

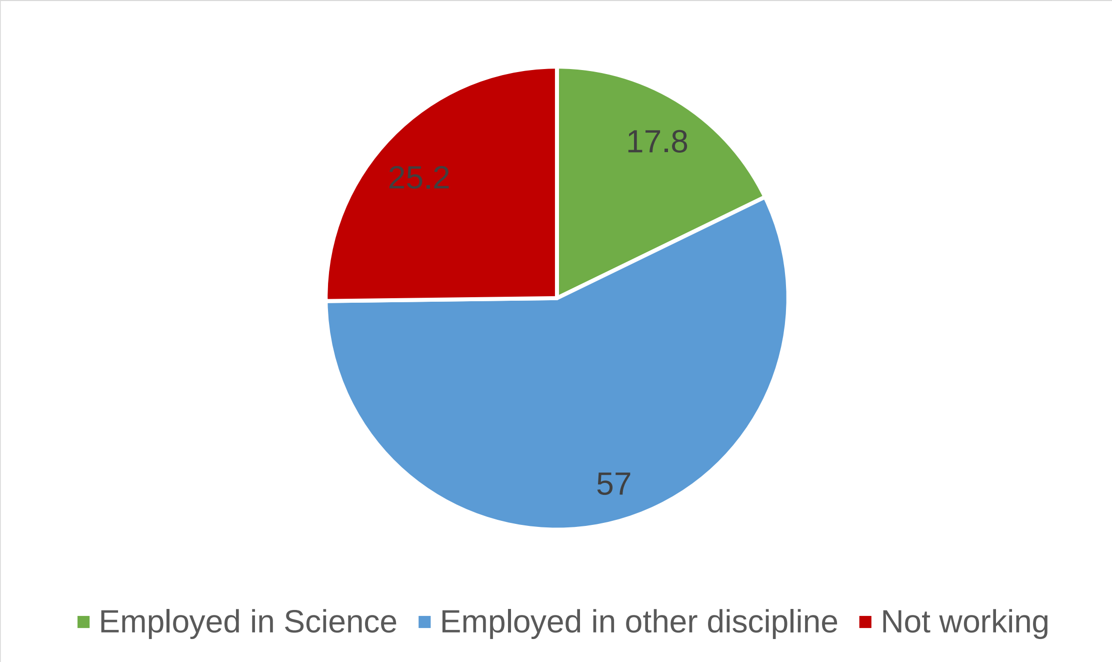

Figure 1.1. Employment status of BSc graduates in Australia. (created using data sourced from Palmer et al. (2018) based on 2011 Australian census data).

1.3 Communication Theory

Communication theories are pertinent to this discussion. However, this research project focusses on the development of disciplinary literacies, rather than the communication process itself. Thus, whilst successful communication is a desired end-product of disciplinary literacy development, there is a large and well-developed body of communication theory literature (Bar-Am, 2016; Barnlund, 1970; Berlo, 1960; Hartley, 1928; Shannon, 2001; Shannon & Weaver, 1949) that will not be addressed in this doctoral research as it falls outside the scope of this project. The focus in this PhD is how disciplinary literacy develops, however the role communication plays in education will be investigated. Communication theories are nested within literacies themselves therefore it is not appropriate in this investigation to frame the knowledge that is produced within a narrow range of theoretical views. Instead, the models of literacy that have emerged since the year 2000, and the New London Group have been instrumental in the understanding they provide for enabling communication within a discipline, and will offer both the spine of the literature review and the frame of the research in this doctorate. As the thesis is formed through artefacts and exegesis, it is important that the literature is tightly configured and maintains both depth and clarity.

1.4 Science Communication Education Research

The communication deficit amongst graduates has led to an international call for universities to respond (Boden & Nedeva, 2010; Bradley et al., 2008; Bridgstock, 2009) with a greater number of institutions across the UK, US and Australia calling for communication 'skills' to be a required learning outcome within undergraduate science programs (American Association for the Advancement of Science, 2009; Australian Government Department of Education and Training, 2013; Quality Assurance Agency for Higher Education, 2015). Addressing this issue in Australia, the Science Threshold Learning Outcomes (TLO's) have been articulated as 'nationally agreed upon descriptions of what a science graduate should know and be able to do' in each of the traditional discipline areas of Biology, Chemistry, Physics, Mathematical and Biomedical Sciences, as well as for overall Science (Australian Council of Deans of Science, 2011). The TLO's provide a framework around which learning objectives should be designed in the tertiary sector. The TLO's state that 'upon completion of a bachelor degree in science, graduates will be effective communicators of science by communicating scientific results, information, or arguments, to a range of audiences, for a range of purposes, and using a variety of modes' (Jones, Yates, & Kelder, 2011). At a policy level, the Australian Qualification Framework (AQF) outlines the requirements for regulated qualifications across Australia, providing clear benchmarks and standards for Australian educators. The AQF standard for undergraduate students states that ‘graduates at this level will have well-developed cognitive, technical and communication skills to select and apply methods and technologies’ (Australian Government Department of Education and Training, 2013) indicating that communication skills are considered essential for Australian Bachelor degree graduates. However, we see little evidence that the introduction of the AQF standards and TLO’s are making an impact on graduates’ communication skills with little change to teaching practice in science communication across Australian universities since their introduction (Mercer-Mapstone & Kuchel, 2017; Stevens et al., 2019). Whilst there is unlikely a single cause behind the lack of change to science communication education, one such aspect is likely to be the experience, or lack thereof, of science educators in developing educational resources focussed on science communication. However, there is hope for increased uptake in the future as researchers focussed on this field such as Mercer-Mapstone and Kuchel (2015) provide examples of engaging and achievable ways of incorporating communication into science curricula. However, this alone is unlikely to be enough to address the issues responsible. Unfortunately, even more worrisome is that the introduction of rigorous standards and outcome measures has had little impact on the way students engage with disciplinary content, reinforcing the divide between higher education and employers. While employers are seeking graduates that can simply communicate effectively, perhaps what they are really after is a graduate who is multiliterate in a range of communication modes and levels appropriate for a range of stakeholders, an employee who has the ability to communicate science across contexts. The current circumstances surrounding science communication outcomes are sadly unsurprising and are consistent with the lack of learning gains in US college students observed by Arum and Roksa (2011) in their longitudinal study measuring cognitive growth in higher education students.

Globally, the focus of science education is on technical and analytical skills and research methodology, with comparatively little time spent on educating future scientists how to communicate their ideas and translate science to stakeholders (Brownell, Price, & Steinman, 2013a). Even in the North American general education model where instructional writing courses are well-developed (Adler-Kassner & Wardle, 2015; Rogers, 2009), we see little difference in the concerns expressed by industry regarding the development of communication skills of science graduates (Dobbs et al., 2012). The translation of science to industry as well as the general public, is crucial for the global knowledge economy (Edmondston, Dawson, & Schibeci, 2010a) and for general acceptance and understanding of science which can influence governmental decision making, policies and funding (Brownell et al., 2013a). Without well developed and broad ranging literacies that enable sharing of ideas, graduates will be ill-prepared to contribute and participate in a future economy that is more reliant on information and knowledge than physical activities or material objects.

While the higher education sector is under pressure to develop students with strong research and business skills, there seems to be comparatively little effort to develop the communication skills of STEM graduates in the workplace (Emerson, 2017). Whilst one might be tempted to take this to indicate that there is little to be improved upon in this area it is doubtful that this is the case; in fact it may be one of the central reasons graduates are unable to articulate what knowledge they do have to contribute towards research and business. What may be contributing to this lack of change is that "any sustained attempts to change teaching practices must focus on the culture of the department" (Wieman, Perkins, & Gilbert, 2010, p. 8) and there is little evidence that this is occurring with regard to embedding writing experiences in the curricula. Emerson (2017) recently reported that of the 106 students surveyed in her study regarding their experience of learning scientific writing skills, only two experienced in-depth, authentic opportunities to develop an understanding of the importance of writing to the process of knowledge creation in science. Scientific writing is most commonly developed during post-graduate or doctoral studies through an apprenticeship model by co-authorship (Kamler, 2008; Maher et al., 2013), imitation, feedback from advisors and peer review, instead of forming a part of undergraduate education. Learning scientific writing informally is inherently problematic as there can be complications working with mentors within socially complex hierarchies, whilst reading and imitating texts presents problems such that students may not be able to decipher the processes involved (Emerson, 2017) and peer review may be unreliable. As highlighted by Emerson (2017) this may lead to a cyclical problem as emerging scientists learn to write in their discipline without the language with which to understand the nuances of their writing, they may then move into senior positions and struggle to mentor their own students. Many of the senior scientists interviewed by Emerson (2017) described feeling ill-equipped to teach their students how to write scientifically. Not only is writing important to the communication of ideas, it allows the individual to process information and translate it into knowledge.

However, what is valued as writing differs dependent on the discipline from which it comes, and this aspect is what has driven my research to explore how disciplinary literacy develops through writing. My research aim began to evolve, no longer focussing on providing graduates with additional skills, it was about changing the culture of science education to value communication – writing – in more than one form.

Consequently, the artefacts that accompany this thesis are designed to support educational instruction, enabling a diversity of pathways and experiences to be valued and validated. Additional resources are not required, and this curriculum loans expertise to an educator, enabling their reflection and development alongside the students. Science academics are already well positioned to support students in the development of communication skills as they perform many of these skills themselves daily as part of their academic and research roles. What these artefacts enable is a shift in focus, highlighting the importance of a variety of communication *forms* rather than the narrow focus that is demonstrated later in this thesis. The artefacts enable teaching staff to embed communication skills seamlessly throughout the science curriculum rather than as an add-on task that fails to mesh with existing content without requiring specialist knowledge of genre and communication studies. These artefacts demonstrate how a shift in the value of disciplinary literacies can be made in conjunction with and supporting other educational outcomes.

An assessment of educational practices across five research-intensive universities in Australia highlighted that 97% of summative communication assessment was targeted towards communication between scientific experts within the same discipline (Stevens et al., 2019) a finding which is supported by an abundance of literature investigating the development of scientific writing in undergraduate students (Griffiths & Davila, 2017; Rakedzon & Baram-Tsabari, 2017; Waters & Schlegel, 2016) leaving few opportunity for students to develop communication skills with other stakeholders. This is problematic for two reasons. Firstly, students are afforded limited opportunities to develop other forms of communication beyond expert-to-expert which is unlikely to be useful in future employment outside of scientific fields where the majority of graduates will be employed (Social Research Centre, 2018). Secondly, the emphasis this practice places on expert-to-expert communication is unbalanced, not considering the variety of communication practices that are performed by a scientist in the workplace. Adding to this in disciplines such as Biology "….students learn more vocabulary words than students taking an introductory foreign language course" (Bravo & Cervetti, 2008, p. 130). This sends a clear message to students that this form of communication is valued over others and results in the exclusion of other meaningful forms of communication and groups beyond expert-to-expert discussions. By singling out expert-to-expert communication and placing a strong focus on the development of this skill, we are silencing the voice of non-experts and excluding them from contributing to the discipline. I am not suggesting that the expert voice does not need to be well developed – in fact, quite the opposite, it is time for a more balanced approach that focuses on the development of multiliteracies.

Research suggests that including explicit science communication assessment tasks in undergraduate degree programs not only improves each student's communication skills, but also improves their understanding of scientific concepts (Brownell, Price, & Steinman, 2013b; Kuchel, Stevens, Wilson, & Cokley, 2014), refuting the common perception amongst academics that spending time focussed on explicitly teaching students how to communicate negatively impacts their ability to cover the necessary scientific content in the required detail. With mounting evidence indicating that the inclusion of science communication skills in undergraduate degree programs also improves each student's core science skills (Brownell et al., 2013b; Kuchel et al., 2014; Mercer-Mapstone & Kuchel, 2015). There are important aspects of curriculum design that need to be addressed. Large sweeping changes to curricula requiring specific academics trained in the field of science communication are unlikely to occur at most institutions (Mercer-Mapstone & Kuchel, 2015) and therefore students may be better served by facilitating small changes within the curriculum by current academic staff. The integration of explicit teaching of communication skills at a unit level is likely to be more practical and feasible than large scale change of a teaching program. Adding to the issues of curriculum changes in science education is the increasing view that students within STEM disciplines bring of being a consumer of these educational resources (Bunce, Baird, & Jones, 2017) with pressure to focus on aspects that are perceived to be most relevant to future careers, even though they lack the experience to identify what they need to learn.

The artefacts that accompany this exegesis make visible the issue of communicating with a variety of audiences in two ways. Firstly, the inclusion within a curriculum of varied forms of communication indicates to students the importance of such activities. And secondly, by explicitly acknowledging the importance of a range of communication genres and audiences draws students' attention to an otherwise invisible issue. Importantly this is done by embedding communication tasks within existing curriculum as Arum and Roksa (2011) highlighted in their observations of factors influencing success at university, the role of faculty members is critical to whether students integrate with academic activities of the institution and is central for student development and retention. Thus, it is important to consider who is best placed to teach science communication considering the value such positions may hold in bridging disciplines, enabling the communication of science more broadly. Problematic are the competing goals of science education and science communication considered by Baram-Tsabari and Osborne (2015), where science education is focussed on the rigours of science, whereas science communication (emerging from social science research) positions scientific interpretations as one of many ways of making sense of the world. Both viewpoints are valid and useful for students to consider, however striking a balance may be challenging. Ultimately, science communication involves a complex combination of scientific culture and literacy, social science practice and well-developed skills in multimodal media such that a typical science academic is unlikely to be well placed to support students learning in this area. However, a review of the literature indicated that the most effective strategy to develop communication skills is to embed instruction within disciplinary units (Arkoudis et al., 2018; Dannels, 2001; Jaidev & Chan, 2018) therefore, even though scientists may lack confidence in delivering communication curricula they are best placed to do so and will require support in order to effectively implement change. This idea has been pivotal in the design process of the artefacts associated with this thesis so that they integrate with existing curricula and enable science educators to support students' development of disciplinary literacy without having to retrain and invest a large amount of their own time.

1.5 Communication Education in Practice

During a recent discussion with an undergraduate student regarding the importance of developing multiple literacies and learning how to communicate with non-scientific audiences, the student expressed his concern about having to "dumb down" the scientific content for a lay audience. In this instance, the student was referring to the lack of specialist language that would be expected in other expert-to-expert forms of communication common amongst their assessment experience. The student was challenged and felt uncomfortable in expressing their specialist understanding to a non-specialist audience and interpreted this as a need to 'dumb down' the content rather than use terminology that rendered the ideas accessible to a lay audience. This conversation is an example of the type of culture and attitudes that are embedded among the scientific community and that are propagated amongst students, ultimately resulting in the practice of communicating within a narrow discipline. I believe there are two factors at play here. Firstly, the student views the assessment task as a chance to perform and display their grasp of scientific language and understanding of the discipline mirroring what they have experienced from their teachers and role models (practising scientists). Secondly, they likely have not been introduced to a wider range of communication skills within the context of the discipline and therefore lack the understanding of the importance of learning to communicate with a variety of stakeholders, leading to the exclusion of many.

From my experience working as a tertiary educator in the field of Biology with undergraduate students, two broad questions emerge when considering the issue of enhancing communication skills of science graduates. Firstly, *why do communication skills matter*? What will be achieved by enhancing the communication skills of our students rather than focussing on discipline specific content and knowledge? Surely this will reduce students' ability to work in their preferred field if we reduce the amount of time spent on discipline specific material in an already tight schedule of an undergraduate degree program. Secondly, if we all communicate in various ways throughout our daily lives, then *why do we need to teach our undergraduate students specific communication skills*? In order to understand these questions further I will consider several theories from within psychological, educational and communication models that provide a framework or lens through which to view these issues with the aim to clarify particular aspects of each problem and highlight possible mechanisms suitable to address teaching in this area.

1.6 Multiliteracy

Literacy pedagogy has been configured as the teaching and learning of formalised, monolingual and monocultural forms of language (Cope & Kalantzis, 2005) typified by the first two of the three R's: reading, '(w)riting and '(a)rithmetic and a focus on development of these skills in children and adolescents. More recently the scope has broadened with an increase in digitisation and accessibility to varied forms of information and we have seen a shift in how literacy is considered. Rather than a skill defined simply by the ability to read or write, literacy is more recently defined by the ability to make meaning from information (Alvermann & Sanders, 2019). No longer can educators consider it enough that students can read and write traditional texts, they need to prepare students for a wide range of types of information and teach them how to interpret and process it within various contexts, providing scaffolded opportunities to incorporate new information with existing knowledge, using multiliteracies to weave new understanding.

Literacy in a 21st century sense requires multiliteracies, a term coined by the New London Group in 1996 (Cope & Kalantzis, 2009). Working collaboratively comprised of 10 expert educators the New London Group reshaped our views of literacy to include the changing landscape of technologies and how this would impact the way we interact with information. The New London Group were looking ahead, realising the change that was coming to the educational landscape as the way information was created and shared began to change. Members of the New London Group approached literacy pedagogy with a mission to ensure that all students would "benefit from learning in ways that allow them to participate fully in public, community and economic life" (The New London Group, 1996, p. 60), recognising the growing cultural diversity and changing environment. The notion of discourse differences was brought to light as differing forms of information became more readily available in everyday experiences, “with new communication practices, new literacies have emerged” (Cope & Kalantzis, 2009, p. 167). Their work resulted in a pedagogical model of practice involving situated practice and overt instruction combined with critical framing and transformed practice. Of importance is the shift from a passive phase of literacy where a student receives information towards a phase of action where the learner is engaging with information and making meaning from it. “Literacy teaching is not about skills and competence; it is aimed at creating a kind of person, an active designer of meaning, with a sensibility open to differences, change and innovation. The logic of multiliteracies is one that recognizes that meaning making is an active, transformative process, and a pedagogy based on that recognition is more likely to open up viable life courses for a world of change and diversity” (Cope & Kalantzis, 2009, p. 175). For future scientists to solve the world’s greatest problems they will need to engage with a range of people and make meaning of the vast amount of information available in a variety of forms and contexts to result in meaningful change and innovation. Therefore, these strategies were applied to the design and implementation of the artefacts that accompany this thesis and inform the approach of the research undertaken.

The New London Group framed their research using multiliteracies to address the “realities of increasing local diversity and global connectedness. Dealing with linguistic differences and cultural differences has now become central to the pragmatics of our working, civic and private lives. Effective citizenship and productive work now require that we interact effectively using multiple languages, multiple Englishes, and communication patterns that more frequently cross cultural, community and national boundaries” (The New London Group, 1996, p. 64). This reflects both what we see at a discipline level and more widely. Students are expected to develop a skill set to communicate with ever increasing audiences and tertiary educators are particularly well-placed to support them, with multiliteracies already intricately weaved throughout their own research and educational roles.

Allan Luke in Garcia, Luke, and Seglem (2018, p. 77) states that

> we live in a kind of dystopian media spectacle—where traditional authoritative sources of knowledge and cultural standpoints of print journalism and broadcast media have been left gasping for air, where science, truth and experience are but more competing texts, where relationships between figure and ground, sign and signified, celebrity opinion and scientific truth, real event and its representation have become blurred.

Multiliteracies is the concept to ensure that future scientists have the voice to speak through this spectacle and more widely support citizens to have the ability to make meaning out of the copious amount of information available. In order to do this we will need to uncover the motivating factors of engagement enabling “students to take hold of their own literacy [development] ……to harness the untapped skills that students promulgate in other environments, such as at home and in- and out-of-school practices” (Burke & Hardware, 2015, p. 144). Through this theoretical framework, meaning is situated in context, rather than as an abstraction or objective formation. In order to truly address the concept of multiliteracies we must also investigate the development in understanding of a variety of modes of which information may be presented. In the following section multimodality will be explored in relation to how it supports multiliteracy development.

1.7 Multimodality

Writing is no longer the primary mode of representation of information, a flip through any recent science textbook will confirm this with imagery and graphics more commonplace alongside weblinks to further information. With more material moving online there are a wider variety of forms to convey information. To explain the relationship between literacy and this variety of information Kress (2003) examined the impact of multiple modes of information, termed multimodality, developing a theory to enable educators to understand how meaning is made from a variety of symbols and forms of information. This is especially useful in a time where words alone are no longer the major means of communication, and never more relevant in the discipline of science than it is today, with images, videos and 3D representations of model systems available as never before.

The nature of scientific practice with a focus on experimentation, analysis of results and communication of those results is well positioned for the use of multimodal mechanisms (Allison & Goldston, 2018). Particularly with a shift towards inquiry-based practices and research-led learning (Labouta et al., 2018) students are more often experiencing authentic and varied learning opportunities, combining visual, audio, text, symbolic, graphical and other modes to represent concepts. The observations of Kress (2009, p. 114) that “mode is meaningful: it is shaped by and carries the ‘deep’ ontological and historical/social orientations of a society and its cultures with it into every sign” is particularly important to understanding the distinct challenges to literacy development for science students. The challenges specifically facing science students and educators in relation to multimodality are deeply embedded within the scientific community and the historical development of scientific ideas informing the way they are represented. Despite a variety of ways of presenting and representing abstract scientific concepts students must ultimately be able to connect these ideas across modalities in order to construct meaning (K. S. Tang, Tan, & Yeo, 2011) and the difficulty doing so is often attributed to difficulties in learning science. Whilst educators are coming to realise the degree to which multimodality is used in a science education settings, examining how a variety of modes are used to create meaning (Bezemer & Kress, 2019; Pozzer & Roth, 2019; K.-S. K. Tang, Ho, & Putra, 2016; Yore et al., 2004; Yore & Treagust, 2006) there is little discussion about preparing practising scientists to perform in an environment or workplace where they are required to produce multimodal material to communicate their work. However, the development of multimodal instruction models has been linked to writing to learn tasks (Tolppanen, Rantaniitty, & Aksela, 2016) particularly focussing on authentic writing tasks aimed at a real audience, with both formal and informal writing styles benefiting student learning (C. S. Wallace, Hand, & Prain, 2004). With evidence that designing tasks that require students to embed multiple modes within their writing improves conceptual understanding (McDermott & Hand, 2013). The artefacts that accompany this thesis incorporate writing tasks that are authentic and embedded in a variety of genres in order to provide students opportunities to communicate their work in the way practicing scientists do. Rarely does a scientist communicate using a single mode or genre, thus the artefacts are modelled to allow students to practice these skills within a relatively low-risk environment while the focus on written communication enables students to create meaning from the content they are learning.

These benefits are not limited to primary, secondary or even undergraduate education systems. Embedding multimodal activities in doctoral programs is also used successfully to support the development and transfer of skills from one mode to another whilst encouraging reflective practice (Brabazon, 2018) Essentially, multimodality enables greater and deeper understanding of concepts and when educators provide opportunities for students to develop skills in multiple modes both transfer and effective communication will occur, however “multimodality recognizes that there are many realities, truths and normalities and if we mismatch platform, information and audience, then communication will not work” (Brabazon, 2018, p. 65).

Representation in multimodal forms may invoke fears of reducing literacy by replacing text with other non-traditional forms (Bezemer & Kress, 2008). However, multimodalities done well will avoid the notion of dumbing down information for non-scientific audiences. The scientific community is stuck in a communication rut that has them seemingly ignored to the point where they are literally marching in the streets calling for action (Figure 1.2), screaming to be heard but the audience doesn’t understand the message. The time has come to challenge the way we think and communicate as scientists and recognise that if we continue as we have always done, change will not occur. We must reflect on the reasons behind why scientists have been preaching the same message about anthropogenic climate change for decades without making a significant difference in behaviours (Crompton & Lennon, 2018; Kaesehage, Leyshon, Ferns, & Leyshon, 2019).

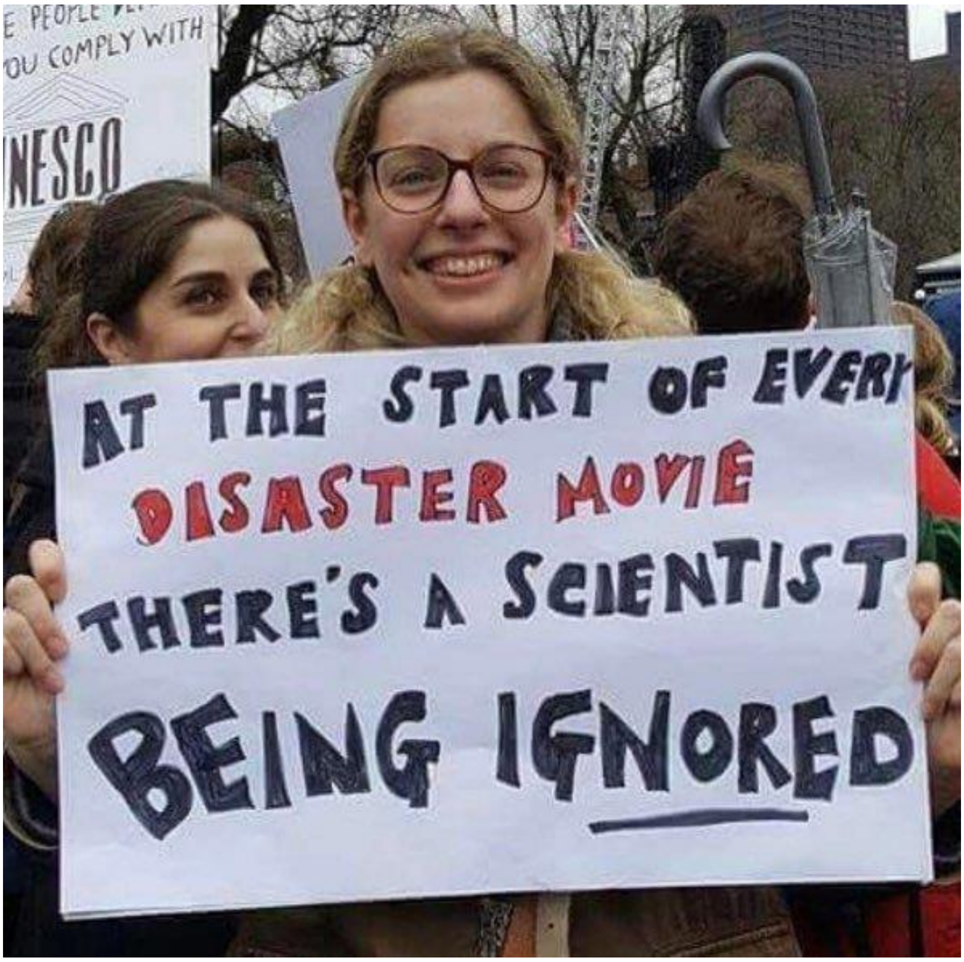

Figure 1.2. Image of a woman participating in the March for Science (Science Alert, 2018).

The woman is holding a sign saying ‘at the start of every disaster movie there’s a scientist being ignored’ (Science Alert, 2018). This is one example of the overwhelming frustration experienced by scientists in communicating their messages. It is time for scientists to channel this frustration into action and understanding. One of the most well-known scientists of all, Albert Einstein is credited with the phrase “The definition of insanity is doing the same thing over and over again, but expecting different results” yet scientists have continued communicating in the same mode, and in the same arrogant tone and wonder why no-one is listening. It’s time to try something different.

In the following section a range of processes for embedding multiliteracy and multimodality are explored, termed knowledge processes. These describe ways of conceptualising curricula that incorporate a wider range of knowledge formation processes and allow wider student access.

1.8 Knowledge Processes for Modern Educational Paradigms

The curriculum practices developed by The New London Group (1996) have since been refined and translated into recognisable ‘Knowledge Processes’ by Kalantzis and Cope (2010) where they describe a multiliteracies approach to learning “is a process of ‘weaving’ backwards and forwards across and between different pedagogical moves” (Cope & Kalantzis, 2015, p. 4) of experiencing, conceptualising, analysing and applying and is described in Figure 1.3.

Image removed due to copyright restriction.

Figure 1.3. Mapping the original Multiliteracies pedagogy against the 'Knowledge Processes'. Adapted from Cope and Kalantzis (2015).

Multimodalities and multiliteracies are critical to how we understand and provide context to teaching and learning practices and offer insight into how students develop a relationship with their discipline.

Situated Practice/Experiencing

Human cognition is situated, learning is linked closely to the context in which it is learned and the experiences of the learner (Gee, 2004). These experiences cannot be separated from learning and if we consider our new definition of literacy (Alvermann & Sanders, 2019) is to make meaning of information then this cannot occur without context. Situated Practice focuses on the learner developing meaning in ways that are relevant to them in their own lives. Laboratory experiences can provide authentic experiences and meaningful situated practice if designed to enable the learner to make meaning of what they are experiencing however, simply carrying out a practical experience in a laboratory does not make a meaningful experience. Situated practice has much in common with constructivist approaches to learning where Jean Piaget argued that new experiences are assimilated and incorporated into learners mental representations, framed by prior experience (Piaget, 1973). The constructivist educational model immerses learners in an authentic experience and the educator's role is to help the student to make sense of that experience, developing mental models of the world through their own agency of learning. Authentic experiences in the natural sciences are often found in laboratories but more often in research projects where students are immersed in the real-world practice of conducting research with the opportunity to experience genuine challenges faced by scientists (Colthurst & Tuite, 2018; Moss, Cervato, Genschel, Ihrig, & Ogilvie, 2018; Smallhorn, Young, Hunter, & Burke da Silva, 2015). However, Bjønness and Knain (2018, p. 56) remind educators that “the problem is that the open inquiry approaches presented in school science are mostly simplistic versions of the scientific method, and they obscure the complex methodological strategies found in real science”. The process of scientific research is messy and complex and challenging to provide authentically within a classroom nevertheless, situated practice is possible and enables developing scientists to be immersed in the practices and experiences of the scientific world allowing them to make meaning of the multimodal information within it and develop their own understanding of what it means to be a scientist, work like a scientist, write and talk like a scientist and how that relates to other disciplines.

Overt Instruction/Conceptualising

Though there is an association between overt instruction and didactic pedagogy it is not characterised by direct transmission of information or rote learning (The New London Group, 1996). Rather the goal of overt instruction is for the learner to gain conscious awareness and control over what they are learning, specifically developing the use of metalanguages to make generalisations within a discipline. Overt instruction is “intended to make implicit patterns of meaning explicit and nurture students’ abilities to consciously describe the process of patterns of a specific form of literacy (Zhang, Nagle, McKishnie, Lin, & Li, 2019, p. 35). Overt instruction does not characterise the learner as an empty vessel to be filled with knowledge, but rather it provides them with the tools of theory and logic to understand and make meaning of their experiences.

Critical Framing/Analysing

How do we know what we know? “The goal of Critical Framing is to help learners frame their growing mastery in practice (from Situated Practice) and conscious control and understanding (from Overt Instruction) in relation to the historical, social, cultural, political, ideological and value-centred relations of particular systems of knowledge and social practice" (The New London Group, 1996, p. 86). Analysis of how meaning is made within a particular context enables students to understand the importance of context to the way information is framed. Framing and analysing information gives learners distance from what they have learned allowing them to constructively critique it (The New London Group, 1996) evaluating the formative experiences, perspectives and motives of those involved (Cope & Kalantzis, 2015). Critical framing is enormously important and particularly relevant to science education which experiences low levels of engagement among women and minority groups (UNESCO, 2017), and yet is conspicuously absent but for the occasional Nature of Science course/unit. In order for students to constructively critique and account for their own position in the discipline there is a need to actively consider the historical and cultural influences. M. Wallace (2018, p. 1051) summarises how this impacts access to minorities as "traditional [neoliberal] narratives of science education are the dominant narrative of science education, and therefore (implicitly and explicitly) reinscribe non-traditional, un-conventional, and non-normative critical voices in science education as unintelligible or illegitimate". By providing opportunities and encouraging students to critically analyse the system of knowledge and social practices of science educators can begin to address the inequality of access.

Transformed Practice/Applying

The transfer of meaning-making practices developed through Situated Practice, Overt Instruction and Critical Framing into new contexts results in Transformed Practice (The New London Group, 1996). Transformed Practice more recently described by Cope and Kalantzis (2015) as Applying "is a Knowledge Process in which learners actively intervene in the human and natural world, learning by applying experiential, conceptual or critical knowledge—acting in the world on the basis of knowing something of the world, and learning something new from the experience of acting" (Cope & Kalantzis, 2015, p. 21). Transformed practice involves learners applying new knowledge to further understand their own lives and existing knowledge, inviting critical engagement and understanding of complex issues, making connections between new and prior knowledge for better understanding of the world.

These knowledge processes allow educators to reflect on how students develop deeper connections within a discipline, but they do not clearly describe how a discipline develops. In order to understand how disciplines influence learner development, we must also explore how those disciplines develop, including the language on which they are based. The following section explores the idea of discourse, and the impact this has on the way students experience their learning environment.

1.9 Discourse

James Paul Gee (1989) described the notion of discourse as the way that language enacts social identities. He stated, "At any moment we are using language we must say or write the right think in the right way while playing the right social role and (appearing) to hole the right values, beliefs and attitudes. Thus, what is important is not language, and surely not grammar, but *saying (writing)-doing-being-valuing-believing combination*. These combinations I call 'Discourses', with a capital "D" … Discourses are ways of being in the world; they are forms of life which integrate words, acts, values, beliefs, attitudes, and social identities as well as gestures, glances, body positions, and clothes" (Gee, 1989, p. 6). Building on this analysis, it is clear that we all develop a discourse related to the world we experience, be that of socioeconomic status, our homeland, or our profession (Gee, 2004). It is this relationship to language that enables us to communicate in the ways defined by society as appropriate to our position within it and helps us to define ourselves within disciplinary boundaries. Gee (1989, p. 7) describes a Discourse as “a sort of ‘identity kit’ which comes complete with the appropriate costume and instructions on how to act, talk, and often write, so as to take on a particular role that others will recognise. Being ‘trained’ as a linguist meant that I learned to speak, think and act like a linguist, and to recognize others when they do so”. In developing language within a Discourse research indicates the need for personal connections and explicit instructions (Baer, 2018) indicating that modelling plays a role in their development. In higher education settings modelling may be in the form of both professionals and peers within the discipline, thus “the developing professional identity is a social identity as the ways others see the developing professional” (Varga-Atkins, Dangerfield, & Brigden, 2010, p. 824).

Importantly, the process of writing highlights the actions associated with performing in the discipline. This is the moment in this thesis where multiliteracies dovetail into disciplinary literacies. In learning how to write using the practices within their field, students must “learn the kinds of claims people make: how they advance them; what literatures people rely on and how these literatures are invoked within arguments; what kind of evidence is needed to warrant arguments and how that evidence can be appropriately developed, analysed, and interpreted given community standards; what kinds of concepts are appropriately evoked; and what kind of stance authors can appropriately take as contributors to their fields. As students engage in serious writing practices, they move beyond a simple formal approach to science to active work with scientific evidence, knowledge, and concepts, thereby learning social disciplinary standards and practices” (Kelly & Bazerman, 2003, p. 30).

While it may seem at this point that I am advocating for science communication to be focussed on how language develops within and to communicate beyond the boundaries of the discipline, this is only one aspect of how students will develop strong communication skills. Educators should also reflect on the point at which it is appropriate to expect students to enact expertise within the discipline, drawing upon their disciplinary literacies to communicate in a way that provides opportunities to extend the boundaries of their content understanding. While in many instances this is left to develop at the later stages of higher education and often not until post-graduate education, I argue that this can be developed during an undergraduate degree program with careful consideration and scaffolding of language as is seen in the artefacts that accompany this exegesis and explored in later chapters. Specifically, by employing strategies to embed multimodal and multiliteracy assessments opportunities can be created for deeper engagement with the discipline. This is explored further in the following section, which addresses the formation of disciplinary nuances and how these may inhibit or enhance student learning.

1.10 Disciplinary Literacy

Becoming multiliterate implies not just a proficiency using language and media forms, but also a degree of confidence and comfort in doing so. Cope and Kalantzis (2009, p. 183) suggest that “learning to write is about forming an identity; some learners can comfortably work their way into that identity and others cannot, and the difference has to do with social class and community background” which can be described as disciplinary literacy. Literacy practices differ between disciplines in part due to the history of how they have developed as well as the natural differences between them. Not only does content vary between disciplines, but the way that content is introduced, discussed, considered and written about is highly dependent on the discipline (Shanahan & Shanahan, 2012).

When discussing literacy practices within a discipline the literature is divided into two distinct fields; Content area literacy (Readence, Bean, & Baldwin, 2004) and Disciplinary literacy (Jetton & Shanahan, 2012; Shanahan & Shanahan, 2008). Content area literacy views reading and writing as generic tools that can be used to generate understanding from content area texts, while disciplinary literacy recognises that the literacy skills and content are inextricably linked and defined by the discipline (Fang & Coatoam, 2013). Multiliteracies and multimodality discussed above acknowledge that students arrive at University with a variety of literacies tied to their background experiences, some of which may be general reading and writing literacies, Content area literacy would assert that students can use these literacy skills in all content areas in order to extract the relevant information, while disciplinary literacy takes into account the social and cognitive skills possessed by the student to understand the discipline more broadly and therefore recognise that students may need support to develop literacy skills in a context-specific way. Hynd-Shanahan (2013, p. 93) describes the differences as “the aspect of literacy that is being emphasized”. Both these perspectives are valuable when we consider how students develop literacy practices.

It is important to note that while much of the literature focusses on discourse similarities found among the members of a discourse community, variation in information and knowledge processes exist between individuals (Bawden & Robinson, 2011). Personal circumstances and informational needs influence how individuals gather information and process knowledge beyond the disciplinary literacy they possess. This is particularly evident in information seeking behaviour of patients making medical decisions being linked to personality and cognitive style (Addison, 2017; Costello & Veinot, 2019).

Lave and Wenger (1991) posit that learning must be viewed as a situated activity, that we cannot separate learning from the social community in which it occurs. The term coined by Lave and Wenger (1991) *Legitimate Peripheral Participation* draws attention to the fact that learners are members of a community of practitioners, and through apprenticeship by experts develop an understanding of the sociocultural practices that form such a community. This concept aligns with the understanding of Disciplinary Literacy. Without developing the discipline specific skills students cannot develop an understanding of the broader concepts within that discipline and therefore will be unable to become a participatory member of that academic community. When we consider that “the text typically used in the discourse community of science is unique in that it differs significantly from the text used in the home communities where most students come from” (K.-S. Tang & Moje, 2010, p. 83) it is difficult to imagine the development of disciplinary specific language being an easy process tied closely with an already developed skill-set. Multiliteracies have much to offer in this space and will be useful in understanding how disciplinary literacies develop.

The artefacts presented here are an example of how students come to experience disciplinary specific language as they develop a sense of disciplinary literacy. What is of importance is that the artefacts are not limited to communication among experts but also includes communication with a wider audience. A crucial aspect of disciplinary literacy is the ability to explain conceptual understanding to those without specialist disciplinary knowledge. By incorporating modules within the artefacts that model communication with non-scientists the importance of this skill is highlighted. Bringing together skills that students already have in the way the speak and write enables them to recognise and transfer other knowledge and skills. In this way writing is used to mobilise knowledge from one discipline to another, engaging students and enabling the use of non-traditional forms of knowledge. By using this technique through the artefacts, students are encouraged to identify what they already know about content and communication in other forms and translate that knowledge into a usable form in a new context.

1.11 Approaches

A significant aspect of developing written communication skills is the precise deployment of discipline-specific language and specialist vocabulary, described as the academic language concept (Daudaravicius, 2015). If we consider how difficult communication would be between two people trying to convey an idea to the other, each using a different language, we may begin to understand the problem. Much of the scientific vocabulary used in formal written communications poses a high level of difficulty for students to learn as it is unfamiliar and abstract (Beck, 2013) therefore perhaps it could be argued that learning scientific terminology may be even more difficult than learning a foreign language. Krashen and Brown (2007) suggest that we acquire language and literacy skills by understanding the meaning of messages, rather than explicitly learning the rules of language and grammar. Rather than explicitly teaching scientific language skills, a more suited strategy to improve written communication and science-specific language skills may be to immerse our students in examples and provide opportunities to practise these skills in real-world or equivalent tasks. It is here that multiliteracies provide a platform to bring together existing skills and developing disciplinary literacies, building upon elements that already well developed in other contexts and transferring them to disciplinary examples.

Approaches to teaching written communication skills can be divided into three main categories, product-based, process-based and genre-based (Nordin, 2017). Advocates of the product-based approach argue that students develop writing proficiency through imitation, modelling vocabulary and syntax on discipline specific examples (Badger & White, 2000). The process-based approach centres on the formation of texts, rather than the text itself, emphasising the importance of drafting and revision and the recursive nature of the writing process (Nordin, 2017). While the genre-approach in many ways is similar to the product-approach (Hyland, 2018; Nordin, 2017) places greater importance on the social context in which writing is produced offering “students explicit and systematic explanations of the ways language functions in social contexts“ (Hyland, 2003, p. 18).

1.12 Genre

When we approach the teaching of writing skills it is difficult to separate the physical act of writing from the genre that is being written within. Writing by nature occurs within the bounds of style and form defined by a particular genre, be that a text message to a close friend or manuscript submission to a scientific journal reviewed by professional peers. “Genres embody a social group’s expectations not just for linguistic form, but also for rhetorical strategies, procedural practices and subject-matter or content” (Tardy & Swales, 2014, p. 54) they are deeply entwined with the understanding and practices of the discipline in which they are found. I therefore argue, that learning ‘expert’ or ‘professional’ level writing without the context of the discipline is impossible. Current theory of genre analysis is based on the work of Swales (1990, p. 58) who described genre as “a class of communicative events, the members of which share some set of communicative purposes. These purposes are recognised by the expert members of the parent discourse community, and thereby constitute the rationale for the genre. This rationale shapes the schematic structure of the discourse and influences and constrains choice of content and style”. Writing is taught in context and cannot be separated from what we are writing about. However, it is equally important to consider how we write for the intended audience. Swales (1990) argues that each genre belongs to a discourse community and as such will possess individual differences particular to that community.

In much the same way that multimodality relies on matching platform, information and audience (Brabazon, 2018), genre relies on matching style, content and audience. In the context of my research, this highlights the importance in defining the communities involved as there are expected to be significant differences in genres used by expert-expert compared to expert-novice communication. Whilst experts are required to have a good working knowledge of scientific genres, novices by definition are unlikely to have much understanding of genre at all. It is important to note the esteem that Swales (1990, p. 11) places on the research article, noting that teaching the skills of writing this genre will result in “winning friends and having influence in higher places” indicating the degree to which communities value discipline specific knowledge. The importance of genre and audience is explicit in the artefacts to ensure the link is clear to students. By simply acknowledging the form and function of a writing task allows students to consider the most appropriate way to respond. Additionally, this allows students to position themselves as an expert, communicating their understanding to a novice and choosing the most appropriate form to do so. By guiding and empowering students in this way it helps them to develop a sense of disciplinary literacy and confidence in using appropriate terminology and genre.

An integral part of understanding genre is investigating the purpose of the communication (Bhatia, 2002), understanding why a community writes the way it does is essential in learning how to write in this form. Genre and style of writing is likely to differ between audiences due to variation in the message being relayed and the experience of the audience. In this study there may be several different intended audiences, depending on the genre and field of the study. The two main types of communication that I will focus on are *within groups of experts* and *between experts and non-experts*. Communication within groups of experts will be defined for the purpose of this study as the process of translating complex science into written language that is understood by expert colleagues. Communication between experts and non-experts will be defined for the purpose of this study as the process of translating complex science into written language that is understandable to non-scientific audiences such as politicians, industry professionals, journalists, government, educators, business and the public (adapted from (Burns, O'Connor, & Stocklmayer, 2003; Mercer-Mapstone & Kuchel, 2017) .

1.13 Scholarship of Teaching and Learning

Traditionally, university academic staff develop and teach discreet units (courses, subjects or topics) of curricula, usually within the bounds of their specialised scientific area of expertise, without consideration of the overall coherence of the undergraduate teaching program (Candy, Crebert, & O'Leary, 1994). Despite projects targeting institutional-level transformation rather than individual degree-level improvement there is little change in the wide-spread adoption of change with “application of best practices such as these …..localized to individual efforts and to a brief timeframe, after which the approach often disappears upon the departure or capitulation of its champion" (Weaver, Burgess, Childress, & Slakey, 2015, p. 4). Even when degree-level perspectives are considered and units are reformed, they quickly evolve as they are refined, particularly when responsibility for their coordination changes hands to a different staff member. Trends in undergraduate science education indicate that there is no regular pattern of how communication programs are integrated into curricula with a variety of offerings including core and elective options (Harner & Rich, 2005). The teaching of communication skills to science undergraduates is either often ad hoc or even removed entirely from within the discipline and overseen by communication education specialists, with over two thirds of technical communication course/units overseen by academics with a background in creative-writing, composition and rhetoric or technical and professional communication (Read & Michaud, 2018). It is important to note that models differ between institutions and the types of communication course/unit in each may range from a strictly technical writing option through to a deeply embedded and discipline specific one. However, research investigating communication skill development within degree programs is scarce (E. Gray, Emerson, & Mackay, 2006). Whilst views on the importance of the inclusion of science communication within education do exist, they tend to portray a rather dire circumstance, where students do not value engagement in communication with non-experts, nor the inclusion of communication skill development within an undergraduate curriculum (Edmondston, Dawson, & Schibeci, 2010b; Leggett, Kinnear, Boyce, & Bennett, 2004). Thus it is not surprising that communication skills may be overlooked and not developed adequately in favour of devoting more time to technical skills and "what we have is a potpourri of initiatives, often at odds with one another, that result in a disjointed and confused science teaching landscape that largely promotes training in science – and a poor one at that" (Clough, 2018, p. 3).

Whilst variations in mode and quality of science communication education are apparent, there appear to exist pockets of creative pedagogy with programs such as SciWrite@URI (Druschke et al., 2018) and many others (Aune, Evans, & Boury, 2018; S. Jacobson, Seavey, & Mueller, 2016; Kuehne & Olden, 2015) aimed at developing science communication between scientists and non-scientists. However, these programs are uncommon and likely to be the result of individual staff members passionate about communication. The artefacts presented here provide an opportunity for wider inclusion of communication in science education by embedding tasks within existing curriculum rather than relying on the scholarship of a few already overworked educators.

The Scholarship of Teaching and Learning (SoTL) describes the process of research and rigorous evaluation of teaching practises by Faculty who are actively engaged in the educational process (S. L. Rowland & Myatt, 2014). SoTL actively promotes a broad view of programs rather than the narrow view that many academics are accustomed to. While more science faculty have been specifically engaged in a SoTL role (Bush et al., 2011; S. L. Rowland & Myatt, 2014) we are yet to see a significant change towards a more cohesive and whole-program approach to teaching communication skills to science undergraduates. The educational approaches currently taken mostly appear to be homological i.e. based upon faculty teaching students to follow in their footsteps with research within Australian research intensive universities indicating 96% of communication assessments tasks are targeted at an audience of scientists in the same discipline (Stevens, 2013 in (Mercer-Mapstone &

Kuchel, 2015). Therefore, only a narrow range of communication skills are being taught despite the recommendations and framework provided by the TLO's. Additionally there appears to be little research into *how* these communication skills are being taught (Mercer-Mapstone & Kuchel, 2015) with a lack of evidence-based examples available to academics. Ferns (2012) raises a significant point regarding the experience of educators in this relationship. Educators perceive the writing skills of graduates to be less developed than both employers and graduates' perceptions of these skills. The cause of these differences is not currently clear, but I suspect it to be related to the academic process. Those assessing the writing skills of graduates are doing so from an academic viewpoint rather than an industry perspective, therefore they are taking a different set of factors into consideration when forming this view.

1.14 Self-Efficacy and Student Engagement

Writing is a skill that enables learning and communication and is strongly linked to academic achievement (Bangert-Drowns, Hurley, & Wilkinson, 2004). However, writing is not an easy skill to master as Zumbrunn, Marrs, and Mewborn (2016, p. 350) describe: "the process of writing can be cognitively challenging for even experienced writers. Many students struggle with writing tasks as a result of lack of knowledge, ineffective methods, lack of planning, content generation, revisions, transcription, low persistence, and unrealistic self-efficacy." Social cognitive theorists (Bandura, 2006; Pajares, 2003, 2007; Zimmerman & Bandura, 1994) posit that a student's beliefs about themselves have the power to act upon and are strong predictors of their performance, effort and perseverance with a task. Thus, if a student is more confident in their ability to perform a task, they are more likely to succeed as they will invest effort and persevere with even difficult challenges such as writing. However, students write in various forms and by capturing opportunities to build on the skills they already have using multiliteracy approaches then confidence may be developed in other areas of writing.

Learner engagement is described variously in the literature as an indicator of student and institutional success (Groccia, 2018), and relates directly to the "time and energy students devote to educationally purposeful activities" (Kuh, 2001, p. 1). Engagement in higher education is not a new concept and the basic principles of developing learner engagement proposed by Chickering and Gamson (1987) are still relevant today and include: 1) encourage contacts between students and faculty; 2) develop reciprocity and cooperation among students; 3) active learning techniques; 4) prompt feedback; 5) emphasize time on task; 6) communicate high expectations; and 7) respect diverse talents and ways of learning. Yet, when we consider the focus of science curricula in higher education it is unclear that writing is made particularly engaging for students as the analysis of assessment practices in section 3.4 will demonstrate.

The engagement of students in writing within a disciplinary context emphasises the knowledge they have as expertise of the discipline (Shanahan & Shanahan, 2012) and may influence a student's motivation towards writing. If a student positions themselves as one who possesses expertise within their discipline, then they are more likely to be motivated to write about it. However, engagement and motivation are tied to value and the Expectancy-Value Theory (Eccles & Wigfield, 2002) suggests that students will engage with a task if there is value and a reasonable chance at success. In an educational setting value may be that a task is assigned a grade, however this is unlikely to bring about deep engagement with an activity as challenging as writing.

Wright, Hodges, and McTigue (2019) argue that educators must examine student beliefs about writing to address student engagement.

1.15 Authenticity: Writing in Context

Engagement within a discipline can be fostered by providing opportunities for students to learn by doing, embedding authentic tasks into the curriculum. Labouta et al. (2018, p. 1477) describes the 'learning-science-by-doing-science' (LSDS) model as "a self-guided process-learning model in which students from different science programmes are embedded in an authentic interdisciplinary science research environment" which includes the communication of their research findings in a variety of real-world genres.

Many university courses attempt to mimic the authentic activities found in industry environments, however it is difficult to replicate the rich multidisciplinary, multicontextual working environment of many professions (Leydens, 2008). Leydens (2008) attempt to understand how the rhetoric of engineering industry communication impacts the writing used within the industry by using the lens of multifaceted activity theory, examining the influence that an individual's own perspective has on their industry specific writing. Leydens (2008) also investigates the differences in perspectives of novices to those of insiders (sophisticated) engineers, particularly around the role of writing in their current practice. Solutions to this dilemma are suggested to involve narrowing the experiential gap between students and expert professionals by providing rhetorical reflection on authentic language tasks, such as writing in internships, in cooperative educational experiences and for actual clients. The act of unveiling and critiquing the language and purpose behind such tasks enables students to begin to understand expert knowledge. Ensuring that context is maintained within writing tasks can be difficult in traditional settings where teaching staff are focussed on students demonstrating their understanding of concepts, however in the artefacts presented here a different approach is used. By supporting students to communicate with a range of audiences in an authentic setting they can demonstrate their understanding of concepts in a meaningful way that is embedded with contextual significance. Importantly the context can be varied without changing the content as can be seen in the variety of the artefacts. Each artefact has the ability to communicate the same idea or concept but to a different audience, thus context remains the crucial aspect of building communication skills.

Explicit courses, such as composition studies delivered in the USA, are not having much effect on transforming the measured and measurable abilities of students (Smit, 2004). The context in which writing occurs is crucial to all elements of communication. The notion that genre specific writing skills are best developed using real-world examples is not new (Anson & Forsberg, 1990; Berkenkotter & Huckin, 2016). Students develop written communication skills based on the opportunities they have access to and the context in which it is situated. Real world problems offer a more authentic learning experience and motivate students to write well to convey their ideas beyond a university setting (Blakeslee, 1997; Douglas, Johnston, Caswell, & Eggermont, 2004). Including opportunities for students to engage in finding solutions to real world problems with real world clients or end users allows students to benefit from the experience of collaboration with interdisciplinary teams. Academic experiences available to students are often only loosely correlated with a professional activity, even though the link may be clear to the teaching academic. Practising scientists do not receive quizzes or essay topics from their employer (Douglas et al., 2004), instead writing reports, research proposals, presentations and the like. The nature of the work that students experience throughout their undergraduate training needs to reflect more closely that which is expected in the workplace to ensure they are able to build the necessary skills to communicate effectively. In modelling and exemplifying effective communication, educators must be familiar with the requirements of industry and include assessment that provides students the opportunity to practise these skills.

The process of writing itself, much like other scientific practises, is iterative (Douglas et al., 2004). Through the process of writing, the author becomes more familiar with what they are writing and the form that it takes. Understanding the purpose of the communication as well as the needs and expectations of the reader is crucial to writing well and contextually. Douglas et al (2004) compare this process with that of the Engineering Design Process, similarly these processes are found throughout areas of Science and are particularly common in experimental design. Douglas et al (2004) raise an important and often overlooked point that student writing is often written to cater for two audiences, the client and the assessor. This presents a dilemma to students as each of these readers will have different expectations and requirements of the communication piece. For example, a science student writing a research report may be trying to cater for both a novice, unfamiliar with the field, whilst also trying to convey a more advanced level of understanding of content for their assessor who is perceived to already have a deep understanding of the material. The assessor, although supposedly invisible to the student, has a set of expectations that differ to the client that the student is writing for (Douglas et al., 2004). The difficulty with this situation is that the student may be inclined to try to produce a piece of work that accommodates both audiences but by doing so loses authenticity for either. It is important to consider that the purpose of writing in industry is to communicate ideas while the purpose of writing in an educational setting is to assess the effectiveness of the communication itself, and that this difference must be kept in mind when designing explicit and clear assessment criteria.

How then do we alter this viewpoint so that educational designers and students alike can see the activity of writing as one of communication rather than the assessment of writing skills? In problem-based learning where students are given the opportunity to work on real world problems, is this issue addressed, or even mitigated? This is possible if assessment is thoughtfully designed to embed the communication of a solution to a posited problem, rather than an assignment merely being a demonstration of writing ability (Douglas et al., 2004). If students are given opportunities to discuss solving problems/design experiments with experts in industry, then there should be greater motivation to communicate the solutions/designs through their writing. In this way the assessors become a secondary audience rather than a primary one. This issue is compounded by factors of student motivation in relation to the intended audience. When students are aware that their communication will be viewed by an industry representative, they are highly motivated to communicate effectively. However, when students are writing for an audience that it is an assessor the quality of writing is decreased (Douglas et al., 2004). In effect, communicating with industry sets an aspirational level higher than that of communicating with an academic, there is value to be had for students communicating with industry experts and perhaps the student's perception of communicating with academics is less so.

Writing is a "constantly evolving, contextually mediated and determined practice, influenced by social and institutional histories, conventions, and expectations" (C. Anson, 2008, p. 114) Therefore, to ensure that our students see the relevance of the writing tasks they do and therefore engage in a meaningful way, we need to create context specific and relevant opportunities to practise their writing.

1.16 Questions and Answers

When considering how communication education is practiced two questions formed and throughout the process of this literature review the answers have also materialised around which the aims of this project, and the principles which subsequently underpin the artefacts' design and use, have been developed. Firstly, *why do communication skills matter*? What will be achieved by enhancing the communication skills of our students rather than focussing on discipline specific content and knowledge? This will not result in the reduction in the amount of time spent on discipline specific material, context is integral to communication, providing students with an overarching picture of their field and allowing them to understand the relationship and importance of each aspect of the discipline. In the process of moving students from novice to expert, educators must support them to develop a "deep understanding of the concepts, principles, and procedures of inquiry in their field, and their framework for *organizing* this knowledge. Experts also know when and how to apply particular aspects of their knowledge…… depth and organization of knowledge enables experts to notice patterns, relationships, and discrepancies that elude novices. It allows them to quickly identify the relevant aspects of a complex problem or situation, make inferences, and draw conclusions" (Kober, 2015, p. 59). Secondly, if we all communicate in various ways throughout our daily lives, then *why do we need to teach our undergraduate students specific communication skills*? I think the answer is that we don't need to teach skills that they have already developed, however there is an issue of transfer and educators play a role in allowing students to identify the communication skills they already have and can apply to a variety of contexts. By approaching science education more holistically and providing opportunities for students to consider the discipline of science and its social context educators are more likely to promote a deeper understanding of the nature of science and its value to society. It is through the inclusion of multiliteracies that these skills can be applied to a new context, building upon what already exists and creating opportunities for authentic connections between one context and another. Science "comes with ethical obligations to do it right. There are obligations that the practice, communication, and application of science are conducted with integrity and human compassion. Inadequate or improper communication of science has consequences" (Priest, Goodwin, & Dahlstrom, 2018, p. viii). It is our responsibility as educators to ensure that future scientists understand the importance of communication and we can only expect this if we show them.

Therefore, informed by an understanding of current practices in science education and the role of disciplinary literacy in developing expertise, the aims that follow will be used to guide this PhD research. These aims have grown out of the research questions posed earlier in this thesis and have been framed to enable an approach suited to the context of science education in practice.

1. ***To determine current assessment practice in relation to written communication in undergraduate degree programs.***
2. ***To determine the resources students require and deploy to develop Disciplinary Literacy during their undergraduate degree program.***
3. ***To design and implement e-learning modules that support the development of Disciplinary Literacy (the artefacts).***

4. ***To develop a theoretical framework based on Disciplinary Literacy to establish good practice in developing educational materials in science education with a focus on improving communication skills between scientists and their target audiences*.**

Aim 1 provides the context to understand how a wider variety of communication skills can be embedded into curricula. By describing current assessment practices. While Aim 2 allows analysis of how these interact with student learning so that we can begin to identify areas for reform through a framework as posed in the original research questions of this thesis. Aim 3 will enable clarification of the processes involved as students develop Disciplinary Literacy throughout an undergraduate degree program. The e-learning modules in conjunction with associated assessment tasks will allow for measurement of communication skill development that is currently not well understood by teaching staff and will address the second research question of this thesis. Finally, aim 4 will allow educators to understand the process through which Disciplinary Literacy develops, providing a scaffolded approach to building inclusive educational materials. This broadly addresses the final research question posed by this thesis as to how a Disciplinary Literacy framework can be applied to remove various factors limited wider student inclusion.

A variety of approaches that have been informed by the preceding literature review are used to explore and develop these aims. These include examining the instructional material (Statement of Assessment Methods, Assessment Instructions, Rubrics) in combination with informal discussions with academic staff involved in designing the assessment activities to build a representation of the target audience (scientist within the discipline, scientist outside of the discipline, non-scientist professional and non-scientist public) and the opportunities to develop disciplinary literacy skills. A comparison of global practices will be undertaken through examination of literature to establish an understanding of current assessment practices in higher education with respect to developing scientific communication in undergraduate degree programs. The way in which students utilise available academic resources will be measured via student surveys, with comparisons between undergraduate and postgraduate cohorts to evaluate any differences in behaviour that may influence the development of disciplinary literacy. This will be examined in the global higher education context through a comparison to literature published in this field. In this instance, postgraduate cohorts will be defined as students undertaking a research doctoral degree.

By using Articulate Storyline 3 software to design e-learning modules that scaffold the learning required for students to complete written assignments in the genres of *journal article*s, *impact statements* and *discussion papers*, this project will establish a resource for educators to use in the development of science communication education. The module design will be developed using three approaches to develop writing skills, product-based, process-based and genre approaches. Observations and analyses of changes in written communication will be used to inform and interpret the learning relationship that develops through the use of the e-learning modules as a mode of incorporating communication into science curricula. This will form the basis of the theoretical framework to understand why disciplinary literacy is a powerful skill to develop expertise and increasing access to the wider public, not only in the discipline of science but more widely across the academy.

CHAPTER 2 : THE IMPORTANCE OF DISCIPLINARY KNOWLEDGE

This chapter builds from the literature review, with attention to multiliteracy and literacies in context, to summon the value, role and relevance of the discipline in consideration of literacies. I explore how the elements of a discipline define it and how they interact to produce disciplinary identities, with a focus on scientific identity formation. Additionally, I consider how literacy or rather, the lack of it, limits access to disciplinary knowledge and how these barriers can be addressed and used to inform teaching and learning practice in developing expertise using multimodal and multiliteracy approaches.

2.1 Learner Identity

Science Education Researchers occupy a unique position in terms of multiple literacies, combining a rich culture of both scientific and educational languages and ways of thinking. However, this juxtaposition of identity, whereby one is an accepted member of neither traditional academic community but an emerging academic community, may provide insight into how to support students to develop their own discipline identity.

We must acknowledge that we tend to pigeon-hole ourselves with disciplinary identities and so do students, but many of our Science graduates will find employment in areas outside of traditional scientific roles. The recent Graduate Outcomes Survey results (Social Research Centre, 2018) indicate that fewer than 45% of Science graduates will find employment as a scientific professional. Where does this leave our students in terms of their discipline identity as a Scientist? And how might *disciplinary literacy* be used to improve student outcomes, both in finding employment as a scientific professional and in other fields?

An important aspect of being able to construct content knowledge within a discipline is being able to understand the associated linguistic, cognitive and cultural text-based practices and processes (Moje, 2007). It is these innate differences in the development of the disciplines that require differences in the way texts are managed, and therefore the way that reading and writing are performed (Shanahan & Shanahan, 2012). It is these innate differences within the disciplines that lead us to think of ourselves as being part of the disciplinary culture, the way that I consider myself a Biologist defined by a way of thinking, acting, writing and reading as a Biologist. It is this disciplinary culture that has informed the design and context of each of the artefacts presented here. Focussing on communicating with three distinct groups or audiences the artefacts focus students on how to communicate as a Biologist with others within the discipline and those outside of it. By considering how to communicate with non-scientists students must think more deeply about how Biologists read and write, carefully constructing prose to ensure that it can be interpreted by someone without specific disciplinary knowledge. Only when we consider how to communicate disciplinary ideas outside of that discipline can we hope to reflect on the disciplinary processes that are involved, unpacking the thinking, reading and writing that forms the culture.

Pawan and Honeyford (2008) suggest there are three literacy forms that determine the academic success of university students, the initial literacies they possess at enrolment, the level to which these literacies enable them to engage with the academic community within the university and the ways in which new literacies are developed based on existing skills and allow integration into the academic community. It is a combination of these skills that enable "students to arrive at a personally- as well as contextually-defined understanding and conclusions regarding the material" (Pawan &

Honeyford, 2008, p. 27). In other words, developed disciplinary literacy enables students to think as a Biologist and see themselves as a Biologist.

The link between personal identity and literacy is strong, with the ways of knowing and being within a discipline tied to the language that is used (Gee, 2004). This makes disciplinary literacy very powerful, particularly in an academic context where novice students must develop disciplinary literacy in order to access content knowledge. As educators it is our responsibility to ensure equitable access for all students, including supporting them to develop disciplinary literacies which in turn will improve access to content knowledge. The challenge that we now face is how to support students to develop a broader range of literacies that enable them to feel they belong to a discipline as well as have the understanding and confidence to apply these skills to other disciplines. I believe the answer to this issue will be found in the way we teach disciplinary literacies. Are science educators aware of their own disciplinary literacies or are they so ingrained that they are just part of their identity? Research indicates that the teaching practices of STEM educators in higher education institutions are shaped by their experiences as a student, teacher, researcher and from their personal lives (Oleson & Hora, 2014) therefore, it is likely that these experiences shape the way educators approach their teaching of disciplinary literacies. Furthermore, there are two educational approaches that are likely to emerge from the experience of educators, those that define the discipline by the way it is taught and those that instead value learning objectives that transcend content, the latter being more likely to consider the importance of building context rich understanding with their students.

As described earlier in this doctorate, many Science Educators are experts in their field of scientific specialisation with a rich background in the scientific process, and therefore highly literate in the language and processes of the discipline. However, until recently it has been unclear how to best guide the development of these literacy skills in novice students. Shanahan and Shanahan (2012) have highlighted the importance of the apprenticeship of students by experts using explicit teaching of disciplinary literacies. As Science Educators how are we to proceed to best support our students in developing disciplinary literacy?

2.2 Disciplinary Literacy

As a Science Education Researcher, I have witnessed the importance of developing an understanding of language used in a variety of disciplines. As tertiary educators we expect our students to arrive at University possessing a certain level of base literacy in reading, writing, using technology, speaking, listening, behaving and learning amongst others, that will enable them to participate and demonstrate their learning. Students are expected to commence their tertiary studies with the literacies necessary to successfully navigate complex language and ideas, enabling participation and contribution to the academic community. Additionally, each disciplinary area carries an expectation that students will further develop those skills in the context of the specific discipline they are studying, regardless of the fact that a first-year student is likely to be studying several different disciplines simultaneously.

Disciplinary literacy can be defined by the language and symbols one needs to construct knowledge and be part of any particular academic discipline (Rainey, Maher, Coupland, Franchi, & Moje, 2018). Literacy practices differ between disciplines in part due to the history of how they have developed as well as the natural differences between them. Not only is the content varied between disciplines, but the way that content is discussed, considered and written about is highly dependent on the discipline. Combined with epistemic practices that value particular social interactions and communication help to legitimize particular knowledge claims of a discipline (Kelly & Licona, 2018).

Hidden in our assessment practices are the expectations of a wide variety of disciplinary literacies that are rarely discussed explicitly with students. We routinely expect students to perform writing tasks situated within the discipline in order to assess their understanding of content, however not only must Biology students understand the Biological concepts they are taught, they must also be aware of the ways of thinking and communication practices used in the discipline in order to convey their conceptual understanding as it is traditionally carried out within the discipline (Paulson, 2012). We expect our students to be literate in finding scholarly resources relevant to the discipline and specific context they are investigating, however research suggests that scientists go about this in a way that differs from other disciplines (Shanahan & Shanahan, 2012) yet we rarely discuss this detailed process with our students. Pawan and Honeyford (2008) suggest that students are often overwhelmed by the sea of information they have access to and can sense that some forms are valued more highly than others, but they are unsure of the criteria used to make such academic decisions. I have used the artefacts, which are integral to the research questions I have summoned in this thesis, to configure clarity to students, to reveal the assumptions hidden within words and phrases like "academic standards," "benchmarks" and "quality assurance". By explicitly stating the purpose an audience of the writing students can gain insight into their own learning as well as the expectations of future employers. By explaining to students the purpose and value of writing tasks, they have an opportunity to engage and understand their own learning. Educators can provide a life-raft and a paddle to help students navigate the sea of information available to them, providing clearly defined outcomes as are modelled in the artefacts. Students arrive at Universities with well-developed literacies resulting from their experiences and background (Pawan & Honeyford, 2008), many of which may be at odds with the way of thinking and learning that is expected of them in a tertiary educational institution. Our role as educators is to support students to develop their identity as a community member of their discipline, providing explicit direction on the development of disciplinary literacy practices.

The discussion of literacy practices within a discipline can be configured in two ways: content area literacy and disciplinary literacy. I have already acknowledged that students arrive at University with a variety of literacies tied to their background experiences, some of which may be general reading and writing literacies. Content area literacy would assert that students can use existing generic literacy skills in all content areas in order to extract the relevant information, while disciplinary literacy would take into account the social and cognitive skills possessed by the student to understand the discipline more broadly and therefore recognise that students may need support to develop literacy skills in a context specific way. Disciplinary literacy recognises that the literacy skills and content are inextricably linked and defined by the discipline (Fang & Coatoam, 2013). Hynd-Shanahan (2013, p. 93) describes the differences as "*the aspect of literacy that is being emphasized*". Both these perspectives are valuable when we consider how students develop literacy practices.

At this point, it is useful to consider how students learn. Lave and Wenger (1991) posit that learning must be viewed as a situated activity, that we cannot separate learning from the social community in which it occurs. The term coined by Lave and Wenger (1991) *Legitimate Peripheral Participation* draws attention to the fact that learners are members of a community of practitioners, and through apprenticeship by experts develop an understanding of the sociocultural practices that form such a community.

This concept aligns with the understanding of disciplinary literacy. Students cannot develop an understanding of the broader concepts without developing discipline specific skills and therefore will be unable to become a participatory member of that academic community.

By viewing learning as a social process, educators can reimagine the way in which students develop disciplinary literacies by encouraging opportunities for disciplinary experts to model the social elements. Focussing on the social opportunities provided and doing so in a way that is reflective of authentic experiences, meaning that long before they are employed in their discipline, they already have developed an understanding of the cultural norms of that discipline. They can think, act, read and write as a scientist. The verbs in this sentence are meaningful, provoking the question, what does it mean to 'act' like a scientist? How do they think, read and write in the 'real world' and how might this be best translated into authentic learning experiences for students?

In his book *Curious Minds: How a Child Becomes a Scientist*, John Brockman (2005) speculates that the discipline influences from a very young age and those that raise to great heights within it have positive and rewarding experiences during childhood that contribute towards their identity as a scientist,. With childhood experiences acting as an inoculation of sorts whereby this way of thinking and behaving is normalised and ultimately valued over others.

All literacy is performed within a specific context, for a specific purpose and a specific audience, thus literacy practice cannot be removed from the specific domain in which it is carried out (Moje, 2015). The notion of teaching scientific reading and writing is often referred to as separate to teaching specific scientific content in the literature, considered as something “other” than the science we are experts in teaching (S. Rowland, Hardy, Colthorpe, Pedwell, & Kuchel, 2018). However, the link between understanding scientific content and performing scientific communication is well established (Bean, 2011).

Educators have developed an understanding of the importance of bringing specific content together with writing instruction and two distinct groups have formed in this area, the larger and more recognised, Writing Across the Curriculum (WAC) which focuses on the importance that language development and writing plays on the conceptual understanding of content, promoting deeper learning. And Writing In the Disciplines (WID) which focuses on the nuances of discipline specific genre, learning to write in the styles accepted in the field (Bean, 2011). However, it is when both approaches are combined that teaching literacy skills becomes purposeful and meaningful to students. When abstracted from their purpose, and removed from the very context that gives them meaning, disciplinary literacy practices are reduced to tasks or methods to be memorised (Moje, 2015). Moje (2007) describes typical high-school or university settings, in which subject matter is presented as ‘disciplinary slices’, and notes that this tradition of experiencing disciplines as separate may lead students to attribute differences in disciplinary thinking and cultural practices as artefacts of particular teachers or teaching spaces. By combining WAC and WID approaches students may be provided with multiple opportunities to apply the literacies of their discipline in a greater variety of contexts, reducing the impact of individual teachers or classrooms.

2.3 Epistemic Practices

Learning scientific content is intertwined with learning the language and social practices that members of the discipline engage in. As students engage in scientific practices such as reading scientific material, performing experiments and describing results to others, they further develop the skills required to participate effectively within the scientific community (Kelly, 2014). The ways in which students access scientific knowledge is usually tightly controlled by teachers or scientists already members of the discipline and therefore the equity of access may be of concern. The use of language and discourse specific to the field plays a role of significant interest to me in that it reinforces a culture of elitist practices whereby those who cannot speak in the accepted language are excluded from participating. Kelly and Licona (2018) describe this enculturation as the epistemic practices which are “interactional (constructed among people through concerted activity), contextual (situated in social practices and cultural norms), intertextual (communicated through a history of coherent discourses, signs and symbols), and consequential (legitimized knowledge instantiates power and culture). Through application of these epistemic practices, communities justify knowledge claims.” (Kelly & Licona, 2018, p. 140) By re-thinking the epistemic practices within the discipline of science we can more broadly engage a wider community of scientists and communicate scientific knowledge to a wider range of audiences. However, this issue is not just up to practising scientists to resolve, in fact the solution lies in how those scientists develop their disciplinary literacy and experience epistemic practices throughout their education and into their careers. The difficulty is that who will make this change since teachers of science have also been inducted into the discourse of their discipline and rarely will have the resources needed to enact critical change for their students (Hanrahan, 2006).

2.4 Literacy Development

In Shanahan and Shanahan (2008) innovative paper on Disciplinary Literacy they propose an explanation of increasing specialisation of literacy development as a pyramid of increasing complexity, where students develop a broad and basic understanding of written texts in general during the early years. This is then developed during the middle years to narrow the range of texts and focus on a deeper understanding of how to decode texts and respond in a variety of reading situations. While disciplinary literacy is a narrow and targeted skill developed in the context of a particular discipline or technical area. These high-level skills are difficult to learn and are rarely taught well, if at all at the tertiary level (Emerson, 2017; Mercer-Mapstone & Kuchel, 2015; Shanahan & Shanahan, 2008). The progression towards disciplinary literacy implies both a narrowing and sophistication of literacy skills and is particularly interesting in its potential to impact on communication outside of the discipline.

This provides two challenges to science educators:

- How does the educational practitioner effectively develop students' disciplinary literacy?
- How is each students' literacy best developed to empower them to communicate effectively across disciplines with others outside of their field?

Again Shanahan and Shanahan (2008) have provided some insight into how to resolve this dilemma. By analysing how experts in each field performed reading tasks they were able to identify differences in literacy practices between disciplines. By building upon this idea and reflecting upon how scientists approach reading and writing in a variety of genres, we may be able to respond to our students' needs by teaching these processes explicitly and providing instruction and scaffolded opportunities for practising these skills in a supported low-risk environment. Tara Brabazon (2020 9:35) reminds us that "writing is not an art, writing is a craft." As educators we must remember that there are skills to be taught and learnt in how to write well. Writing is not an elusive art form. Each discipline, indeed, each genre has its own style meaning that where there are reproducible approaches towards the construction of writing in context, much like a sculptor uses their tools in specific ways, there are methods to writing.

Emerson (2017) has explored the experiences of scientists in their development of writing skills and identified that the vast majority experience the cognitive apprenticeship model, as described by Bury (2015). The cognitive apprenticeship model posits that “learning by doing and reflecting alongside proficient practitioners in authentic environments [serves] as a process of enculturation into practitioner culture” as an effective strategy for learners to develop disciplinary literacy skills (Bury, 2015 para. 1). Whilst this seemingly describes the process by which many scientists learnt to write themselves and may prove useful in the development of post-graduate writing skills, it is not a suitable practice for use in an undergraduate environment with large class sizes. This was an important factor to consider in developing the artefacts to enable wide uptake and use in undergraduate classes. Therefore, each module was designed to enable students to complete activities numerous times and develop writing skills over time. This was combined with providing authentic examples of literature, both published and synthesised. The selection of examples when appropriate was sourced from research academics known to students in order to strengthen the relationships between staff and students, building upon existing relationships and encouraging enculturation into the academic community, effectively enabling a large cohort of apprentice scientists performing assessment activities modelled on genuine scientific work.

2.5 Metacognition

Understanding the strategies used to read and write within a discipline are key to developing disciplinary literacy. Douglas Hacker (2018, p. 222) notes that "because writing requires the active production of ideas, the writer must be explicitly engaged with monitoring and controlling their writing, but there are some language processes that occur so rapidly, they remain implicit". Without the experience and confidence in language choice and usage writing becomes significantly more challenging. As a novice moves towards expertise and becomes more familiar with appropriate language use within a discipline research indicates that they will be able to spend more effort on the production of ideas rather than thinking about appropriate language choices. Sampson and Walker (2012, p. 1444) also suggest that "writing can help promote and support metacognition and a deeper understanding of the content because, 'written language, stabilized on paper, invites kinds of reflection not so natural to oral exchanges".

2.6 Writing is Thinking and Learning

Whilst there is considerable focus in undergraduate science education on learning how to write (Christian & Kearns, 2019; Moskovitz & Kellogg, 2011; Yang, Stockwell, & McDonnell, 2019) there is less emphasis on the role writing performs in the processes of thinking and learning in the sciences (Gere, Limlamai, Wilson, MacDougall Saylor, & Pugh, 2019; Reynolds, Thaiss, Katkin, & Thompson Jr, 2012) with contention around the efficacy of writing to learn programs (Gere et al., 2019) in part due to the variation of methodology employed by educators in assessing these types of curricula.

Freedman, Hull, Higgs, and Booten (2016, p. 1389) suggest that "where writing is concerned, our present moment is both the best of times and the worst of times" such that the opportunities to engage with writing and the tools with which to write have become increasingly available en masse. However, this has not resulted in the practice of writing being taken up in the same way. “Even in highly literate societies such as the United States, opportunities to engage expressively, creatively, and practically in writing are unequally distributed” (Freedman et al., 2016, p. 1389) thereby excluding already marginalised individuals (and groups) from participating in the community. In the context of this research project those groups already marginalised through lack of scientific literacy are further excluded from reading, writing and thinking scientifically, resulting in an ever-widening gap between scientists and the public.

As Scardemalia and Bereiter (1986, p. 790) describe, success in using writing-to-learn curriculum assumes “that the writer is engaged in active reprocessing at the level of concepts and central ideas”, indicating that particular patterns of thinking are related to the production of written texts. This means that not all writing tasks will result in high-quality learning experiences or even require much thought on occasion. In order to actively process concepts and ideas through writing, the writing tasks must be meaningful and designed to challenge and engage the learner rather than simply reiterate rote content. Some writing skills will move between genres. However, students must learn the value of the different genres and develop the skills to be able to think and perform in a variety of genres.

> Here’s the rationale for writing every day: Writing is thinking.…. Because writing is thinking, brilliant thoughts do not just appear on the page after long hours of arduous musing on a subject. In my experience, the best ideas almost always come about through the act of writing itself…. If the smartest person in the world cannot learn to write, then she won’t be a successful academic. Period. (MacPhail, 2014 para. 5)

The artefacts developed, aligned and meshed with this research project directly address this dilemma by focussing on the key aspects of writing within the discipline of science. By making the relationship between reading, writing and thinking visible the artefacts provide a point of access for those without the necessary disciplinary literacy to read, interpret, and contribute to scientific literature. The artefacts open the door to scientific literacy by scaffolding writing within the discipline. Additionally, by providing opportunity for review and practise of a variety of language types and writing genres, the artefacts have the ability to enact a cultural change in the way scientific language is used, normalising its use so that it becomes more widely accessible to a variety of people. Examples that depict this scaffold are provided in Figures 2.1 and 2.2 below, which demonstrate how students are guided in linking reading and writing development and the incorporation of authentic examples of scientific texts.

It is important that we consider why we need to explicitly teach reading and writing in the sciences and to understand this in context we must investigate how current practices have evolved. The next section addresses how the teaching and learning of science has developed throughout history. It is crucial that educators understand how these processes have developed and the curiosities that have been produced due to the historical context of the discipline. Only by understanding what has occurred in the past can we hope to improve the future of science teaching and learning.

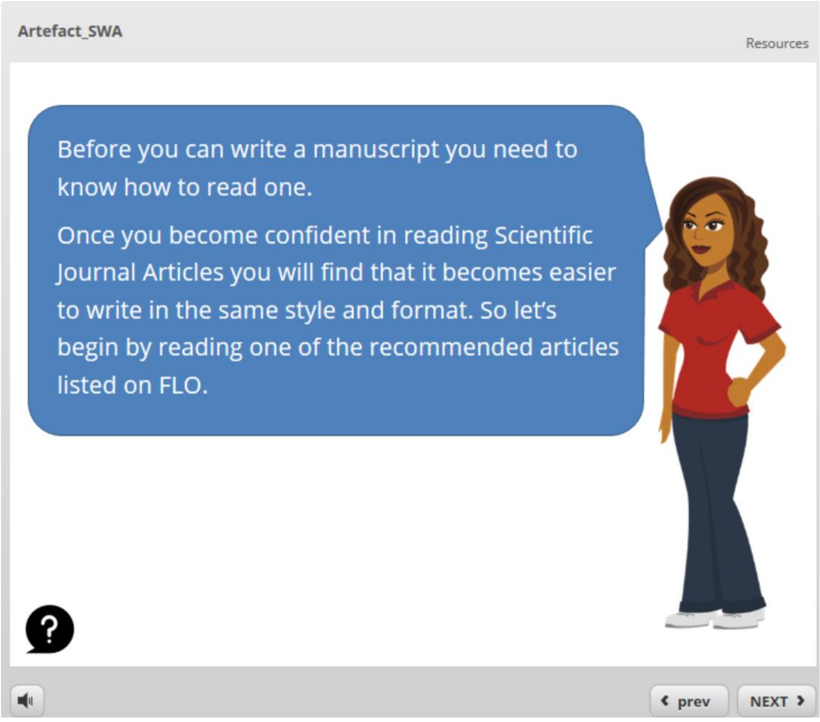

Figure 2.1 An excerpt from the Scientific Writing Assignment artefact depicting the e-guide linking the importance of scientific reading and writing.

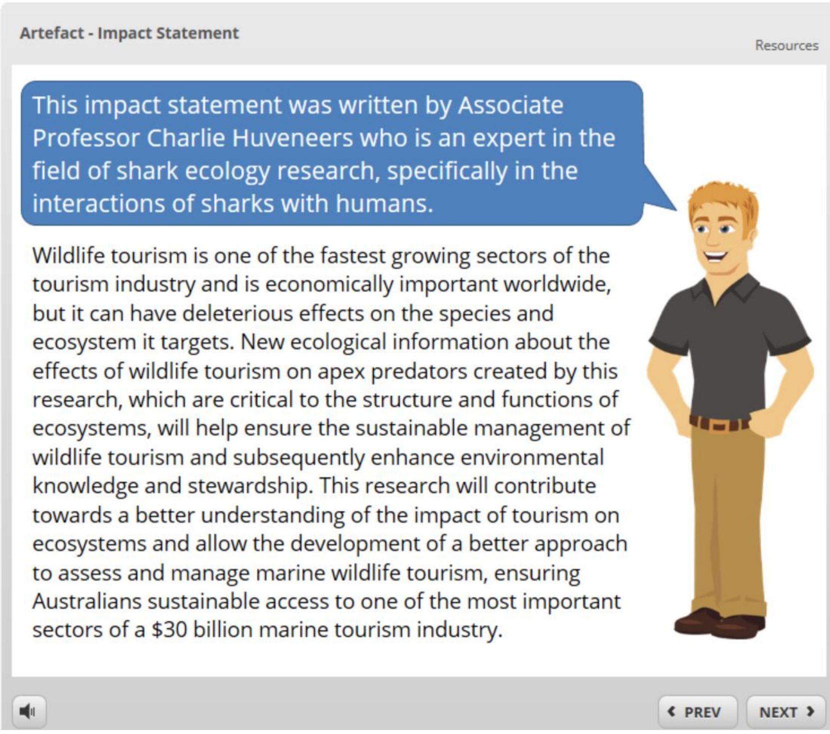

Figure 2.2 An excerpt from the Impact Statement artefact depicting the e-guide presenting an authentic example of scientific literature in the genre students are learning.

2.7 Historical Context of Science

Diversity among the scientific community is important for three main reasons. 1. Equity ensures that everyone has an equal opportunity to study and work in the field that they choose. 2. The discipline is losing women who may make a significant contribution because they are choosing other subjects instead of science. 3. Scientific endeavours will only be improved through an increased range of viewpoints which only comes with diversity (Clark Blickenstaff, 2005). By encouraging and enabling wider participation we can ensure that more people from a variety of backgrounds are able to contribute to scientific solutions as well as feel as though they are part of the scientific community. By addressing these issues, we may be able to encourage participation of women and other minorities in the sciences.

In this thesis the term minorities is used to broadly describe those who are inherently disadvantaged due to gender, race, disability and/or socioeconomic status. As described by Crenshaw (1990, p. 1244) the "intersection of racism and sexism factors into [WOC's] lives in ways that cannot be captured wholly by looking at the race or gender dimensions of those experiences separately", similarly a single aspect of a minority will not be the focus of this thesis, rather how inclusion and open communication can provide a basis for greater access to science for all minority groups.

Elliott (2016, p. 187) suggests that "Our classrooms are where our students begin their journey as scientific specialists" however, I disagree. The culture of the discipline of Science is already clear to students at an early age during primary years (Miller et al., 2018), and by the age of 13 students are likely to have already made their decision about a future in the field (UNESCO, 2017). To enable more young women to participate in the pursuit of science we need to change our approach to teaching to be more inclusive. Throughout this thesis the term inclusion is used to describe the participation of minority groups in scientific endeavours, increasing the access to the discipline and encouraging members of minority groups to become scientists themselves.

The traditional focus of science is represented as highly mathematical and individualistic. Fogg-Rogers and Hobbs (2019, p. 2) note that this leads to “girls and women therefore hav[ing] lower social identification with STEM and lower self-efficacy that they will perform well in STEM”. Research indicates that by demonstrating the contributions of minorities in science, women's interest and participation in the discipline can be increased (Diekman, Clark, Johnston, Brown, & Steinberg, 2011), which may lead to changes in the stereotypes of who belongs within a scientific discipline (Boucher, Fuesting, Diekman, & Murphy, 2017) and increase the rates of minorities that are retained with fewer ‘leaking’ from the disciplinary pipeline (Liu, Brown, & Sabat, 2019).

One factor that is equally important yet rarely discussed is the historical context of science as a discipline. Science is deeply ingrained with masculine characteristics (Keller, 2003) which is likely impacting the engagement of women with scientific content. Objectivity is typically considered a masculine characteristic. Scientific thinking is often described as objective thinking, supposedly removing the influence of the observer by removing bias, prior beliefs and presuppositions (Niaz, 2018). The notion that science is objective is based on the traditional and well-known scientific method following the process:

1. Make an observation,
2. Ask a question,

3. Form a hypothesis (informed by scientific laws),
4. Make a prediction based on the hypothesis,
5. Test the prediction (often in the form of an experiment),
6. Interpret results

None of the steps in the process of scientific investigation are gendered by design, therefore any bias is cognitive. These steps contribute towards objective knowledge about how we understand the natural world. Objectivity is embedded in each step of the scientific method by the perceived neutrality of scientific statements based on observational and experimental evidence (Niaz, 2018). However, observations and experimental evidence being free and independent of any values held by the observer is nonsense. In fact, every scientist must make value judgements in the course of scientific inquiry, carefully weighing the evidence of their research and deciding its value. Much of scientific research is driven by quantitative data that is seemingly independent, however as we are reminded by Alvin Toffler, the renowned writer and futurist that “you can use all the quantitative data you can get, but you still have to distrust it and use your own intelligence and judgment” (Ginter, Duncan, & Swayne, 2018, p. 259). Values are intrinsically subjective and biased, and to perform scientific research responsibly, values must be taken into account when considering how and why all research is performed (M. J. Brown, 2019). But the notion of scientific objectivity persists, particularly when considering the ethics of science and is highlighted by the following quote from Resnik (2013, p. 153):

> Scientists should strive for objectivity in research and publication, and in their interactions with peers, research sponsors, oversight agencies, and the public. If one assumes that truth and knowledge are objective, then this norm also helps to promote science’s epistemic goals of truthfulness and error-avoidance.

> Strategies and methods designed to minimize bias and error in research, such as good record-keeping practices, the peer review system, replication of results, and conflict of interest rules, are based on a commitment to objectivity.

This commitment is widespread, with researchers being taught to make their findings open (via publication), think critically about results (by designing experiments to falsify theories) and to reduce bias (ensuring the use of strict scientific method) (Boulter, 1999). The notion that scientific results are impacted in some way by the biases held by researchers performing experiments is viewed as profoundly distasteful by the public and whilst this is blamed on researcher ethics or bias, perhaps is more indicative of the mechanisms of science and the disciplinary specific jargon scientists use to communicate their findings (Boulter, 1999).

2.8 Information Literacy in Science

Science is undoubtably one of the most information rich disciplines in terms of specialised content and language required to engage well within the academy. Bawden and Robinson (2017) describe how the requirements of information literacy are specific to the context in which they appear and challenge the notion that generalist information literacy skills are transferrable between disciplines. They build on the ideas described by Lloyd (2003); G. B. Thompson and Lathey (2013) and Pinto, Pulgarín, and Escalona (2014) and suggest that while there are likely to be similarities in some aspects of information literacy between disciplines, the context of the information creates fundamental differences between concepts and the relationships between them. However, whilst there may be some distinct differences that are specific to each context, the underlying goal of understanding the relationship and connections between concepts and information remains the same across disciplines, which is supported by numerous efforts to effectively teach generalised information literacy skills (Mi, 2016; Mullins, 2016; Robinson & Bawden, 2017).

As stated by Alison Head, Founder and Director of Project Information Literacy in T. E. Jacobson and Mackey (2017) " For decades, educators – particularly academic and school librarians – have devoted tremendous effort and resources to teaching students how to navigate increasingly complex information systems in the digital age. Their task is to teach students how to be discriminating information seekers and consumers as well as ethical content producers." This remit is the same, regardless of context. Thus, while the context is vitally important in engaging students, the strategies employed to develop literacy skills are highly transferrable. Given that generalised literacy skills are considered highly transferrable this suggests that as context varies, the application and embedding of information literacies can be reasonably applied to various situations (Forster, 2017). In much the same way, other skills such as written communication, have the potential to be transferred between contexts.

The following two sections explore the influence of language on the development of disciplinary context and how this impacts science communication and understanding. Language encompasses a wide range of communication and in this instance will also include the language of mathematics, which is deeply embedded in the disciplinary literacy of the sciences broadly.

2.9 The Role of Mathematics

The discipline of science is content focussed, placing most importance and value on observations which over time become known as facts. Central to success in studying science is the ability to observe, interpret, analyse, and quantify data, put simply Math. All scientists, regardless of discipline will evaluate evidence, with mathematics and computational thinking forming the foundations in science enabling the symbolic representation of results (Osborne, 2014). Thus, we can consider mathematics as the language used to describe scientific results and would expect that all scientists be proficient in the language with the role of advanced mathematics being integral to modern science. However, this has not always been the case, with historical examples such as Michael Faraday, a physicist and chemist who discovered many phenomena including the basic principles of electromagnetism but who knew little to no advanced mathematics (Marcus & Davis, 2013).

Mathematics, often seen as a tool to explain science has a disciplinary literacy of its own, enabling mathematical reasoning and thinking to be applied to solving scientific problems (Wong & Dillon, 2019). Given the complexity of the discipline it is unsurprising to find that for many students who aspire to become scientists, anxiety towards mathematics can prevent them from doing so (E. O. Wilson, 2013). However, many of the students that do enter undergraduate science courses will have low levels of mathematical literacy and struggle, as described by Koenig (2011, p. 1) “These students are unlikely to be able to carry out many of the basic mathematical approaches, for example unable to manipulate scientific notation with negative powers so commonly used in biology, measurements of the length of a nerve cell or the concentration of a hormone in the blood. They are also unable to rearrange simple equations or to reliably use concepts such as ratio and proportion to calculate dilutions of solutions”. In many cases for example in nursing, peoples’ lives depend on being given correct dosages of medicines, calculating dilutions and drip infusion correctly is critical.

However, quantitative data has its limitations. Whilst statistics provide a narrow interpretation of observations that allow for comparison, it does not explain why or how a phenomenon occurs (Nielsen, 2004). Therefore, while mathematics is important and maintains a foundational place in science there are other factors that must also be considered in the development of scientists and the value placed on quantitative in favour of qualitative data.

2.10 The Role of Language in Science

We often use the terms ‘hard’ and ‘soft’ sciences to describe the natural sciences (Chemistry, Physics and Maths) and social sciences (sociology and philosophy) respectively, which may be considered another gendered term that has found its way into scientific culture. Reflecting upon why this might be the case Keller (2003) considers the relationship between science and nature, whereby nature is viewed ubiquitously as female. Interestingly many sub disciplines of Biology are referred to as ‘soft’ sciences, often those associated more closely with nature.

Within the discipline of Biology there appears to be a lesser requirement for a strong mathematical underpinning, rather a reliance on biological language to describe observations with “….introductory biology students learn[ing] more vocabulary words than students taking an introductory foreign language course” (Bravo & Cervetti, 2008, p. 132). Biology is steeped in a rich history of language with many terms derived from classical Latin. Understanding this difference between Biology and ‘hard’ sciences is vital in discovering the importance of language to wider engagement in the sciences, perhaps even breaking down the notion of ‘hard’ and ‘soft’ sciences altogether.

Gender stereotypes have traditionally positioned women as more language centred, positing that they are more talkative than men and whilst research indicates this is not true (Onnela, Waber, Pentland, Schnorf, & Lazer, 2014), the myth remains. Language is inherently social, both in conversation and in writing, we use language to communicate with others. Women and men on average communicate verbally approximately the same amount however there appears to be a difference in the way each gender uses language. Newman, Groom, Handelman, and Pennebaker (2008) suggest that men are more likely to use language to convey information, while women are more likely to use language for social purposes. Might this gendered association impact participation of women across the disciplines and enhance it in Biology, a typically language-rich science?

There are a variety of issues impacting the participation of women in science, however in undergraduate Biology courses we see a significant difference in the number of women participating with almost twice as many women as men studying biological sciences at university (Australian Government Office of the Chief Scientist, 2016). Unfortunately, we do not see this translate into more women working in science related fields (Elliott, 2016). Literature suggests the main factors influencing this are based on gender normative expectations (Eddy, Brownell, Wenderoth, & Allen, 2014; Grunspan et al., 2016) as there are no significant differences in the ability of men and women to perform in the discipline (Australian Government Office of the Chief Scientist, 2016; Clark Blickenstaff, 2005).

With more women participating in biology we see more women graduating in the discipline, sometimes surpassing the number of men (Elliott, 2016). Of those graduates who go on to an academic career, women will be disproportionately represented in the academic community as teaching focussed (Dever et al., 2008). This is likely a contributing factor towards the prolific community of science educators publishing in the discipline of biology. And it is from this biology educator community that we can learn lessons in developing disciplinary literacy amongst our students to apply more broadly towards science education, and work towards engaging more broadly with the community.

2.11 The Deficit Model of Communication

Scientists steeped in a rich history of their discipline typically have a well-developed understanding of the requirements of communicating with each other, with the most accepted form of communication the peer-reviewed journal article. Publication in peer-reviewed journals is the only form of communication that is consistently engaged with collectively amongst the scientific community (Suleski & Ibaraki, 2010). However, this form of communication is rarely utilised by the general public, with reliance on journalists to synthesise and distribute the information more widely.

Most commonly the public rely on news and entertainment media for scientific content, often delivered by specialised science communicators (Besley & Tanner, 2011), rarely with scientists directly involved in research. For science to become more accessible to a broader audience, scientists need to engage in communication directly with non-scientists. Stepping outside of the boundaries of traditional peer reviewed journal articles and communicating their work in a variety of ways. A major challenge to this is the way scientists typically view non-scientists, under the deficit model.

The deficit model asserts that the public's lack of engagement with science, and scepticism towards it, is caused by a lack of knowledge about science (Besley & Tanner, 2011; Bubela et al., 2009). The deficit model focusses on expert knowledge and assumes this is correct (Hansen, Holm, Frewer, Robinson, & Sandøe, 2003) without accounting for any other ways of knowing or understanding, such as lived experiences (Irwin & Michael, 2003). The deficit model was initially developed from one-way transmission models within the telecommunications industry, the aim of communication is to transmit a message from a ‘transmitter’ to a ‘receiver’ with as little interference or distortion as possible (Shannon & Weaver, 1949). At first glance this model may seem quite logical, that simply the public don’t understand science because they don’t know enough about it. However, when we look more closely the situation is much more complex, the issue of distortion being significant. By focussing solely on knowledge acquisition the deficit model ignores other equally important factors such as ideology, social identity and trust that influence individuals decision making (Bubela et al., 2009). These factors significantly impact someone’s ability to view messages objectively as they are intended, particularly in the discipline of science with its own language the message is even more likely to be distorted by the time it reaches an audience of the general public.

In educational practice, this can be observed in the two broad approaches of educators, those who are defined by their discipline, teaching the way the subject was taught to them and entrenched in discipline specific practices (Oleson & Hora, 2014), and those who are more student oriented, understanding their role in knowledge development and more flexible in their approach. It is this second type of educator that facilitates learning in their students by articulating their explicit beliefs about the learning process and helping students to construct their own models of learning (Halpern & Hakel, 2003). Whilst this process involves a shift in viewpoint, evidence suggests that in some educators this shift can occur over time, developed through experience in teaching and learning (Van Heerden, 2019).

More recently a model embracing two-way participatory practice or public engagement has developed (Stocklmayer, 2012) involving various stakeholders to contribute and build information rather than a unidirectional transmission from expert to layperson. This model enables those impacted by science (namely everyone) to contribute towards scientific discussions from an informed perspective, respecting that they are able to contribute from their own position of expertise within business, industry, farming and the general community (Stocklmayer, 2012). Examples of this practice can be found in the field of environmental risk assessment where scientists are beginning to engage in public dialogue to incorporate the knowledge and experiences of lay-people into problem solving scenarios (Blok, Jensen, & Kaltoft, 2008). The artefacts presented here provide opportunities to enact this model through a variety of scientific disciplines, engaging the wider community in the development of resources to be used in teaching practices. Through genuine public engagement where various forms of knowledge and experiences are accepted and valued equally scientists can transform the way science is viewed by the public and work towards meaningful scientific communication.

Unfortunately, while it is recognised by science communication experts that public engagement must be inclusive in order to impact a change in the way the public experience science, this is not necessarily the case for the broad scientific community, with many scientists still subscribing to the notion that if the public understood more about science they would have difference opinions about scientific issues (Besley & Tanner, 2011). The relationship between science, politics and society is more complex and necessary than ever before, for example evident with the recent introduction of the National Interest Test for Australian Research Grant applications. Researchers who seek national competitive grant funding need to provide a 100 word summary describing how their proposal is of socio-political significance, which, after the proposals are reviewed and ranked for funding, are then vetted by an Australian Government Minister to ensure Australian voters that "*their money is being spent wisely*" (Australian Research Council, 2018 para. 6). Yet scientists are largely continuing to fail to take into account the broader influences on society upon decision making (Simis, Madden, Cacciatore, & Yeo, 2016), perhaps influenced by the perception that the public are emotional rather than rational regarding making decisions informed by science and favouring empirical objectivity (Cook, Pieri, & Robbins, 2004).

Communication training is increasingly offered as part of undergraduate programs or to practising scientists (Basken 2009, Turney 1994, Peters et al 2008) typically preparing scientists to work with media and train them to present to the public. However, this model is problematic, treating communication as an accessory to science rather than an integral part of it. Simis et al. (2016) recommend addressing this issue directly with scientists to enable them to understand and adapt the rigour of social science research to cultivate a more positive attitude towards how the public view science. The key to this may be to change the way scientists engage the public.

The biggest shift that will be needed to address both broader engagement with science and engagement of scientists with the public will be in how scientists reimagine the role of communication. The strict focus of objectiveness and scientific terminology does not simply translate to a simplified version for public consumption, but rather when science engages the community it takes into account the experiences including political and ethical implications or personal reactions to scientific research (Cook et al., 2004), resulting in a more rounded explanation of science that the public can meaningfully join. We can no-longer maintain disciplines of scientists that view their fields as elite and somehow better than the rest of the world, instead we need to shift our expectations and embrace the varied knowledge that non-scientists have to offer and include this voice in the conversation. Only once we do this can we expect more and varied participation in the sciences, not just from more women but also other minorities.

The remainder of this thesis will conduct the intellectual work to build disciplinary expertise into disciplinary literacy, examining the relationship of authentic context in building disciplinary literacy in learners. The following chapters stand upon the shoulders of those who have come before me, building upon existing knowledge to understand how disciplinary literacy develops so that clear strategies can be scaffolded into educational practices.

CHAPTER 3 : THE LANGUAGE OF SCIENCE

3.1 Ontology and Epistemology

On many occasions through this research project, I have paused to reflect and consider '*how* do I know what I know?' In the context of developing disciplinary literacy through science education, how have my experiences shaped the way that I understand the relationships between teaching and learning, and thus that required of teachers and learners? How can this knowledge be crafted to help explain what I see – and should see - in a classroom? The act of naming and describing what it is that I see in myself, my colleagues and my students is a little amusing, as biologists are renowned for naming and describing living things in our environment. Therefore, I must ask myself, is this any different from my role as a biologist investigating the roles, behaviour and environment of biological communities? I find myself answering, yes, quite different for two main reasons. Throughout previous scientific research, I have maintained a sense of independence from the research, eliminating cognitive bias as much as possible. However, in this situation I have become part of the research myself, inextricable from the research thus tethering the interpretations of outcomes to my own bias and subjectivity. Additionally, the scientific method on which my research has been reliant is grounded in a theoretical framework, posing and testing a series of hypotheses that reflect already well-established scientific theories. Throughout this research project, while there is a wealth of theoretical underpinning including education theories, psychology theories, communication theories and many more I am seeking a deeper explanation than the answer to a hypothesis. An answer that requires its own theoretical explanation which currently does not exist.

My original contribution to knowledge is the development of a theoretical framework to explain teaching and learning in science education under the lens of disciplinary literacy development. By approaching the problem through the lens of disciplinary literacy I aim to understand the role of student experiences in developing transferrable skills. This dimension of teaching and learning is rapidly expanding with the massification of higher education seeing a greater number and variety of students on campus than ever before and the shift in its focus towards producing work-ready graduates (Boden & Nedeva, 2010; Tight, 2019). The landscape of higher education is changing also, with a greater diversity of learners with students entering with a wider range of socioeconomic, racial and educational backgrounds than ever before (Buckridge & Guest, 2007; Martin, Karmel, & Training Youth Affairs Higher Education Division Australia Dept of Education, 2002; McInnis, 2003), combined with increased standardisation of curricula and benchmarking of educational practices (Australian Government Department of Education and Training, 2013; Quality Assurance Agency for Higher Education, 2015). There is a need for teachers and learners to work together in creating an accessible, engaging and transformative teaching and learning environment. My research provides the framework to make this possible.

My own experience of teaching and learning is intricately tied to this research project. I am tethered to science in such a way that it anchors all my thinking, it is an integral part of who I am as a researcher, educator and a learner. My knowledge of teaching and learning has been forever altered as a result of this process, and from this unique experience I can offer an unusual perspective not previously expressed in scientific literature.

At times during this project, I have experienced the feeling of what I can only liken to an academic pull between two diverse disciplines: education and science. Both disciplines claim an understanding of their students and their learning needs, but approach teaching and learning very differently to one another. At Flinders University, the campus at which I study and teach, the education and science faculties are physically situated on either side of a grassy valley and an artificial lake. Their physical separation provides a wonderful analogy for the way the two disciplines interact. Both within sight of one another, but with very little co-operation or collaboration. Throughout the project I have found areas of great similarity and vast differences between each discipline. Through this research process I hope to understand these similarities and differences and use them to bring the disciplines together, bridging the valley between educational research and science research.

3.2 A note to the reader: the selection of a lens

Throughout this unconventional research project, I have attempted to bring together the two diverse and divergent disciplines of science and education. At no point is this challenge clearer than addressing the empirical evidence of my research. To this point I have been speaking to you as an educator, using the language and practices common in the discipline of Education. In order to enact change in current teaching practices it is crucial that scientists engage with my research, thus it must be presented in a language that is recognisable, familiar and comfortable. In the following sections I have switched to using a traditional scientific approach in research presentation. Evidence is presented and evaluated to address each of the aims outlined at the beginning of this thesis.

Scientists employ an empirical methodology in their research, and this flows through to how that research is communicated, including the format of a traditional scientific thesis (Yore, Hand, & Prain, 2002). Therefore, I am asking you to view the following section through the specialised lens of a scientist, understanding that this shift is necessary to reach the desired audience. As Carolyn Keys (1999, p. 120) highlighted "The requirement to formulate language and syntax choice for written text, especially when writing to communicate to an audience, promotes direct connections between data as evidence and knowledge claims in the form of meaningful inferences". By choosing discipline specific language and style I am hoping to make the evidence clear to my readers so that they may also interpret the results within a disciplinary context.

The results presented here are important and provide insight into the teaching and learning processes involved in the development of disciplinary literacy. Clearly, not all aspects of teaching and learning are measurable. There are limitations of what we can measure using empirical methodology, however in this instance it provides an important conduit to reach the desired audience. It enacts the disciplinary framework that is described later in this exegesis. Therefore, the following chapter will be presented in a traditional scientific format including methodology, methods, results and discussion in order to connect to the disciplinary literacy of the audience that it is intended to reach.

3.3 Study Design

This project combines a variety of elements which are outlined in Figure 3.1 in order to address the research aims. This research project draws on data collected from a range of areas to capture the experiences of both teachers and learners, as well as the structures that underpin the relationship between teaching and learning. The design and implementation of the artefacts sit outside of the elements described here and are discussed in detail in section 3.7.

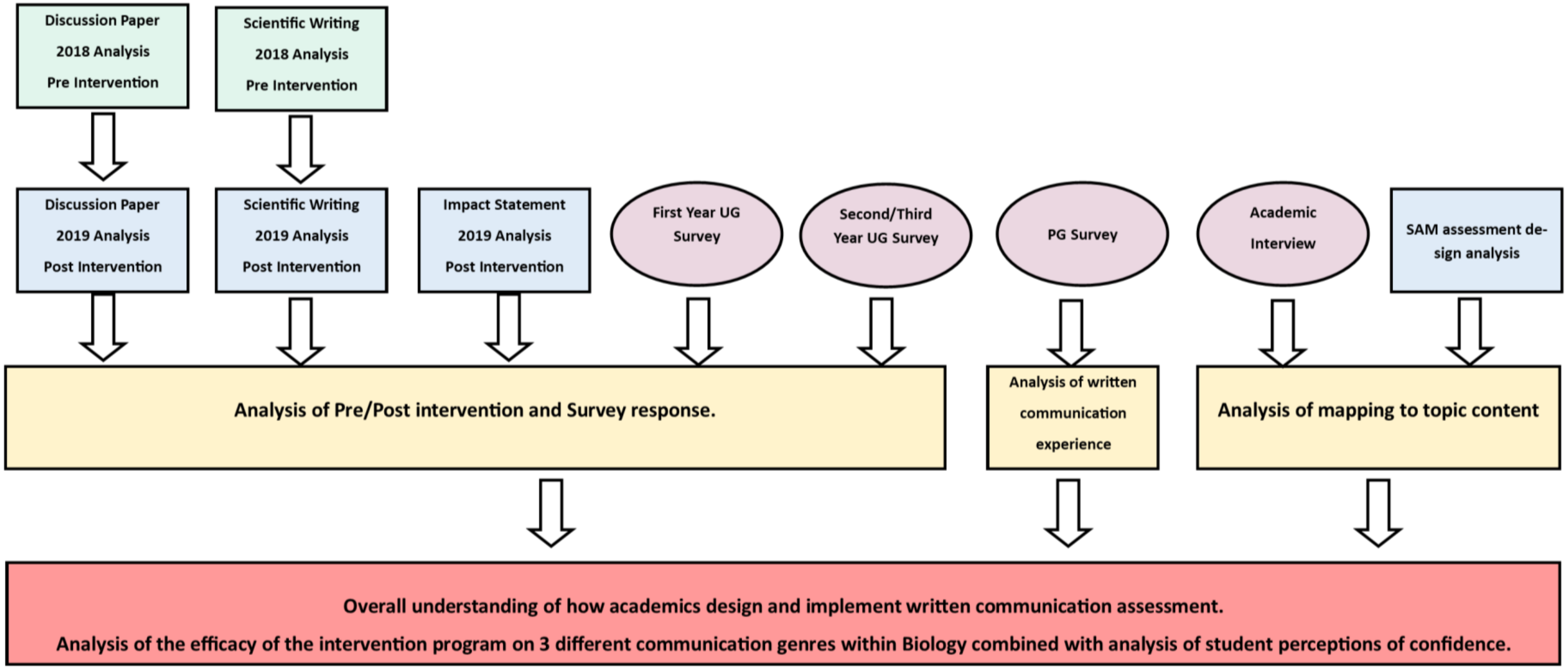

Figure 3.1. Methodological elements of the research project.

3.4 Experimental Elements

3.4.1 Undergraduate Data Collection

As depicted in Figure 3.1 undergraduate students were invited to complete a survey (Appendix C) that comprised of two elements in relation to the aims of the research outlined in section 1.16. To determine student experience of current assessment practice in relation to written communication in undergraduate degree programs, students were asked to identify from a provided list the types of written assessment tasks they had completed as part of their undergraduate degree program (question 8 of Appendix C). An option was provided to include additional types of assessment that were not listed, and this data was used to perform the analysis described in section 3.4. To determine the resources that students use to develop disciplinary literacy during their undergraduate degree program, they were asked to identify the resources they found most useful in learning to write scientifically. Common resources were listed and an option for open response provided to enable students to explain their selection further or provide additional resources that were not listed (question 9 of Appendix C), and this data was used to perform the analysis described in section 3.5. A total of 2,200 undergraduate students ranging from first to third year of study were invited to participate in the research survey. An invitation to participate in the research was sent via email from the researcher and included a link to the survey and information about the study to ensure that participants were appropriately informed of how the data would be collected and used. Of those who responded 138 were undertaking their first year of study, 100 their second year and 56 their third year.

The same survey was used to assess the impact of implementing e-learning modules designed to support the development of disciplinary literacy on the confidence of students performing an assessment task. Questions were phrased to students to reflect on how confident they were in performing various genre of scientific writing posed as an assessment task (questions 10-21 of Appendix C). This data was used to analyse the impact of introducing a novel writing task on student confidence in order to understand how experiences contribute towards the development of disciplinary literacy. The implementation of the novel task is described in further detail in section 3.6.

The survey was administered to students in 2019 in the first, second or third year of their degree program who were either currently enrolled (first-year) or previously enrolled (second and third-year) in a first-year core Biology unit. This unit was deemed the most suitable for analysis within this research project as it has the largest of enrolments across all science units and thus a reasonable response rate would mean no need to repeat in other units, reducing any perceived or genuine increase in cognitive load experienced by students. Additionally, this unit also has the widest variety in student degree programs, ensuring that the survey reached as diverse an audience as possible whilst still being relevant to the discipline. Students who had previously completed the unit in 2017 and 2018 and were enrolled in second and third-year units were invited to complete the survey and reflect on their experiences of learning in relation to this unit and others within their degree program.

3.4.2 Postgraduate Data Collection

To prevent any real or perceived impact of the researcher emailing postgraduate students directly, the survey information and links were provided to students through their respective faculty higher degree research program coordinator, therefore the total numbers of students contacted are unavailable. The invitation to participate in the research was sent via email to postgraduate students within the Colleges of Science and Engineering, as well as Medicine and Public Health at Flinders University. The invitation to participate included a link to the survey (Appendix D). Information about the study was provided to ensure that participants were appropriately informed of how the data would be used. A total of 37 postgraduate students completed the survey, of which 20 identified as having completed their undergraduate education at the same institution. To assess the experience of postgraduate students in relation to written communication in undergraduate degree programs, students were asked to identify from a provided list the types of written assessment tasks they had completed as part of their degree program (question 11 of Appendix D). An option was provided to include additional types of assessment that were not listed, and this data was used to perform the analysis described in section 3.4. The survey for postgraduates included questions asking them to reflect on their experience as an undergraduate student as well as additional areas of writing development that are often present in postgraduate education, such as opportunities for apprenticeship with supervisors and professional activities such as peer review processes (questions 7-10 of Appendix D).

To determine the types of resources postgraduate students found most useful in developing their writing, they were asked to self-identify from a provided list of possible resources, with an option to describe any other types of resources missing from the list. Respondents were able to select multiple resources in their response. Respondents in this group were also asked to report on their experiences of any specific training they had undertaken to learn to write scientifically, as well as considering discussions had with supervisors about writing (questions 7-10 of Appendix D). Responses about past experiences were open-ended to enable students to reflect on the vast range of professional development available and the variation in post-graduate supervision that occurs.

Postgraduate students were also asked to reflect on their confidence in performing a variety of scientific writing tasks that are common throughout undergraduate and postgraduate education experiences and in the workplace (questions 13-24 of Appendix D). These responses were used to examine the relationship of confidence in developing disciplinary literacy throughout a degree program and are discussed in further detail in section 3.6.

All surveys were administered via the SurveyMonkey website to ensure secure and anonymous collection of data, using a paid subscription held by the researcher. Ethics clearances were in place for this project. The use of survey data and de-identified student assessment has been approved by the Prideaux Centre Research Support Network and Flinders University Social and Behavioural Research Ethics Committee, Project Number 2.19.

3.4.3 Mapping Topic Content

To map topic content and assessment methods deployed in units of study within this PhD research two methods were combined. An initial analysis of the Statement of Assessment Methods for each unit was undertaken by the researcher. This involved identifying any assessment that featured communication and cataloguing the communication type. As there exists much variation in assessment methods informal academic interviews were conducted where the communication type was unclear or ambiguous. Academic interviews were conducted with the unit coordinator responsible for the creation and implementation of the assessment methods, either in person or via email depending on the availability of the unit coordinator. The purpose of these interviews was to ensure consistent assessment coding as a wide range of terminology is in use to describe student assessment.

3.4.4 Data Analysis

All data was analysed using IBM SPSS Statistics 25 software and data was stored securely by the researcher at Flinders University. Statistical analyses were performed according to methods described by Laerd Statistics (2017). Graphs were created using Microsoft Excel for Office 365 and IBM SPSS Statistics 25. Complete data analyses are provided in Appendix B.

Open-ended responses were solicited in the surveys to undergraduate and postgraduate students. The response rates to the open-ended sections were very low in comparison to nominated response answers, thus the open-ended response data was only used to clarify understanding and interpretation of the nominated response answers and was not sufficient to be used in a stand-alone analysis.

3.4.5 Digital Learning Platforms

Many digital learning platforms are already widely available and well designed to support science curricula (Chirikov, Semenova, Maloshonok, Bettinger, & Kizilcec, 2020; Wahabi et al., 2019). However, few include resources directly related to scientific writing skills. Those that do exist focus on the traditional tasks of laboratory reports and scientific journal articles (Willems-Jones, Tan, Kountouri, & Russell, 2019) or on English language skill development in writing (Lin, Liu, & Wang, 2017). Therefore, it was identified that a significant part of this project would require the development of resources in order to expand the range of genres available to be included within the study parameters – a crucial aspect of the PhD in broadening the scope of scientific writing development.

A variety of options were explored before settling on the use of Articulate Storyline as the most appropriate for the context of this PhD research. There exists a wide range of digital learning platforms, described as course authoring software, that lend themselves to the type of activities explored throughout this project. The software investigated for use in this project included Smart Sparrow, Articulate Storyline 3, Articulate 360 and Adobe Captivate. The necessary criteria for use in this project and viability long-term in the use of modules that would be created using the software was the ongoing cost of access and the ease of use in developing learning materials. All of the platforms were trialled and were deemed comparable in terms of useability in creating learning material. Differences in presentation were minimal between the varied platforms, although Smart Sparrow resulted in a more professional appearance and user-friendly model of the final learning resources. Therefore, the main driver in the decision of which platform to select was determined based on cost. Articulate Storyline 3 was determined to be far more affordable, both short and long-term. Smart Sparrow, Articulate 360 and Adobe Captivate all require on-going fees, with Smart Sparrow employing a per student cost, which deemed this unsuitable for the project and unviable for future proofing the learning materials. Of the resources examined only Articulate Storyline 3 was available with a once-off low cost option and included no on-going fees. Therefore, Articulate Storyline 3 was identified as the most suitable option to ensure continued viability of the project into the future.

3.4.6 Genre

Scientific writing spans many genres and whilst covering a wide range of writing development in this research would be ideal, there are constraints to doing so within a PhD program. The three genre selected for this research include Scientific Journal Articles, Impact Statements and Discussion Papers, which each reflect differing forms of audience and communication styles required of authors. These selections were made deliberately and with careful consideration for evaluation purposes of the project and taking into account the constraints of time and access to student cohorts to host the e-learning modules. The teaching of Scientific Journal Article writing is both important and commonplace in both undergraduate and postgraduate environments, thus provides a point of reflection on common practice in science education. Whilst the inclusion of the Impact Statement and Discussion Paper genres allows comparison to writing types that are less commonly included in higher education science curricula. The selection of three genres cannot fully represent the vast array of scientific writing that exists and accordingly the interpretations and inferences made following the analysis in the proceeding section cannot be applied to all forms of scientific writing. However, by selecting this particular range of writing genres, with a representative of communication between scientists, educated non-scientists and the public we may be able to begin to scaffold other forms of science communication based on what we learn here.

3.4.7 Alignment to Research Questions

Throughout this research it has been crucial to keep focus of the overarching aims and research questions posed at the beginning of this journey. Each aspect of the project has been designed with these objectives in mind. In addressing how Disciplinary Literacy develops an empirical approach was used to investigate the implementation of e-learning resources on student assessment as an indicator of successful development of literacy skills within the discipline. This approach enabled a detailed analysis of various aspects of writing formation, which can be applied to a range of genres of scientific texts.

In addressing the specific aims of the research multiple approaches were used. In addressing Aim 1 it was important to directly observe the assessment practices that are deployed in undergraduate degree programs in order to develop an understanding of how these influence the development of written communication in higher degree programs. As these practices are designed to be open and transparent it was possible to achieve this aim using the described methods. In addressing the second aim of this research direct observation was not possible as much of the resources used by students are not managed by universities and are enormously varied. Thus, this aspect of the research relied on indirect measurements via student self-reporting in surveys. This approach is limited in both the design elements of surveys themselves and the reporting by students. Attempts to overcome these limitations included providing students the opportunity to clarify or explain their choices in open-ended questions within the survey. Together the third and fourth aim of this research involved the development of e-learning modules to support the development of disciplinary literacy in undergraduate students. The design of the e-learning modules was informed by good-practice in the field of e-learning and online resource development and the empirical results from students using the modules, in the form of assessment, was used to inform the development of the theoretical framework.

3.5 Current Assessment Practices

3.5.1 Introduction

The educational approaches enacted in contemporary higher education practices are mostly based upon faculty teaching students to follow in their footsteps, with research within Australian research intensive universities indicating 96% of communication assessments tasks are targeted at an audience of scientists in the same discipline (Stevens et al., 2019); Stevens, 2013 in (Mercer-Mapstone & Kuchel, 2015). Therefore, despite the recommendations and framework provided by the TLO's only a narrow range of communication skills are being taught. Additionally, there appears to be little research into *how* these communication skills are being taught (Mercer-Mapstone & Kuchel, 2015) with a lack of evidence-based examples available to academics. With a current need for information regarding how communication is being taught and who is teaching it across the higher education sector, this chapter aims to determine what type of communication education is prevalent amongst assessment tasks.

Whilst generic communication skills may develop naturally as part of performing assessments within undergraduate education, the development of discipline specific communication skills require careful and explicit instruction. By focusing on learning outcomes in assessment design, described by Wiggins and McTighe (2005) as backward design, educators can consider the overall purpose of assessment and ensure that appropriate opportunities are available for students to develop the necessary skills. Backward design allows curriculum mapping to occur by clearly articulating student objectives and then designing curriculum to support and assess that these objectives are met. Backward design is well established in education and has become prominent in language education (Richards, 2013). Backward design is suitable in the context discussed in this research as it places focus on student learning outcomes and enables educators to identify areas of curriculum which align to those outcomes. When educators have a clear idea of what they expect for student outcomes, then the design of assessment activities is more likely to address those learning outcomes. One way in which this may be expressed in the development of communication activities is in clear language choice in assessment criteria that reflect assessment of communication skills.

3.5.2 Methodologies

The practice of using Assessment Methods documents to uphold a certain level of transparency in educational settings is common and designed to enable a clear and consistent understanding of what is expected of a student within each unit of work. It is important to acknowledge the variability that is inherent in the method employed here and the way in which I have attempted to reduce it. Assessment methods documents are commonly written by a single academic and reviewed by just one other. To reduce administrative load on the reviewers in this process, these documents are often templated and include prescribed terminology with little indication of what each of the terms translate to within a classroom. During this process the reviewer will bring their own interpretations and assumptions which may differ from the academic that designed the assessment methods. Whilst the review process is designed to improve consistency in terminology it does not often address variation in descriptions of assessment tasks and rather than standardise, assessment methods leads to a great deal of variation. Additionally, instead of resulting in genuine standards against which learning outcomes can be measured, standardised templates used in this way result in academics viewing the process as an administrative hurdle.

Assessment practices by their very nature are ontologically and epistemologically tied to their discipline. Within the broad field of science, we may expect some consistency in the way assessment is carried out, however between sub-disciplines there may be variation in expression which I have attempted to capture using a comparative approach.

3.5.3 Method

To gauge the variety of tasks being used in assessment practices within higher education, Statement of Assessment Methods (SAM) documents from Flinders University undergraduate units within the College of Science and Engineering for 2018/2019 were analysed as an exemplar of practices across the nation at that time. SAMs are used in each unit of study to inform students in writing of the objectives, methods and implementation of every assessment task they will meet, along with the criteria for successful completion. A total of 37 units were analysed and only those that included assessment tasks explicitly targeting communication skills were included for further analysis (n=17). To ensure that the results of this research project were consistent with previous literature and enable clear comparison to published data, methods of item categorisation were adapted from Stevens et al. (2019). Individual assessment items were categorised by audience, mode and purpose as outlined in Table 3.1. Only those assessment items that could be categorised as communication beyond simply transferring an understanding of disciplinary concepts were considered as communication in this context. This distinction is important, as all assessment tasks by their nature must include some aspect of communication or they would not allow students to demonstrate their content knowledge. Therefore, even though a student must communicate their understanding of content in order to complete an online quiz or examination, these types of activities were not categorised as communication tasks as the communication component was a by-product rather than an intentional outcome of the assessment. The "objectives are especially important in teaching because teaching is an *intentional* and *reasoned* act" with a purpose to facilitate student learning (Anderson & Bloom, 2001, p. 3). Communication was therefore described as an intentional outcome of the assessment task in which a component of assessment specifically included descriptors related to the ability to communicate ideas to an audience, as one would expect when the assessment has been backward mapped for the learning outcomes, for example where language and suitability to audience were mentioned. Where further clarification was required to make a decision the author of the SAM was contacted, and an informal discussion had to clarify the intended learning outcomes.

Table 3.1 Descriptors and examples of categorisation of assessment activities. Modified from Stevens et al. (2019).

	Category	*Example*
Audience	Scientist (including students) in the same discipline	Unit coordinator, tutor, lecturer, student peers in the same unit.
	Scientist in a different discipline	Lecturer or student in a different field of science
	Non-scientist public	Community groups, children, parents
	Non-scientist professional	Journalist, government, industry and business
Mode	Traditional written	Report, abstract, essay, literature review, journal article
	Traditional oral	Oral presentation/seminar
	Traditional visual	Poster, PowerPoint presentation
	New media	Blog, online discussion, YouTube video, website

Student survey responses were analysed using the chi-square test of homogeneity to determine if a difference exists between the binomial proportions of three or more independent groups on a dichotomous dependent variable. The accuracy of the chi-square test is reliant on sample size. For samples that violated the requirements the Fischer's exact test was used, which determines whether two dichotomous variables are independent. Where statistically significant differences in proportions were found, the z-test of two proportions with a Bonferroni correction was applied to determine the differences between groups. The Bonferroni correction compensates for the increase in likelihood of incorrectly rejecting a null hypothesis due to multiple comparisons by testing each individual hypothesis at a significance level determined by the number of comparisons. The p-value describes the probability of obtaining the observed result if the null hypothesis is correct, thus the smaller the p-value the stronger the evidence that the alternative hypothesis accurately describes the observations. The significance level used here is 0.05 unless otherwise stated as per Bonferroni corrections.

3.5.4 Results

Intended Outcomes of Assessment Practices

Of the 37 first year units that were available to analyse, 20 of these included no assessment task that required communication as an assessable outcome based on the criteria defined in the methods above. The majority of these were Mathematics and Statistics units which comprised mostly of examinations as assessment which included no mention of communication as an intentional outcome. Assessment method documents were further analysed from a total of 17 units. Whilst this represents a small number of items, they are reflective of methods used across Australian universities more widely. Of these, 43 individual assessment items from these units were identified as having a focus on communication as an assessment outcome. These items were further categorised based on the methods described in Stevens et al. (2019) beginning with an analysis of the mode of each communication task to determine if there was a prevalence of any particular form. The results of this analysis are presented in Figure 3.2 which depicts the various modes of communication assessment tasks that were analysed and indicates that approximately 60.5% of assessment tasks were of a written form while 18.6% were described as New Media. Interesting the majority (75%) of the New Media tasks were targeted towards engaging with a non-scientist public audience, compared to only 15% of written modes targeting the same audience.

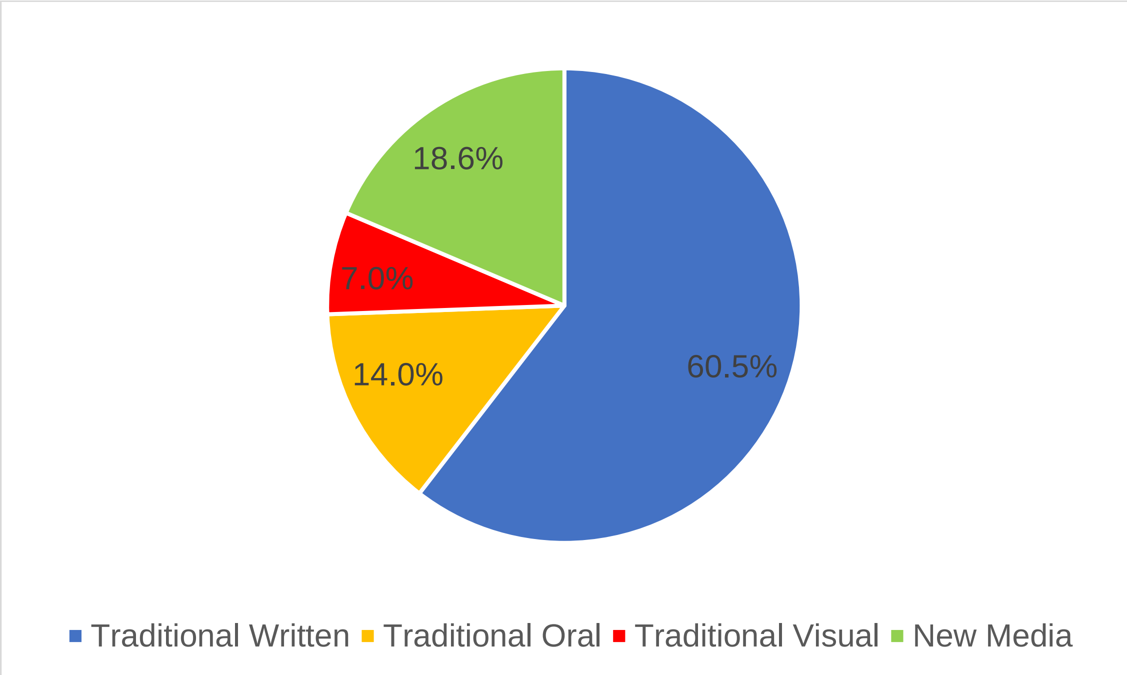

Figure 3.2. Mode of assessment tasks in first year communication assessment items.

Thus, there seems to be an understanding amongst science educators that alternate modes have a role to play in communication with the public, yet written forms are much more commonly used in the communication of scientific ideas.

The assessment tasks were then classified according to the intended audience as described in Table 3.1. Results of this classification are presented in Figure 3.3, which displays the proportion of assessment tasks for each target audience. Approximately 77% of all assessment activities with a communication component targeted an audience of scientists within the discipline from which they were embedded. None of the assessments analysed were designed to communicate with another scientist from outside of the discipline.

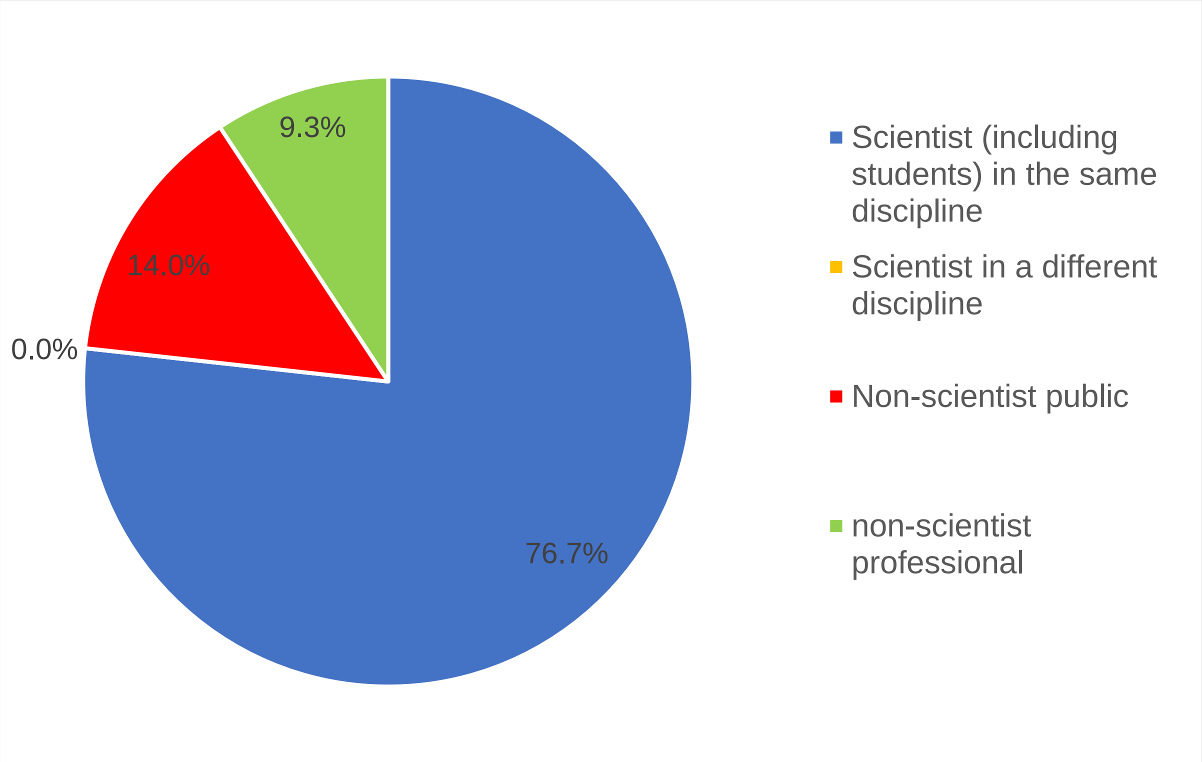

Figure 3.3. Intended audience of written assessment tasks in first year communication assessment items.

Figure 3.4 further reveals this relationship by investigating the target audience of assessment tasks based the sub-discipline in which they occur. This data was collected from within the College of Science & Engineering at Flinders University in 2018 and included 43 individual items. The results indicate that each sub-discipline shows little diversity in the range of audiences that communication assessment tasks are designed for which is problematic, as it shows that students are likely to experience only a narrow range of the diverse communication skills that are required by a practicing scientist. Additionally, the results suggest a lack of communication tasks that target audiences other than scientists within the discipline being embedded into disciplinary curricula as they only appear in the sub-disciplines of Biology and Communication. The assessment tasks within the Biology discipline include tasks in which I am involved in both design and implementation thus, naturally will reflect the wider diversity in audience that I am striving to achieve in written communication assessments. The sub-discipline of communication is made up of a single unit that focuses on the various forms of communication and skills necessary for successful scientific communication with both specialists and non-specialists and does not include discipline specific content i.e. there is no specific chemistry, physics, biology or maths content in this unit, rather the learning outcomes are for students to develop scientific communication skills and an understanding of the philosophy of science. Therefore, the assessments in this unit have been designed to specifically target non-specialist writing development, thus the greater representation of assessment tasks focussed on communicating with non-scientist professionals and public that is observed in the results presented here.

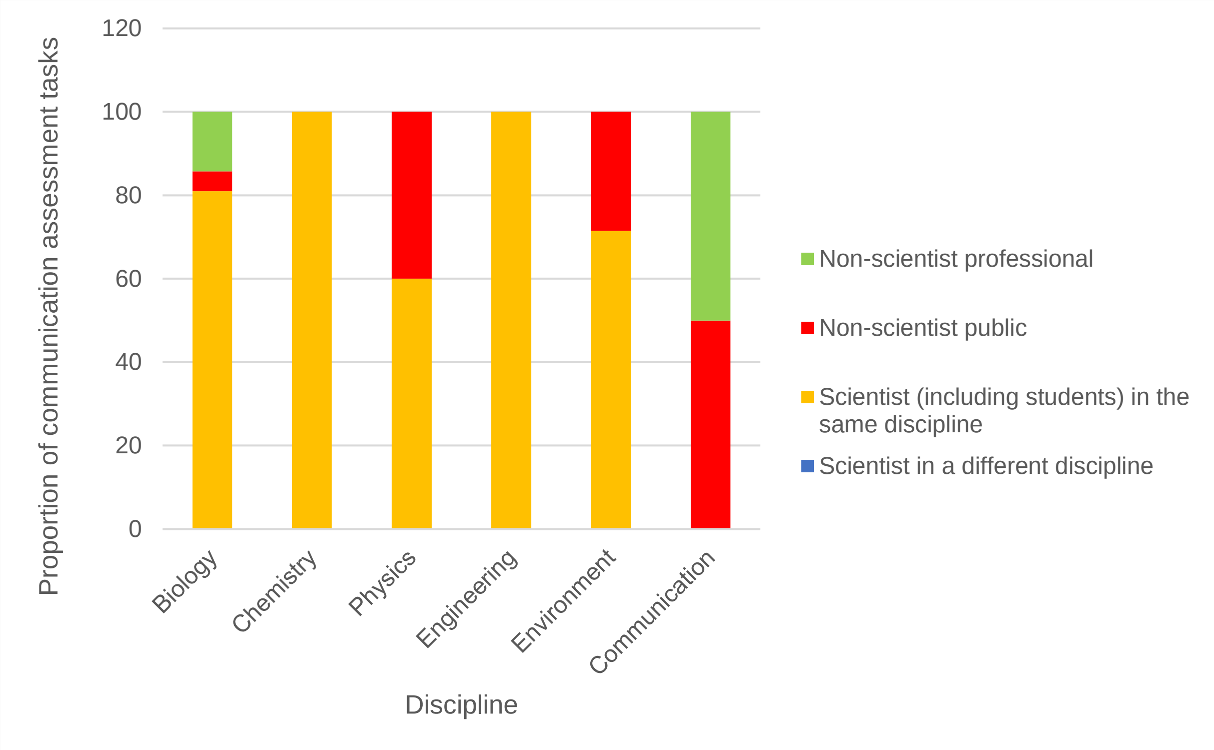

Figure 3.4. Proportion of written communication assessment tasks and the intended audience they target in sub-disciplines of science within the College of Science and Engineering.

Conspicuously absent from Figure 3.4 are any Mathematics units, as communication assessment tasks were entirely absent from any Mathematics units included in this study. This is somewhat consistent with previous research in this area (Stevens et al., 2019) that found communication tasks in the discipline of Mathematics to be fewer in number and when present, weighted less than in other disciplines. However, these results show an even greater difference between assessment practices in Mathematics in comparison to other disciplines within the sciences. Previous research (Stevens et al., 2019) has also described a lack of communication tasks aimed at developing communication between scientists within different disciplines and unsurprisingly, none of the communication tasks analysed in this study were observed to involve communication between scientists in a different discipline. As this research is interested in written forms of communication further analysis was performed to determine the intended audiences of the written communication tasks alone. Alarmingly this showed even further bias in written communication with 84.6% of tasks aimed towards an audience of scientists within the discipline and only 15.4% of tasks aimed at non-scientist professionals.

Student Experience of Assessment Practices

In order to understand the student experience of assessment practices undergraduate students were surveyed to establish their experiences throughout their undergraduate degree program. Figure 3.5 is a plot of assessment type against the proportion of respondents that report to have completed various types of scientific writing assessments throughout their undergraduate degree program.

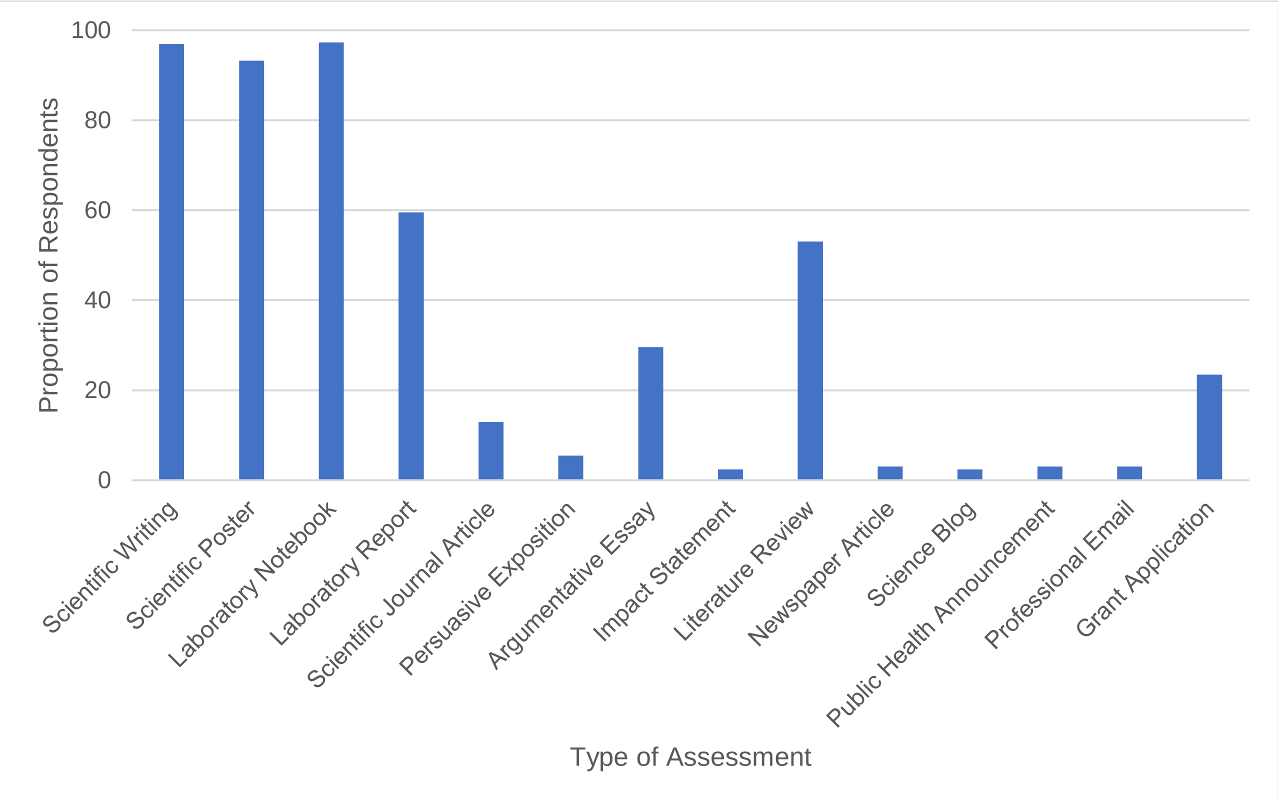

Figure 3.5. Proportion of written communication assessment tasks reported by undergraduate students.

The experiences of students reported in the survey results are consistent with the findings of SAM analysis presented in Figures 3.3 and 3.4 and indicate an abundance of assessment tasks that typically focus on communication with experts within the discipline. The results presented in Figure 3.5 are reported by students in undergraduate degree programs at all year levels within the College of Science & Engineering at Flinders University in 2019, n=294. A total of 1433 discrete responses were collected. The results show that the categories of Scientific Writing, Scientific Poster and Laboratory Notebook score highly, while Laboratory Report, Argumentative Essay, Literature Review and Grant Application score moderately and the remainder of assessment items score poorly. These results indicate that written assessment tasks undertaken by students are heavily skewed towards communication between experts within a discipline, indicated by the high scores for types of written communication assessments that include Scientific Writing (commonly termed a Scientific Writing Assignment (SWA), the structure of this assessment is a simplified journal article or manuscript), Scientific Poster and Laboratory Notebook. While scored moderately, the Laboratory Report is often considered in a similar context as a Laboratory Notebook, being a more formal and synthesised version where students can explain their results to their assessor. The Literature Review may also function as a form of communication between experts as it involves students synthesising the literature within a narrow field to show their understanding to their assessors. All these assessment tasks show markedly higher response rates than tasks designed to communicate with other audiences.

If assessment practices are scaffolded to develop disciplinary literacy, we would expect that assessment tasks differ as students' progress through their undergraduate degree program. Therefore, to determine whether differences between assessment tasks were present between year levels further analysis of survey responses was undertaken. Respondents were categorised by year of current study and the responses are depicted in Figure 3.6.

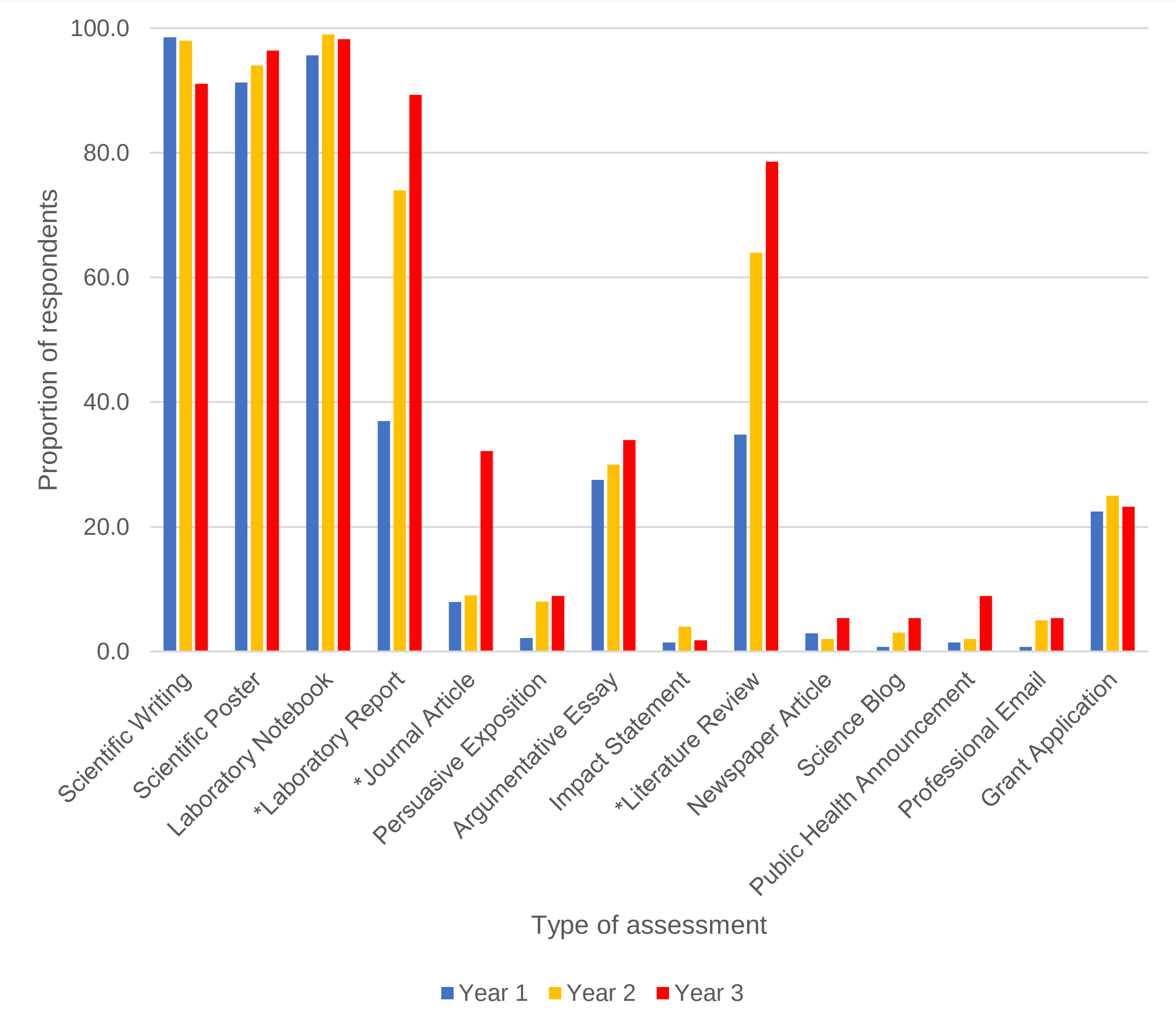

Figure 3.6. Proportion of written communication assessment tasks undertaken during undergraduate degree programs. Items marked with * indicates statistically significant difference between cohorts.

The results presented in Figure 3.6 are reported by undergraduate students in degree program at years 1, 2 and 3 within the College of Science & Engineering at Flinders University in 2019, n=294. A total of 1433 discrete responses were analysed. Assessment items marked with * indicate statistically significant difference between groups. Data was analysed using a Chi-squared analysis however, the sample size adequacy assumption of the Chi-Square test of homogeneity was violated thus, a Fisher's Exact test was performed to determine whether students reported their experiences of assessment tasks differently. Students were categorised as either first, second or third year of their undergraduate degree program. This analysis tested the null hypothesis that assessment undertaken by students was the same across year levels. The results of the Fisher's Exact test indicated a statistically significant difference between the proportion of students reporting to have completed assessment tasks characterised as Laboratory Report ($p < .001$), Journal Article ($p < .001$) and Literature Review ($p < .001$). Post hoc analysis involved pairwise comparisons using the z-test of two proportions with a Bonferroni correction. Statistical significance was accepted at $p < .016667$. Table 3.2,3.3 and 3.4 describe the statistical differences between first, second and third-year students who report undertaking a Lab Report, Journal Article and literature Review respectively. The results presented in Table 3.2 indicate that significantly fewer first year students (37%) reported undertaking this form of assessment than did either second (74%) or third-year students (89.3%). The results presented in Table 3.3 show that first (8%) and second (9%) year students report very low incidents of undertaking a Journal Article as a form of assessment, while third-year students (32.1%) report it moderately. Table 3.4 describes the difference observed between first-year student experience of undertaking a Literature Review (34.8%) which is significantly lower than reported by second (64%) and third-year (78.6%) students. The results of the post hoc analysis indicated that null hypothesis was accepted for all other forms of assessment as differences observed between cohorts were not statistically significant.

Table 3.2 Descriptive statistics of the differences between proportion of students completing assessment item Lab Report.

			Year			
			1.00	2.00	3.00	Total
Lab_Report	.00	Count	87a	26b	6b	119
		% within Year	63.0%	26.0%	10.7%	40.5%
	1.00	Count	51a	74b	50b	175
		% within Year	37.0%	74.0%	89.3%	59.5%
Total		Count	138	100	56	294
		% within Year	100.0%	100.0%	100.0%	100.0%

Each subscript letter denotes a subset of Year categories whose column proportions do not differ significantly from each other at the .05 level.

Table 3.3 Descriptive statistics of the differences between proportion of students completing assessment item Journal Article.

			Year			
			1.00	2.00	3.00	Total
Journal_article	.00	Count	127a	91a	38b	256
		% within Year	92.0%	91.0%	67.9%	87.1%
	1.00	Count	11a	9a	18b	38
		% within Year	8.0%	9.0%	32.1%	12.9%
Total		Count	138	100	56	294
		% within Year	100.0%	100.0%	100.0%	100.0%

Each subscript letter denotes a subset of Year categories whose column proportions do not differ significantly from each other at the .05 level.

Table 3.4 Descriptive statistics of the differences between proportion of students completing assessment item Literature Review.

			Year			
			1.00	2.00	3.00	Total
Lit_review	.00	Count	90a	36b	12b	138
		% within Year	65.2%	36.0%	21.4%	46.9%
	1.00	Count	48a	64b	44b	156
		% within Year	34.8%	64.0%	78.6%	53.1%
Total		Count	138	100	56	294
		% within Year	100.0%	100.0%	100.0%	100.0%

Each subscript letter denotes a subset of Year categories whose column proportions do not differ significantly from each other at the .05 level.

The results show that the categories of Scientific Writing, Scientific Poster and Laboratory Notebook score highly amongst all cohorts. The small difference observed in the third-year students decrease in Scientific Writing assessment is complemented by an increase in the third-year cohort in Journal Article assessment which is likely to reflect a shift in assessment practices towards more authentic tasks in later year levels in preparation for the workplace. Interestingly, there are large and significant differences observed in the reporting of Laboratory Report, Journal Article and Literature Review which all score significantly higher as students' progress through their degree program, indicating that there is indeed scaffolding of assessment tasks aligned with disciplinary practices expected in the workplace. The Argumentative Essay and Grant Application also score moderately but there is no observable difference between year levels. These results indicate a shift in specific assessment types throughout an undergraduate degree program, yet little change in target audience, with almost all assessments still aimed at communications with other scientists within the discipline. All assessment items that would include communication targeted outside of the discipline recorded low or moderate responses and at a much lower rate than items focussing on communication between experts. These included Persuasive Exposition, Argumentative Essay, Impact Statement, Newspaper Article, Science Blog, Public Health Announcement, Professional Email and Grant Application.

3.5.5 Discussion

Scientists in the modern workplace are expected to communicate with a variety of audiences. With less than 18% of Bachelor of Science graduates in Australia finding employment within a scientific field (Palmer et al., 2018) it is now more important than ever before that graduates are prepared to communicate with people from varied backgrounds. Most scientific research funded via public investment is still presented in academic texts that are inaccessible to most audiences, and attract very few readers, resulting in little social or academic impact (Carrigan, 2017). While scientific research may be considered relevant it is not being used in policy decision-making due to these accessibility issues (Ferguson et al., 2014).

The results presented here support the findings of Stevens (2013) in (Mercer-Mapstone & Kuchel, 2015) such that the majority of written assessment tasks are designed to develop writing skills communicating to a narrow audience of scientific peers and students are assessed based on a narrow range of scientific communication skills (Stevens et al., 2019). An analysis of assessment tasks indicated that approximately 77% of communication tasks were aimed at communication between experts within a discipline, and of those that were based in a traditional written mode this increased to 84.6%. Further analysis by sub-discipline presented in Figure 3.4 indicates that this may be an underestimate of wider practices due to the inclusion of a stand-alone unit specifically designed to develop student communication for a variety of audiences. Student survey responses also indicated that most written assessment tasks were types associated with communication within the discipline and were consistent with the findings of assessment practice analysis. By examining how assessment practices change across an undergraduate degree program depicted in Figure 3.6 we can see there is little difference between years. However, where small differences occur between years one and two in learning how to write a SWA and in third year a Journal Article, is indicative of opportunities to develop disciplinary literacy with a progression in types of writing through scaffolded writing assignments to a manuscript that is more reflective of authentic workplace practice. Nevertheless, the audience of the communication activity remains the same, communicating with scientists within the discipline. Even in the final years of the undergraduate degree program these results indicate that there is little opportunity to develop written communication skills for wider audiences.

Whilst the value of communicating with a broader audience is substantial, it is not surprising that the focus of educators and academics remains writing to communicate with each other. This mode of communication is in fact how their success as a scientist is measured, thus should we expect anything else? Scientists may be attempting to prepare their students for the experiences they have encountered in their own work. The problem with this approach is that the type of work that graduates will be employed in is unlikely to look the same as their teachers have experienced.

It is crucial that educators recognise the importance of incorporating multiple forms of communication assessment into the curriculum as graduate employment opportunities diversify. Research suggests that the most effective way to do this is to embed communication skills assessment within units of study (Dannels, 2001; Harris, 2016; Stevens et al., 2019) rather than stand-alone communication units. However, without guidance and support to do so change is unlikely to occur and this will be addressed in further detail in section 3.7, which examines the effect of introducing a new assessment task that is focussed on developing written communication for non-scientist professionals. As demonstrated by the artefacts associated with this thesis, embedding a range of communication assessments need not result in the exclusion of content, rather the artefacts provide an example of how this can be performed while retaining strong links to disciplinary content and incorporating a range of audiences.

3.6 Student Resourcing

3.6.1 Introduction

In order to understand how to develop writing skills in an undergraduate classroom, we need to investigate how practising scientists develop their writing skills. Lisa Emerson (2012, 2016, 2017) has laid the foundations for us to understand the processes involved in learning how to write as a scientist. Whilst Emerson (2016) is focussed on the process that occurs as scientists move through their career, this research is specifically interested in how to lay the foundations to foster engagement with a variety of forms of writing in undergraduate students. Imitation of professional texts is just one way that students learn scientific writing, amongst others. Through the journey of novice to expert within a discipline students employ a range of strategies. Alexander (2003) describes the initial stage of domain expertise as acclimation, where students have a fragmented understanding of the knowledge of content and structure resulting in frequent use of surface-level learning strategies to orient themselves within the discipline. How these strategies are deployed is likely to vary by discipline with those subject areas traditionally considered as more difficult, such as Mathematics, relying more heavily on surface-learning strategies for longer. Additionally, Alexander (2003, p. 11) suggests that “the domain-specific tasks these students encounter in schools are commonly novel and challenging, thereby prompting frequent use of surface-level strategies". Imitation of texts can be considered a surface-level strategy that students use to help acclimatise to a discipline, helping them to understand the conventions expected and allowing them to begin developing their disciplinary literacy. While this description of the learner is very useful, it leaves the impression that it is solely the learner that is changing based on the environment they find themselves in, and that it is a reversible condition, like a salmon acclimating to salt or fresh water depending on the season. Rather, once a learner has developed familiarity of the disciplinary environment, I would argue that this learning cannot be undone. Furthermore, the learner develops the ability to engage with the discipline and influence it as well as be influenced by it. Therefore, I propose a more illustrative term to describe the early stages of a student engaging with a discipline. This term - contextualisation - encompasses another aspect of disciplinary engagement, which is crucial for literacy development, that of context.

The characteristics of expertise development presented here are based upon research by Alexander (2003) and Alexander et al. (2004) which investigated the behaviours exhibited by learners moving through an undergraduate degree program in Special Education. I have included additional features relating to discipline specific reading and writing skills that are especially relevant to this PhD research. The learner domains of contextualisation, early-competence, competence and expertise can be aligned with the expectations of educators to enable scaffolding of the learning environment to provide opportunities for expertise to develop. Learners may not naturally shift through these domains without supportive educator guidance, and by embedding opportunities to develop strategies that move learners through learner domains, they can be guided towards competence and expertise throughout their higher education experience.

Contextualisation

The learner has limited and fragmented knowledge of the discipline, they are unlikely to make connections across disciplinary boundaries. Learners who are orienting themselves with the discipline exhibit low levels of individual interest in the field (Alexander et al., 2004). Learners have difficulty determining what information is relevant (Jetton & Alexander, 1997; Middlebrooks, 2018). They begin learning what types of texts are used and how to read them, understanding some of the specialist language used in the discipline. Surface-level strategies are commonly employed as learners encounter novel and challenging tasks (Alexander, 2003).

Early-Competence

Learners have a foundational body of disciplinary knowledge, rarely making connections across disciplines. Early-competence learners show an increased interest in the discipline. However, they process information in much the same way as those in the contextualisation stage of the learning process, employing surface-level strategies. They can demonstrate early competence in using disciplinary texts and how to read them. However, they may still retain many characteristics of a learner orienting themselves with the disciplinary literature in the way they seek and interpret information. Early-competence learners are not yet engaged with writing in a way that is reflective of the discipline, relying on imitation for appropriate genre structure however, they are moving towards using writing not only to communicate their understanding but also to develop their own understanding of the disciplinary content.

Competence

Learners have a foundational body of disciplinary knowledge that is cohesive and structured, they may make connections across disciplines. Demonstrating an increased interest in the discipline, they are engaged with learning. They can demonstrate competence in using disciplinary texts and how to read them, moving towards being able to engage in the disciplinary community by forming their own text using discipline-appropriate genre. Competent learners are able to process disciplinary information using reflective practice and critical text analysis (Alexander et al., 2004). Whilst they still employ surface-level strategies in learning, this is less common, and they show more engagement and an increase in deeper processing strategies.

Expertise

Experts demonstrate a deep understanding of the discipline as well as the broader connections with other disciplinary areas. They demonstrate long-term high interest in the discipline (Alexander et al., 2004). Experts not only engage with disciplinary texts but contribute knowledge by producing texts that are shared with the disciplinary community. Experts use deep-level learning strategies almost exclusively (Alexander 2003).

It is only through performing new writing tasks within a discipline that learning can take place, that expertise in writing can develop as described by Yancey, Robertson, and Taczak (2014, p. 39) “whenever we take up a new task in a new genre—the faculty member writing her first grant application, the law student writing his first brief, the car driver completing the first accident report, and the insurance adjuster filing the first estimate—we are all novices. In sum, writing development is predicated on noviceship. In this sense, expertise is always limited and contingent…. developing expertise often requires that we behave as experts; we write our way into expertise." We fake it until we make it. Thus, the resources used by students to learn how to write scientifically will provide an indication of the strategies employed and help to understand how students develop disciplinary literacy during their undergraduate degree program. If students alter their learning strategies as they develop a deeper understanding of the discipline, developing disciplinary literacies, we would expect to see an associated change in the resources used to develop their writing as they shift from surface approaches to deeper engagement with the writing process. Demonstrating a shift from imitating disciplinary texts towards a deeper understanding of disciplinary practices and contributing toward disciplinary knowledge.

3.6.2 Methodology

A quantitative approach was selected in this instance for two reasons. Firstly, as previously outlined, uptake by the scientific audience necessitates that the findings are supported by quantitative data but secondly and perhaps more importantly this will enable me to generate a baseline of information to build upon in future research. By understanding the types of resources that students use when performing writing assessment tasks, gaps are revealed. From this diagnosis, the support structures required to develop student writing skills can be configured.

3.6.3 Methods

To understand the resources used by students to develop their writing skills two surveys were deployed. The surveys were distributed within the Colleges of Science & Engineering and Medicine & Public Health at Flinders University to students in first, second and third year of their undergraduate degree program as well as to post-graduate students in order to understand how resource usage changes during an undergraduate degree program and beyond. Respondents were able to select multiple resources that they found useful in learning to write scientifically in their responses. The context of the survey questions was in relation to learning to write scientifically throughout their entire degree program to date, however specific resources mentioned were based on common practices in assessment support provided in first-year units as in the first year of study students are traditionally provided with more resources that support learning than in subsequent years in order to address issues around transition to higher education (Wang & Kennedy-Phillips, 2013), thus ensuring that the majority of resources that students were formally presented with over their degree program would be included. Additionally, respondents were able to provide information regarding any other types of resources that were not included in the provided list. The survey questions were framed with options that are commonly made available to students when completing an assessment task including written instructions and rubrics. Other supporting materials and activities included face-to-face consulting with teaching staff, assignment examples, student learning centre resources, other online resources external to those provided by teaching staff and Q&A sessions, which consist of teaching staff discussing specific aspects of assessment tasks, answering student questions about assessment and assisting students with data interpretation. In most instances a video recording of this type of session is made available to all students after the event via the unit learning management system.

Student survey responses were analysed using the chi-square test of homogeneity to determine if a difference exists between the binomial proportions of three or more independent groups on a dichotomous dependent variable. Where statistically significant differences in proportions were found, the z-test of two proportions with a Bonferroni correction was applied to determine the differences between groups.

3.6.4 Results

A total of 294 participants responded to the survey. The survey data indicates that the type of resources most commonly used by undergraduate students include rubrics (249 participants) and written instructions (243 participants), closely followed by examples of assignments (234 participants). The relationship between resource useage and year level of students is described in Figure 3.7 which depicts the proportion of students in each year of study that attributed use of each type of resource listed. The data was reported by first (n=138), second (n=100) third (n=56) year undergraduate biology students and postgraduate (n=37) students at Flinders University in 2019.

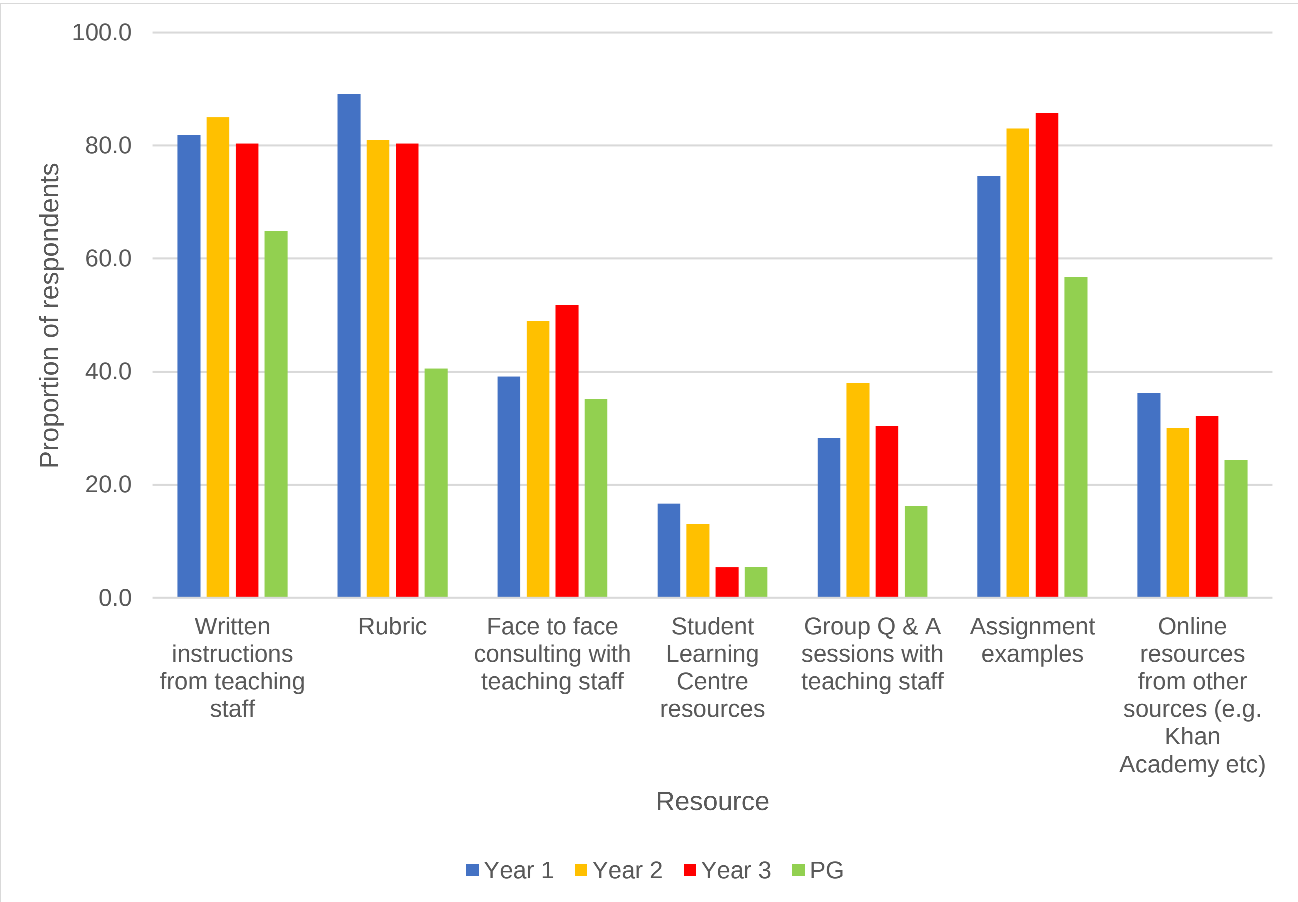

Figure 3.7. Resources identified by students as most useful in learning to write scientifically.

Absent from responses are journal articles that form the basis of much traditional scientific communications and could be potentially used as an examplar of the writing style to emulate in many instances of assessment. This is a remarkable and important gap. However, this option was not included in the standard responses and therefore may have been overlooked by students completing the survey. Respondents that selected other resources were able to provide a written response to elaborate. These responses included resources such as the use of Grammarly software, Studiosity on-demand study help and discussions with their peers. Interestingly, face-to-face consulting with teaching staff who could be considered expert mentors received only a moderate score and generic support services offered centrally through the Student Learning Centre scored poorly indicating low engagement with these resources.

Postgraduate students (PG) (37 participants) responded with overall less reliance on the standard resources available during their undergraduate degree program as indicated by the low scores in comparison to undergraduate students. Approximately 57% of the postgraduate students responding indicated that they had completed their undergraduate studies at Flinders University, thus are likley to have experienced a similar teaching program to the current undergraduate cohort. Two respondents specifically stated that the resources provided by their institution during their undergraduate degree program were not useful to their learning.

Data was further investigated using a Chi-squared analysis and the sample size adequacy assumption of the Chi-Square test of homogeneity held. Students were categorised as either first, second or third year of their undergraduate degree program, or postgraduate students. This analysis tested the null hypothesis that resources used by students were the same across all year levels. The results of the Chi-square test indicated a statistically significant difference between the proportion of students reporting to have used resources characterised as Rubrics ($p < .001$) and Assignment Examples ($p = .004$). Post hoc analysis involved pairwise comparisons using the z-test of two proportions with a Bonferroni correction. Statistical significance was accepted at $p < .016667$. Table 3.5 and 3.6 describe the statistical differences between undergraduate and postgraduate students who reported significantly different usage of Rubrics and Assignment Examples, respectively. The results presented in Table 3.5 indicate that significantly fewer postgraduate students (40.5%) reported using this form of resource than did first-year (89.1%) second-year (81%) or third-year students (80.4%). The results presented in Table 3.6 show that significantly fewer postgraduate students utilise Assignment Examples as a resource to develop scientific writing with only 56.8% reporting this, whereas first-year (74.6%), second-year (83%) and third-year (85.7%) students report higher usage of this form of resource. The results of the post hoc analysis indicated that null hypothesis was accepted for all other types of resources as differences observed between undergraduate and postgraduate groups were not statistically significant.

Table 3.5 Descriptive statistics of the differences between proportion of students reporting to use Rubrics as a resource in learning to write scientifically.

			Year				
			1	2	3	PG	Total
Rubric	0	Count	15_a	19_a	11_a	22_b	67
		% within Year	10.9%	19.0%	19.6%	59.5%	20.2%
	1	Count	123_a	81_a	45_a	15_b	264
		% within Year	89.1%	81.0%	80.4%	40.5%	79.8%
Total		Count	138	100	56	37	331
		% within Year	100.0%	100.0%	100.0%	100.0%	100.0%

Each subscript letter denotes a subset of Year categories whose column proportions do not differ significantly from each other at the .05 level.

Table 3.6 Descriptive statistics of the differences between proportion of students reporting to use Assignment Examples as a resource in learning to write scientifically.

			Year				
			1	2	3	PG	Total
Examples	0	Count	35a, b	17b	8b	16a	76
		% within Year	25.4%	17.0%	14.3%	43.2%	23.0%
	1	Count	103a, b	83b	48b	21a	255
		% within Year	74.6%	83.0%	85.7%	56.8%	77.0%
Total		Count	138	100	56	37	331
		% within Year	100.0%	100.0%	100.0%	100.0%	100.0%

Each subscript letter denotes a subset of Year categories whose column proportions do not differ significantly from each other at the .05 level.

Postgraduate students were additionally asked to reflect on the types of activities undertaken during their postgraduate studies that contributed significantly towards preparation to write scientific publications, typically considered a major output of their studies. These results are summarised in Figure 3.8 below and indicate that postgraduate students consider feedback from their supervisors to be the greatest contributor towards their preparation to write scientific publications. While peer review, imitation of publications in the field and co-authorship with supervisors all ranked moderately. The data was reported by students from the Colleges of Science & Engineering and Medicine & Public Health, n=37.

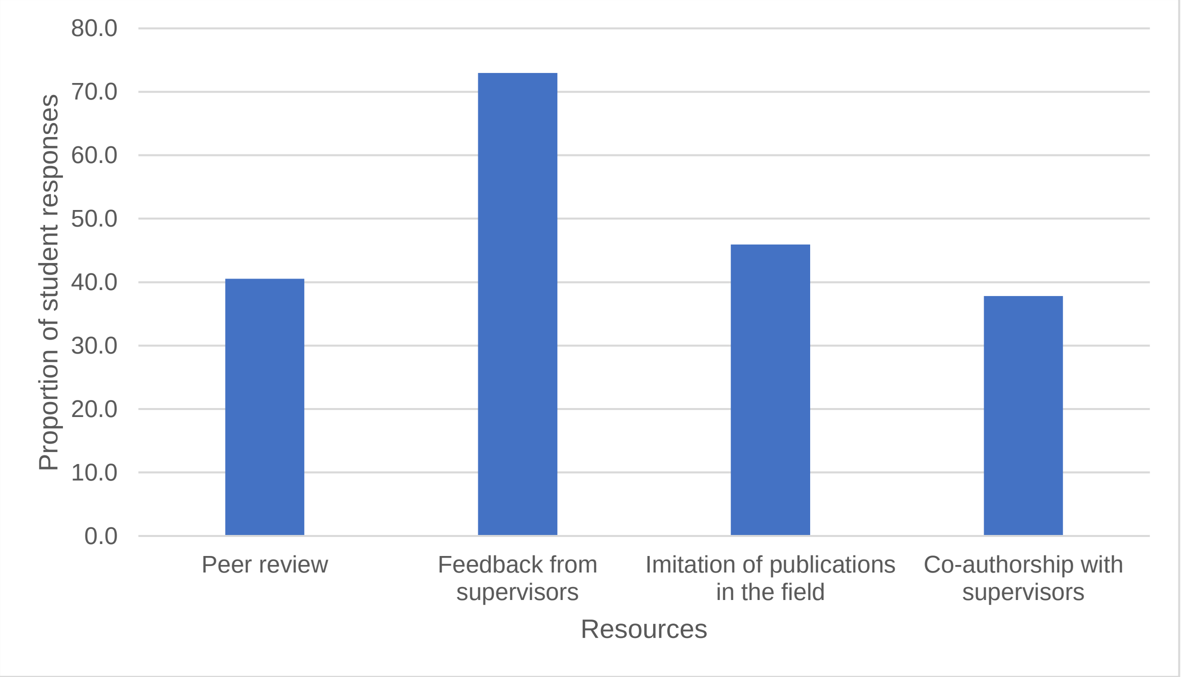

Figure 3.8. Resources identified by postgraduate students as most useful in learning to write scientifically.

Results indicate that postgraduate students deem feedback from their supervisors to be the most valuable resource in developing their written skills (73% of respondents, n=37). Responses outside those that are shown here also included students own reflective practice such as engaging in research and continued writing in some form to “keep up skills”.

3.6.5 Discussion

The results indicate no significant differences between resource usage between undergraduate year levels, but significant differences between undergraduate and postgraduate resource usage with a decrease in the use of Rubrics and Assignment Examples. If there is no significant change in the types of resources that students use to develop their writing throughout their undergraduate degree program, or the way in which they are used, then it is likely that students are continuing to use surface-level learning strategies as described by Alexander (2003) of simple imitation as they acclimatise to the disciplinary environment. This type of learning behaviour is expected during the first year in higher education as students transition to a new learning environment and understand new academic requirements (Donnison & Penn-Edwards, 2012). However, previous research by Alexander et al. (2004) demonstrated the learning approaches of undergraduate students within specialist majors did not differ to those outside of that major, indicating that surface-level learning strategies are common amongst entry level learners and are not linked to interest in a discipline. Simply being interested in science is not sufficient to alter learning behaviours of students, therefore further investigation is needed to understand when this shift occurs. A shift in strategy or resource usage is expected when learners use deeper level cognitive process related to competence and proficiency within a disciplinary activity (Dinsmore & Zoellner, 2018), and can even predict student outcomes in disciplinary engagement and learning (Platow, Mavor, & Grace, 2013). Therefore, we would expect that if learners are developing disciplinary writing skills as they progress through their degree program to see a change in the types of resources that they use to develop those skills. Learning approach has been linked to motivation in language studies (Campbell & Storch, 2011) and this can shift over time. Thus, learner approach may not necessarily be determined by the developmental progression of a student through a degree program, instead it may be influenced by factors of engagement. Such a shift in behaviour is likely to be strongly tied to learner attitudes but may also be impacted by the environment that a student finds themselves in. Greenleaf and Valencia (2017, p. 2) assert that students “have very little opportunity and support to use texts for purposeful learning in the subject areas, and thereby to gain needed dispositions, strategies, and skills” before they reach higher education. Students rely heavily on the learning materials that their teachers tell them to use. Thus, students entering their first year of an undergraduate degree program are particularly in need of explicit strategies and support to develop these skills. This type of behaviour is common amongst students and is reflected in the way information seeking is often tied to assessment (Tury, Robinson, & Bawden, 2015). Guiding students in not only which resources to use, but how to use them. With increasing reliance on technology and cut and paste attitude to writing development, there is a need for educators to guide students on the ways to learn how to write using a range of resources. Students do not innately know how to find these resources, or which are suitable in helping them learn to write, thus educators have a responsibility to guide students towards useful resources to support student learning. The artefacts associated with this exegesis address this need by orienting students with the literature that is relevant to the discipline and the specific context that they have been asked to address for assessment. By guiding students to read and understand texts that are like those they have been asked to create through assessment, there are opportunities for students to make connections between reading and writing. By focussing questions to prompt reflection on the example text students are required to engage with a deeper level of learning in their reading, thus when they move to writing they are likely to be better prepared, not just in understanding the content but also the form and mode of the writing that is expected within the discipline.

The results demonstrated a shift in resource usage in postgraduate students, however this may be explained due to the resources being commonly associated with specific assessment tasks more often found in undergraduate coursework and not in postgraduate study. However, interpretations of why these differences occur must be treated carefully as the wording of the survey question specifically asked respondents to reflect on their experience as an undergraduate and it can be difficult to reflect only on past behaviour once a student has moved into postgraduate studies, therefore the responses recorded may indicate a shift in behaviour during the period of postgraduate study instead.

The notion that the transfer of knowledge and skills between disciplines can occur and that disciplinary expertise can be developed is contentious in the literature (Bransford & Schwartz, 1999; Luca, 2019; McCarty, 2019) however, there is broad agreement that experts have the following characteristics: “extensive and highly integrated bodies of domain knowledge, are effective at identifying underlying problem structures, select appropriate solution strategies for domain-specific problems, and can retrieve pertinent content knowledge with minimal cognitive effort” (Alexander et al., 2004, p. 545). These skills have the potential for development, suggesting that expertise can also be developed or taught. However, the behaviours described in the results presented here indicate that undergraduate students are not using a variety of resources or experiences to foster these skills.

In developing expertise, students must take a broader view of the discipline, understanding and considering a wider context than a simple assignment offers within a unit or course. The ability to relate individual tasks to the broader application within a discipline is described by Yancey et al. (2014) in an analogy of a road map and a GPS in guiding students to a learning destination. It is the role of educators to provide this clear pathway with explicit direction, effectively scaffolding the learning experience and guiding students to the resources needed to develop their reading and writing potential. Academics who already have an understanding of how to navigate the discipline are in a position to provide guidance to those who are still learning in the field. As Yancey et al. (2014, p. 42) explains, educators must provide an overall view of writing to students, helping them to navigate through individual writing assessments while building upon the experience as a whole to support the development of disciplinary literacy and expertise.

> Without a large road map of writing, students are too often traveling from one writing task to another using a definition and map of writing that is the moral equivalent of a GPS device. It will help students move from one writing task to another, but it can't provide them with the sense of the whole, the relationships among the various genres and discourse communities that constitute writing in the university (and outside it), and the opportunity for an accompanying agency that a fuller map contributes to—nor will the GPS support the development of expertise.

Similarly, as students limit the resources that inform their writing development, they will continue to maintain a narrow pathway on their learning journey, rarely diverging into the exciting and rarely trodden grounds that lead to expertise.

These results support findings by Arum and Roksa (2011) and may help to explain why students fail to improve in writing skill development throughout an undergraduate degree program as they are not doing anything differently than they have done before. Development of new skills requires changing behaviour, testing those skills in a new environment and changing the way learning is approached, effectively scaffolding the learning pathway. Yet the results here indicate that student behaviour, at least regarding resources used in writing development, do not significantly change across an undergraduate degree program. Therefore, we must ask is there a point at which these skills develop, or are they a serendipitous by-product of completing a degree program?

The differences between responses from undergraduate and postgraduate students may help to us to understand the point at which student behaviour and experience changes. Whilst more than half of the postgraduate students surveyed had completed their undergraduate studies at Flinders University their reflections on that experience differed from current students. Given that a similar undergraduate program has been in place for approximately 10 years it is likely that many of these students share the experiences of current students, yet their survey responses indicate differing use of resources. There are two possible explanations for this dichotomy. Firstly, students that continue onto postgraduate studies are behaving differently to most of the student cohort, employing a wider range of strategies to develop writing skills within their discipline. Secondly, upon reflecting on their experiences of writing as an undergraduate it is likely to be difficult to separate this from behaviours that they now use and the skills that they have learnt through their postgraduate experiences. Open ended responses indicate that there was dissatisfaction with learning material provided during the undergraduate degree program with one student stating "Uni resources are rubbish. Learned though self-assessment and peer feedback", a sentiment that was not expressed by the undergraduate cohort. However, it is not possible from this data to determine the exact nature of this reflection upon the experience of learning. Of note, and an aspect that may have contributed to the reflections of postgraduate students is the widespread introduction over the last decade of Turnitin, a program used to check the academic integrity of students' written submissions and touted as anti-plagiarism technology. As good practice students are reminded to check not just the originality of their submission via the Turnitin report but also reflect on the structure of their writing (Graham-Matheson & Starr, 2013; Penketh & Beaumont, 2014; Rees & Emerson, 2009). More recently the focus on using this type of technology has been on the advantages of students developing literacy in appropriate conventions within the writing style through multiple drafting (Silvey, Snowball, & Do, 2016). It is possible that the introduction of Turnitin has prompted students to use this as an additional resource in developing their writing skills, and this may provide an opportunity to further develop disciplinary literacies associated with text configuration.

The results show that there are differences in the behaviours of undergraduate and postgraduate students in the way they perceive, interpret and use their learning environment. The path to expertise is not easy to travel, it is overgrown and strewn with hazards. But it is these hazards that students must tackle, the challenges along the way, that allow understanding to grow and expertise to develop, the path that is being trodden by postgraduate students. Only by experiencing the challenges can students develop expertise in writing. By undertaking writing and using a variety of resources to do so students develop a range of skills that enable the integration of domain knowledge, a characteristic of expertise.

It is the role of educators to support students to develop these skills by incorporating supportive strategies into the curriculum. Imitation is not a poor strategy for novices to use, it can help orient them in the discipline (Alexander, 2003) providing context for their learning. However, in order to move students from novice towards expertise educators must differentiate resources and learning approaches. With students overwhelmed with the plethora of information and resources available to them it is our role as educators to guide them in navigating and learning this process, not doing it for them (Brabazon, 2016a). Students should be encouraged to read more widely, including real examples of the types of writing that are expected through their assessment. It is how this is presented in the artefacts associated with this thesis that differentiates them from other forms of writing support materials, as they are designed to balance the needs of students unfamiliar with discipline specific forms of writing as well as providing opportunities for transfer between their writing and in-class experiences. The artefacts are based on authentic examples of disciplinary text, providing exemplars of writing for students to orient them within the discipline, whilst providing opportunities to link this understanding with the knowledge they have already developed around laboratory or field experiences. Thus, building upon existing knowledge and situating the new information in a way that enables transfer of knowledge from one mode to another.

Noticeably absent from the student responses were real examples of writing situated in published literature. Undergraduate students included in this research project were specifically required to complete a written assessment based on a scientific journal article, yet no responses indicated that their own writing modelled this form or used genuine examples in their writing development. It should be noted that the inclusion of peer reviewed journal articles was a minimum requirement of the assessment criteria, and students adhered to this. Thus, students were aware of this mode of writing, were already accessing it and using the content to inform the structure of their writing, but not necessarily translating this to developing their own writing skills around language choice, style and sophistication. This may indicate that students were simply not aware of the link between the assessment and the real-world task or perhaps did not consider writing resources outside those that were provided by their teachers. Since gathering these data sets, I have had the opportunity for informal conversations with students regarding their selection of resources in supporting their writing. When students approached me for additional feedback regarding their assessment, I asked them to reflect on what resources they used to help them understand how to write sections of the assignment. As this was not part of the initial project methods, and therefore not covered by the ethics approval, conversations are not included here. This revealed that for those few students that I spoke to, they had not made the connection to the potential for imitation or modelling using published journal articles, rather when this was pointed out to them it was described as an ‘Aha’ moment where they could now see the links and translate them to their own writing development. This was especially evident in the presentation of tables and figures, which have specified requirements for each discipline and often differ between each publisher. After these discussions’ students noticed the elements that were common between published journal articles and the assessment requirements.

The results presented here highlight an opportunity to support learners in their journey to develop writing expertise within the discipline. The gaps that appear in a learner’s toolkit should be developed during progression through an undergraduate degree program, not left to postgraduate supervisors to begin this task. Through carefully considered assessment design allowing scaffolding of written tasks and explicit alignment to real-world writing activities educators can provide meaningful opportunities for students to develop writing skills and move beyond novice modes of learning.

3.7 E-Learning Modules

3.7.1 Introduction

The role of e-learning and digitisation in developing and communicating writing skills is diverse. Whilst this medium offers substantial cost savings by moving what might be done face-to-face into an online platform with the potential to service vast numbers of students simultaneously, there are additional benefits to students in implementing digital learning support materials such as the e-learning modules that form the artefacts of this research project.

Building confidence in one's own abilities is a crucial aspect of our students learning journey. Student's beliefs about themselves are strong predictors of their performance, effort and perseverance with a task (Bandura, 2006; Pajares, 2003, 2007; Zimmerman & Bandura, 1994). The e-learning tools were specifically designed to ensure that students were able to attempt them multiple times in a low-risk setting prior to assessment tasks. Students had access to the e-learning modules several weeks prior to the introduction of the associated assessment tasks and were encouraged to review the materials to become familiar with the content. For students that typically find approaching academic staff confronting or intimidating, or those suffering from assessment anxiety (McEwan, Elander, & Gilbert, 2018) this afforded an opportunity for students to develop their writing in a formative setting which research indicates helps to reduce assessment related anxiety (Sarı, 2019) allowing learners to engage more effectively with the task.

While students need clear instructions in the form of guidelines or rubrics to help guide the structure and make clear expectations for assessment purposes, these alone are not sufficient in preparing students for academic activities such as professional or technical writing (Biggs, 2011; Tonissen, Lee, Woods, & Osborne, 2014). Rather students learn through active modes where they experience moments of learning and are provided opportunities to practise these in meaningful and authentic ways. Digital learning platforms, with the ability to practise these skills in a low-risk setting make this experience possible.

The e-learning modules that form the artefacts of this PhD thesis support learners in the contextualisation and early-competence phases of disciplinary literacy. They are designed to assist students in orientation of the discipline, guiding them towards appropriate text selection and formation for the discipline, as demonstrated in Figure 3.9 and 3.10 which depict excerpts from the artefacts to demonstrate writing a scientific writing assignment.

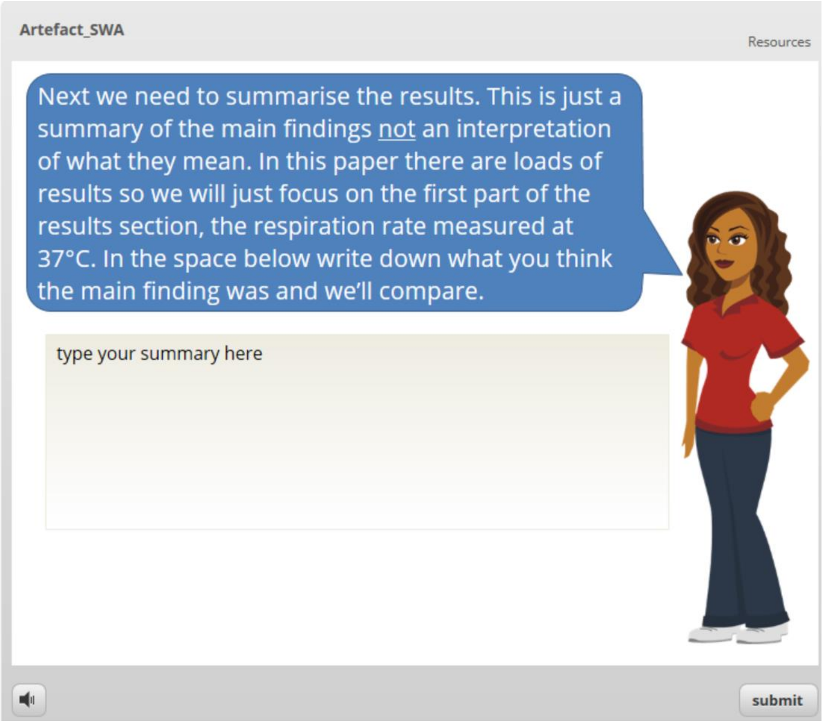

Figure 3.9 An excerpt from the Scientific Writing Assignment e-learning module depicting an activity to orient students in reading and interpreting texts within the discipline.

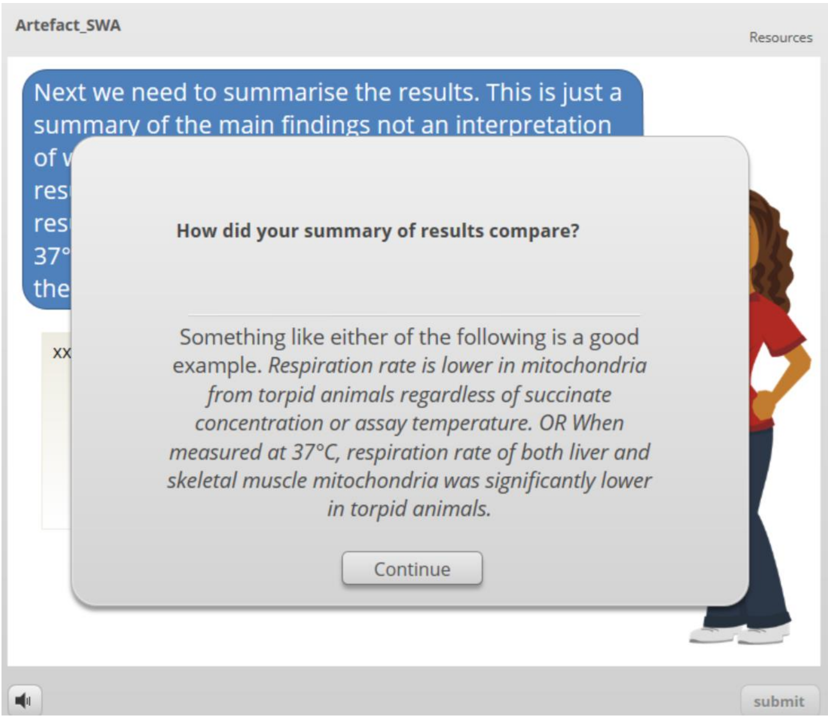

Figure 3.10 An excerpt from the Scientific Writing Assignment e-learning module depicting an activity with embedded examples to orient reading and writing of disciplinary texts.

The artefacts demonstrate the importance of supporting contextualisation with text formation in a discipline, by scaffolding the learning environment moving students from contextualisation to early competence in the way they develop their approach to writing in the discipline. Providing those opportunities for students to develop confidence in an effort to shift them from using surface-level approaches to engage more with the discipline and begin to make connections between other disciplines. It is critical that surface level approaches as well as opportunities for deeper learning strategies are supported at the first-year level in higher education, as this enables the learner to become oriented in the discipline. However, as the learner progresses the learning environment must shift towards deeper strategies or there is a risk that learners continue to use surface level learning and do not develop the wider range of skills associated with expertise development.

Embedding the practice of writing within existing curriculum is known to have significant benefits in student learning (Tonissen et al., 2014; Willems-Jones et al., 2019) and using an e-learning approach ensures that precious discipline content is not pushed aside to make room for the development of writing skills. Additionally use of e-learning modules to support literacy development is likely to have benefits for academic staff such as improved consistency in teaching practice across broad disciplines; consistency in feedback, even in very large classes; ease of implementation and delivery through a variety of learning management systems as well as access to detailed learning analytics to aid in the assessment of e-learning modules as a learning tool (Willems-Jones et al., 2019).

Whilst outside the parameters of this doctoral research, the use of e-learning modules also allows for opportunities to incorporate a variety of modes of communication other than written genres. As e-learning modules can be readily modified to include imagery, video, podcast, vlogs etc producing an interactive medium, allowing the demonstration of multimodal communication. By providing relevant and authentic examples of scientific writing within e-learning modules it is anticipated that students would be more likely to develop writing skills that are long lasting, rather than disconnected from reality and focussed on passing an individual assessment task. By performing these tasks and situating them in an authentic context, learners are provided insight into workplace expectations signifying that writing is valued by the disciplinary community (Ware et al., 2019).

The form and presentation of e-learning modules is integral to the way students engage multimodality theory as a learning tool (Bezemer & Kress, 2008) with inclusion of both text and images in combination to allow greater clarity for learners. The use of a guide to assist the learner in identifying important aspects on which to focus is deliberate and speaks to the values that are inherent in the scientific community. By making these explicit in an accessible way, students can make the connections between assessment practices that they experience and current discipline practices in their field. Bezemer and Kress (2008, p. 168) describe the use of text, visuals and layout by learning designers as the *Potentials for Learning* "the ensemble of semiotic features of a text or of an environment—objects, texts, people—that provides the ground for learning and in that way may shape what learning is and how it may take place." The embedding of multiple forms of information is crucial to learning and the transfer of knowledge, enabling a learner to recognise and transfer existing knowledge into a new context.

The results presented in this section investigate the impact of implementing the artefacts. Each artefact was implemented in a different first-year Biology unit offering in 2019 to demonstrate the value of providing a range of diverse forms of scientific communication to both students and academic staff. By exploring how students make use of the artefacts and their relationship between skill development and student confidence in performing similar tasks an understanding of how disciplinary literacy develops will emerge.

3.7.2 Methodology

Disciplinary identity is developed through disciplinary socialisation (A. Wilson, Howitt, Wilson, & Roberts, 2012), resulting in self-efficacy and confidence to perform within the norms of a discipline (Robnett, Chemers, & Zurbriggen, 2015). The results presented in this chapter are two-fold, analysing the self-efficacy of students in performing writing activities routinely associated with the discipline while also assessing their performance carrying out these tasks. Therefore, two approaches are necessary. In assessing self-efficacy in performing an academic task the predictive value is only reliable when the task is specific and clearly articulated (Pajares, 1996) which has been carefully considered in the method design. In this study self-efficacy will be used as a measure of confidence in one's ability rather than an indicator of actual ability, thus reducing any impact of misalignment of the two factors. In order to asses any impact of e-learning modules on writing skill development an analysis of performance measures was undertaken using an ontological approach, reducing the subjectivity associated with determining what 'good' writing looks like.

3.7.3 Pedagogy

Careful consideration was given to the design, development and implementation of the e-learning modules that form the artefacts of this thesis to ensure that learners experienced an engaging and disciplinary relevant learning experience. Underpinning the development of e-learning modules to provide students experience in writing within a scientific setting used constructivist perspectives of learning science and the embedded-explicit intervention model typically used with younger audiences to develop general reading and writing skills (Justice & Kaderavek, 2004; Kaderavek & Justice, 2004) and more recently to develop disciplinary literacy skills with middle school science students (Anthony, Tippett, & Yore, 2010), resulting in an experience where learners write-to-learn (Yore et al., 2003).

Three approaches to writing development pedagogies were deployed across the modules and where possible in combination through all modules. These approaches included:

- **Product-based.** Students develop writing proficiency through imitation, modelling vocabulary and syntax on discipline specific examples (Badger & White, 2000).
- **Process-based**. The formation of texts is the focus, rather than the text itself, emphasising the importance of drafting and revision and the recursive nature of the writing process (Nordin, 2017).
- **Genre**. Attention is placed on the social context in which writing is produced, providing explicit and systematic explanations of the ways in which language functions in social contexts (Hyland, 2003).

In combination, these approaches provide a powerful tool in writing skill development, enabling learners to understand not just one aspect of writing within their discipline but the nuanced features that are important to their own context.

These approaches were also combined with providing students a range of choices in contexts meaning that not only would they access material from their own specific sub-discipline. If they chose to expand their discipline boundaries, they could do so, providing them with insight into how scientific language is used in a variety of fields.

Students were given autonomy to choose their own pathway through the e-learning modules, thus each learner created their own personalised learning experience, which research suggests results in improved engagement with the learning activities (Rodríguez-Ardura & Meseguer-Artola, 2019).

The educational aims of deploying e-learning modules in undergraduate classes are two-fold; firstly, to address academic performance of students undertaking the assessment task and provide support to enable improved performance of the task and secondly, to provide opportunity for students to develop confidence in performing the associated task. Each of these aspects of the e-learning modules will be analysed in detail.

3.7.4 Method

The e-learning modules are specifically designed to assist students to develop disciplinary specific writing skills related to key scientific communication genre (scientific journal articles, impact statements and persuasive essays) that communicate with a variety of audiences (discipline specific experts, non-expert professionals and the general public). The e-learning modules have been applied and evaluated within first year Biology topics within the College of Science and Engineering during 2019. The e-learning modules accompanying this thesis are presented in the same form that students accessed them during the study.

Analysis of the impact of two of the interventions (SWA and DP) was carried out using a comparison of pre/post assignments as well as responses to surveys to interpret student perceptions of writing ability. The SWA e-learning module was implemented in semester one of 2019, and the DP e-learning module was implemented in semester two of 2019. Both forms of assessment were already in place in the units prior to the present study commencing. Surveys were deployed at the end of the first semester and again at the end of the second semester to gather responses from first-year students regarding their experiences. The survey responses were anonymous and pre/post survey data was not linked. Students were invited to include identifying information to enable analysis of how student confidence developed over time, however very few students who completed the initial survey also completed the second survey, thus analysis proceeded using unlinked data.

In the second semester of 2019 an Impact Statement assessment task was introduced into the core first year Biology unit, expanding the breadth of communication skills expected of students. The Impact Statement e-learning module includes genuine examples of Impact Statements written by academic staff within their discipline demonstrating the importance and significance of this type of task to the real world and future employment. The task was linked to an authentic research project in which the students carried out laboratory or field-based projects and reported on the results in the form of a poster presentation at a student conference. The Impact Statement component was designed in establishing authentic experiences of scientists in seeking funding for their research project. As the Impact Statement was introduced as part of this research project pre/post analysis was not possible. Assignment assessment was compared to student perceptions of ability to determine if there is a link between confidence and development in disciplinary literacy skills.

In the implementation of the e-learning modules course/unit, coordinators opted to make the completion of the modules mandatory in 2019 by setting them as a hurdle to complete before access to the assessment submission point via the learning management system (LMS). Therefore, students were unable to submit an assessment item until they had completed the associated formative e-learning module.

This requirement was removed on the day of submission to enable students who had not engaged well to still submit if they chose to. This resulted in approximately 94% student engagement with the e-learning modules and over 10,000 views as students were encouraged to attempt e-learning modules several times to assist in the development of assignments.

All assessment instructions, guidelines and rubrics were available for students to review and were discussed explicitly within the e-learning modules to connect these materials to the assessment tasks. This also addresses the common issue in educational research of bias due to opt-in data collection. All students completed the e-learning module, however the survey regarding their perceptions of confidence was opt-in. Assessing any improvements in grading due to the e-learning modules was made possible due to the use of detailed electronic rubrics across both years, making analysis of assessable learning gains clear. The cohort between 2018 and 2019 were assessed by a similar group of casual academic staff, many of whom taught and assessed in both years.

To assess student confidence in performing scientific writing tasks both undergraduate and postgraduate students were included in this analysis. Undergraduate confidence was reported pre and post the introduction of the novel assessment task. Postgraduate students were included to provide a point of reference as they would traditionally be expected to have a strong grasp of disciplinary knowledge and were at varying stages of expertise but would no longer be considered novices within their field.

Student assessment data was considered independent between years, with no individual student belonging to more than one cohort. The de-identified data was first examined for homogeneity of variance using box and whisker plots with error bars and any outliers closely inspected to determine if they should be retained. A Shapiro-Wilk test was undertaken to determine the distribution of samples to ensure the most appropriate statistical analyses were applied. The Shapiro-Wilk test determines if the observed samples deviate from the normal curve. Samples that were normally distributed were analysed using an independent samples t-test, which determines if a difference exists between the means of two independent groups on a continuous dependent variable. Samples that were non-normally distributed were analysed using a nonparametric Mann-Whitney U test, which is also used to determine if there is a difference between two groups on a continuous dependent variable, however is more robust when the data fails the assumptions of normality. The Mann-Whitney U test statistic is indicated by U and the standardized test statistic by z, which represents the standard score used to obtain an asymptotic p-value in a normal distribution. Significance was set at a p-value of less than 0.05. To further describe the data the median (M), mean ($\bar{x}$) and standard deviation (σ) are also presented.

Student survey responses were analysed using the chi-square test of homogeneity to determine if a difference exists between the binomial proportions of three or more independent groups on a dichotomous dependent variable. For samples that violated the requirements the Fischer's exact test was used, which determines whether two dichotomous variables are independent. Where statistically significant differences in proportions were found, the z-test of two proportions with a Bonferroni correction was applied to determine the differences between groups. The Bonferroni correction compensates for the increase in likelihood of incorrectly rejecting a null hypothesis due to multiple comparisons by testing each individual hypothesis at a significance level determined by the number of comparisons.

3.7.5 Results

Impact of e-Learning Modules on Student Performance

To investigate if the introduction of the e-learning modules impacted student performance assessment results were analysed for both the Scientific Writing Assignment (SWA) undertaken as part of the unit Molecular Basis of Life, a first year, first semester unit of study, and Discussion Paper (DP) undertaken as part of the unit Biology and Society, a first year, second semester unit of study. These assessment items are graded for their academic merit using an electronic rubric facilitated through the LMS. Due to the large number of student submissions for the SWA in Molecular Basis of Life, the grading is undertaken by a group of casual academic staff who are trained to make consistent judgements of student work. To ensure this consistency is maintained unit coordinators moderate a subset of student submissions, providing feedback to casual academic staff on expectations. Assessment for the DP was not moderated in the same fashion and is described in detail later in this section.

Scientific Writing Assignment

The use of an electronic rubric means that detailed data is available for comparison, providing an opportunity to compare student performance in detail from year to year, thus results could be compared before and after the introduction of the e-learning resources. The detailed rubric can be found in Appendix C. An exploration of the data from student assessment of performance on the SWA was undertaken to determine if it was homogeneous by creating a box plot using SPSS and investigating for values greater than 1.5 box-lengths from the edge of the box. Each outlier was individually inspected in further detail to understand any reasons for divergence from the data set. Each outlier was removed as they all were examples of incomplete submissions, thus did not represent the overall product for comparison to the rest of the cohort.

Additionally, a Shapiro-Wilk's test was performed to determine if the samples were normally distributed and this indicated non-normal data ($p < .001$). Therefore, further analysis to compare means was performed using an independent samples nonparametric Mann-Whitney U test. The result of this analysis indicated that the distribution of grades was the same across both years, $U = 91775$, $z = -0.546$, $p = .585$. Figure 3.11 describes the median assessment score for the SWA in both 2018 and 2019. The mean ($\bar{x}$) and standard deviation (σ) were calculated for each individual criterion of the assessment task and comparison between the cohorts was undertaken and shows the 462 students that did not use the module in 2018 (M = 80, $\bar{x}$ = 77.9, σ = 13.3) compared to the 406 students that used the e-learning module in 2019 (M = 79, $\bar{x}$ = 77.7, σ = 11.9) demonstrated no significant difference in overall assessment grade. The box and whisker plot error bars show the 95% confidence interval, the bottom and top of the box are the 25th and 75th percentiles, the line inside the box is the median. Results were achieved by students in 2018 (n=462) and 2019 (n=406) enrolled in the unit Molecular Basis of Life. The inhomogeneity between the two cohorts of students that completed the Scientific Writing assessment may be explained by the requirement of all students to complete the e-learning module in 2019, a requirement not previously in place. This is likely to have reduced the number of students submitting assessments that were incomplete and would otherwise have achieved very low scores, as is seen in the 2018 cohort.

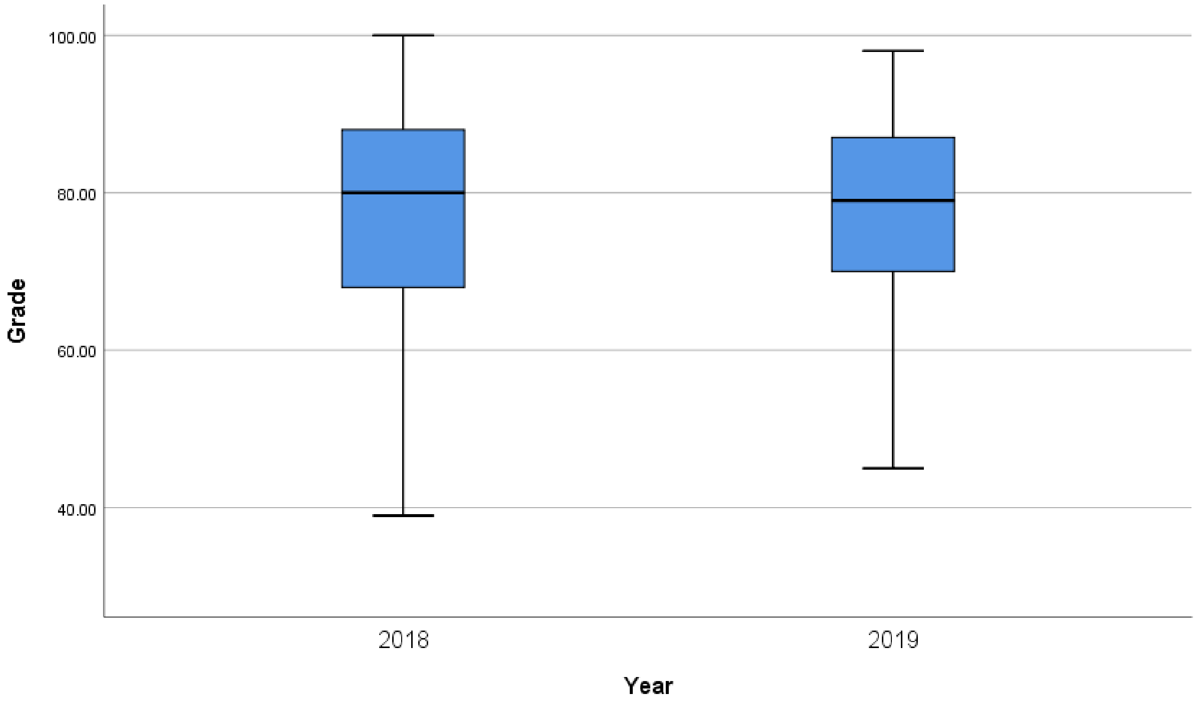

Figure 3.11. Median scores of Scientific Writing Assignment between 2018 and 2019. The bold horizontal line indicates the sample median. The blue areas indicate the upper and lower quartiles and the error bars indicate the upper and lower extremes of the samples.

To determine whether any differences occurred within each section of the assessment criteria, further detailed analysis was undertaken. Figure 3.12 describes the mean +/- standard deviation for each of the criteria listed in the assessment rubric in order to determine if there was any impact of the e-learning module on particular aspects of student writing. The error bars indicate the standard deviation from the mean of each data set. Results were achieved by students in 2018 (n=462) and 2019 (n=406) enrolled in the unit Molecular Basis of Life. To compare means between the cohorts an independent samples nonparametric Mann-Whitney U test was performed. Complete analyses are included in appendix B. The result of this analysis indicated that there was a small yet significant difference in the distribution of grades in some areas of the assessment criteria. Small yet significant decreases in performance were observed in the 2019 cohort in the criteria of Introduction (link between aims and background information) ($p = .004$), Introduction (hypothesis) ($p = .001$), Methods (content) ($p = .015$), Conclusion (application of research) ($p = .018$) and Language ($p < .001$). Small yet significant improvements in performance were observed in the 2019 cohort in the criteria of Results (figure) ($p = .003$) and Layout ($p < .001$). The results of the independent samples nonparametric Mann-Whitney U test indicated that null hypothesis was accepted for all other assessment criteria as differences observed between years were not statistically significant. Thus, the impact of the SWA e-learning module is complex, and it is likely to be influencing student writing in a variety of ways. On further investigation it is noted that the criteria that student performance decreased after completing the e-learning module for the SWA were also those criteria that are present in many other forms of scientific writing and are likely to have been undertaken previously by many students, indicating a reliance on the e-learning modules for these areas rather than an application of pre-existing skills. The same can be said for the aspects that recorded no significant difference in performance as these criteria are common in laboratory reports that many students experience during secondary education. However, the criteria that are novel in this assessment, which include the Results (figure) and the Layout demonstrated small yet significant improvement in student performance indicating that by imitating the examples provided in the e-learning module that students were able to develop their writing skills by applying the knowledge gained from the e-learning module. Of note is that many assessors commented that they felt overall student performance had improved in the 2019 cohort (anecdotal comments recorded during unit staff meetings, 76.5% n=34) , that students had better adhered to the criteria described in the instructions and rubric, yet this is not reflected in their rubric assessment of the task. This may indicate a limitation in the alignment of the rubric with the assessment task and the writing development that is scaffolded. With focus within the rubric on overall structural components rather than specific language development, these factors must be considered when interpreting this data.

To determine if the differences observed between cohorts were specifically related to writing ability or indicative of differences in academic ability more generally the final exam grades for each cohort were compared. The final exam consists of 100 multiple choice questions designed to assess the material presented in both lectures and practical classes throughout the semester. The exam questions differed only in small ways between years so they could be considered to assess the same level of content and understanding and were not reliant on students' ability to explain concepts using text. Analysis to compare mean exam grades was performed using an independent samples nonparametric Mann-Whitney U test. The result of this analysis indicated that the distribution of grades was the same across both years, $U = 2688022$, $z = -1.083$, $p = .279$, suggesting that there was no underlying difference in academic ability between the cohorts. Thus, researchers can be confident that any decreases observed in assessment grades are likely a product of the e-learning module rather than the result of a less capable cohort of students.

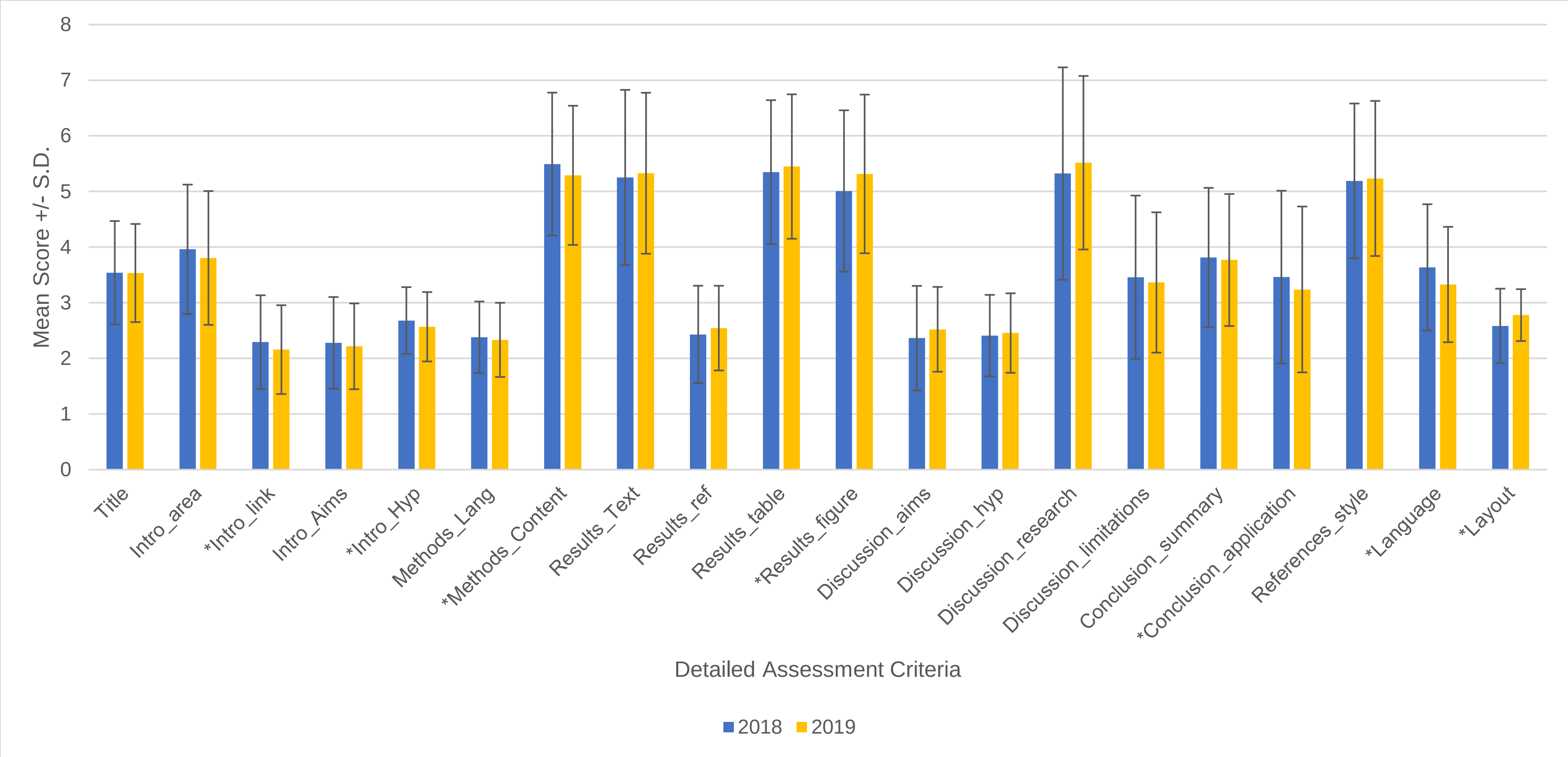

Figure 3.12. Mean scores characterised by assessment criteria of section headings in the Scientific Writing Assignment. Criteria labelled with * indicate a significant difference between cohorts.

E-learning through a Pandemic

An unprecedented disruption to teaching arose during the first teaching semester of 2020 from which an occasion emerged to support students continue their undergraduate programs fully online. The COVID-19 pandemic resulted in all teaching activities associated with the SWA shifting to a virtual environment and created a unique opportunity to test the impact of the e-learning module on student performance. Students had been able to complete the first portion of the associated practical activity in the laboratory prior to the shift online and thus were familiar with the experimental procedures. The remaining data collection that would usually be performed in a second laboratory session was provided in a virtual simulation and students recorded and analysed sample data in order to complete the associated assessment. As students were shifting to a virtual environment and dealing with a range of new and unexpected challenges the hurdle of compulsory completion of the e-learning module prior to submission was removed, reducing the likelihood that students would experience an overload in online content. However, students were provided with the same range of support materials as in previous years and were reminded to make use of the e-learning module to support their writing development.

Analysis of student completion indicated that 40.3% of students in the 2020 cohort accessed the e-learning module as a resource to complete the SWA. An exploration of the data from student assessment of performance on the SWA was undertaken to determine if it was homogeneous by creating a box plot using SPSS and investigating for values greater than 1.5 box-lengths from the edge of the box. Each outlier was individually inspected in further detail to understand any reasons for divergence from the data set. Each outlier was removed as they all were examples of incomplete submissions, thus did not represent the overall product for comparison to the rest of the cohort. A Shapiro-Wilk's test was performed to determine if the samples were normally distributed, which indicated non-normal data ($p < .001$). Analysis to compare means was performed using an independent samples nonparametric Kruskal-Wallis test. The result of this analysis indicated that the distribution of grades across years was significantly different, X^2 (2) = 13.663, p =.001. Figure 3.13 depicts the comparison of median assignment grades between cohorts in 2018 (without e-learning module), 2019 (all students used the e-learning module) and 2020 (student choice of module completion) and shows a significant decrease in the median grade in 2020 (M = 77, $\bar{x}$ = 75.3, σ = 12.6) from either of the previous cohorts in 2019 (M = 79, $\bar{x}$ = 77.7, σ = 11.9) and 2018 (M = 80, $\bar{x}$ = 77.9, σ = 13.3).

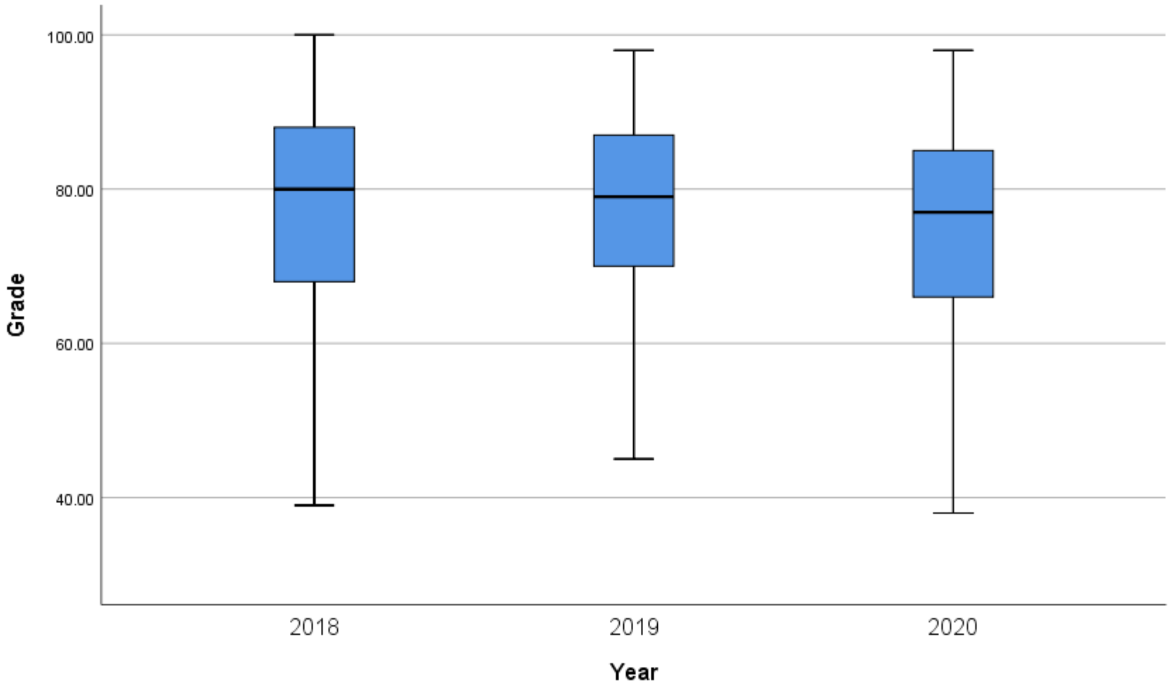

Figure 3.13. Median grades between cohorts in 2018, 2019 and 2020. The bold horizontal line indicates the sample median. The blue areas indicate the upper and lower quartiles and the error bars indicate the upper and lower extremes of the samples.

Whilst the decrease in performance may be somewhat attributed to the distruptive experience of shifting to an online learning environment at speed, it is likely that there are additional causes. To investigate this further the differences between student assessment of those who did or did not use the e-learning resource were compared. The same process was followed as described above to determine homogeneity of samples and outliers were removed only if they were incomplete submissions. A Shapiro-Wilk's test indicated that the samples were not normally distributed, thus an independent samples nonparametric Mann-Whitney U test was used to determine any differences between the mean grade of each group. Figure 3.14 depicts the median assessment grades between students in 2020 that did or did not complete the module. The results demonstrate that students that did use the e-learning resource to develop their writing skills achieved significantly higher grades U = 39417, z = 5.187, p <.001, (M = 80, $\bar{x}$ = 78.8, σ = 12.0) than their peers that did not use the e-learning resource (M = 73, $\bar{x}$ = 73.1, σ = 12.4). In fact when only comparing the students that used the e-learning resources in 2020 to previous cohorts in 2019 and 2018 the results indicate no significant difference between median grades of any group X^2 (2) = 0.893, p =.640.

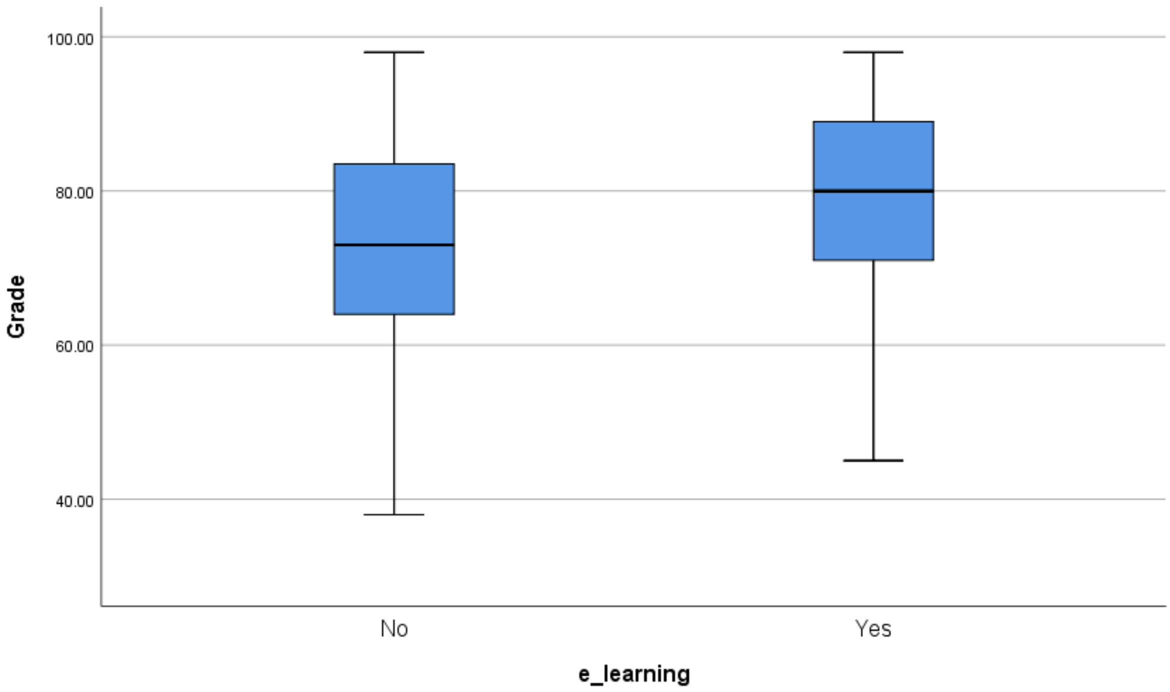

Figure 3.14. Median grades between students that did not use the e-learning module (depicted by ‘no’) and students that used the e-learning module (depicted by ‘yes’). The bold horizontal line indicates the sample median. The blue areas indicate the upper and lower quartiles and the error bars indicate the upper and lower extremes of the samples.

Figure 3.15 describes the mean +/- standard deviation of each of the criterion listed in the assessment rubric in order to determine if the overall improvement in mean grade was reflected in any particular criterion or across many criteria. These results were achieved by students without the e-learning module (n=304) and with the e-learning module (n=205). Further analysis to compare means between students who had or had not completed the e-learning module was performed by means of an independent samples nonparametric Mann-Whitney U test, which established that students who had undertaken the e-learning module performed significantly better in all aspects of the assessment except for the criteria of Title, Methods (content), Results (table), Conclusion (summary), References and Layout. Most of these criteria are not only present in many other forms of scientific writing but are also most closely based on the experimental results gathered in the laboratory setting and supporting materials that are provided to students modelling appropriate referencing standards. Thus, students were likely to have completed these criteria in a supported environment with their peers and laboratory demonstrator as part of the laboratory investigation and post-lab discussion or by using other resources freely available to them. Therefore, it is unsurprising that little improvement is observed in these areas as most of the development in these criteria had already occurred prior to students undertaking the assignment or the e-learning module.

These results demonstrate that even through challenging times, where students experienced ongoing disruption to their learning and were therefore more at risk of performing poorly in assessment tasks, those that engaged with the e-learning module experienced no negative impacts on their assessment grade in comparison to previous cohorts. However, the opt-in nature of the e-learning module in the 2020 cohort cannot be ignored. Therefore, these results must be considered carefully as student engagement is likely to influence behaviour not only in using the e-learning modules, but in other aspects of the curriculum. As the unit was still underway as these results were analysed it was not possible to compare the results of the final exam. However, the cohort in 2020 undertook a mid-semester exam based on lecture and practical content, which can be used to see if there are underlying differences in the academic performance between students that completed the e-learning module and those who did not. Analysis to compare mean exam grades was performed using an independent samples nonparametric Mann-Whitney U test. The result of this analysis indicated that the distribution of grades differed significantly between the groups, U = 38025, z = 4.783, $p < .001$, with those students who completed the e-learning module scoring significantly higher mid-semester exam scores (M = 20, $\bar{x}$ = 19.17, σ = 4.04) than students who did not complete the module (M = 18, $\bar{x}$ = 17.34, σ = 4.34). This suggests that there were other underlying differences in academic ability between the students who completed the e-learning module and those who did not. Thus, we cannot be confident that the improvements observed in writing assessment grades are solely a product of the e-learning module, and there are likely to be other factors relating to engagement that contribute towards the increases in performance that were observed.

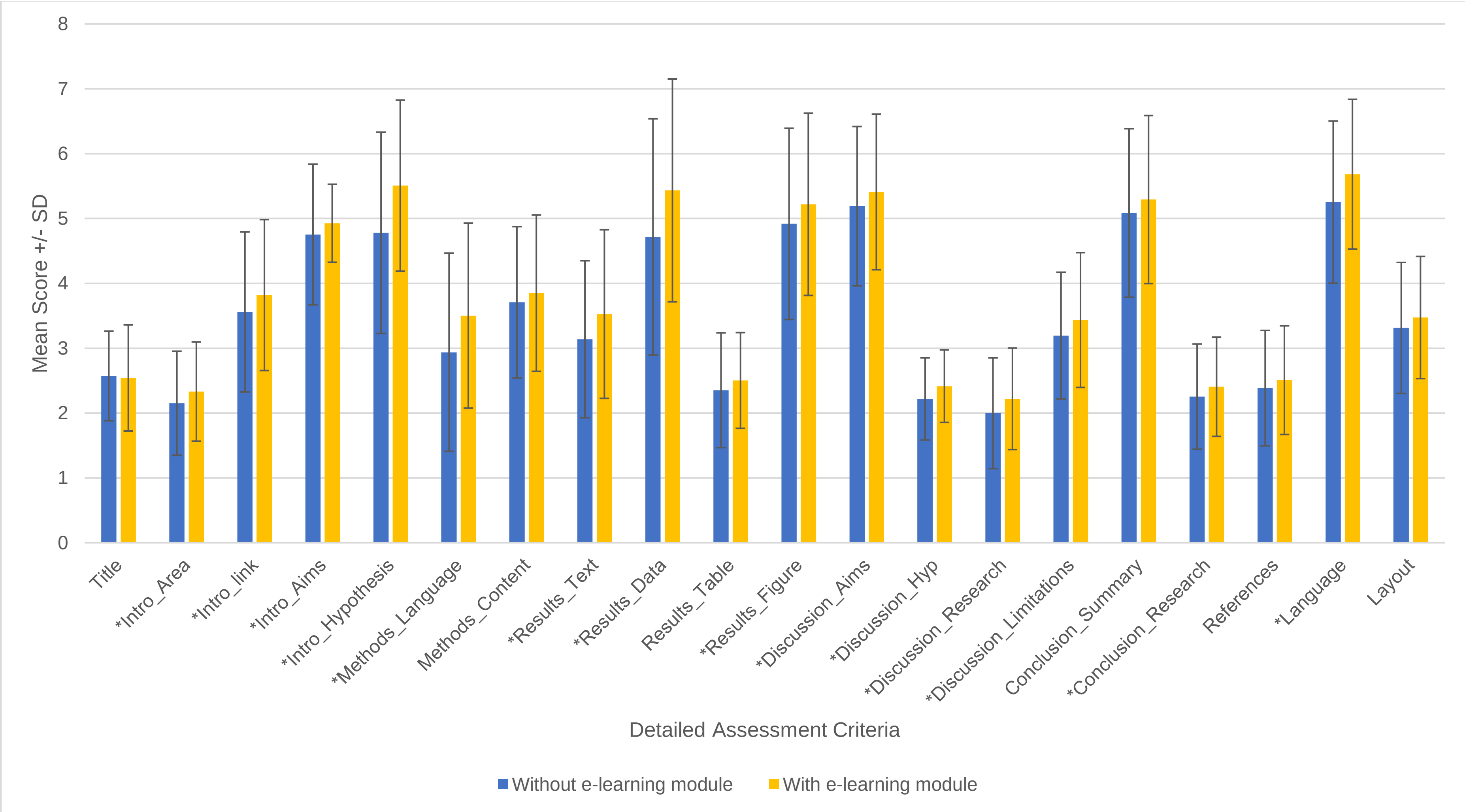

Figure 3.15 Mean scores characterised by assessment criteria of section headings in the Scientific Writing Assignment in 2020. Criteria marked with * indicate a statistically significant difference.

Discussion Paper

A sub-set of data from student assessment of the DP was used in analysis due to inexperience in assessor grading. In 2019 only two experienced causal academic staff members were available to return to the teaching team responsible for the assessment of this unit, thus only data from these individuals was included to ensure consistency in assessment, therefore reducing the impact of influences outside that of the e-learning modules on any changes in assessment outcomes.

An exploration of the data from student assessment of performance on the DP was undertaken to determine if it was homogeneous by creating a box plot using SPSS, there were no outliers in the data as assessed by investigating for values greater than 1.5 box-lengths from the edge of the box. Additionally, a Shapiro-Wilk's test determined normal distribution of the data ($p > .05$). Therefore, further analysis to compare means was performed using an independent samples t-test. The result of this analysis indicated that the distribution of grades was the same across both years, $t(34) = 0.111$, $p = .741$. Figure 3.16 describes the median assessment score for the DP in both 2018 and 2019 and shows the 20 students that did not use the module in 2018 (M = 67.5, $\bar{x}$ = 65.7, σ = 16.6) compared to the 16 students that used the e-learning module in 2019 (M = 66.5, $\bar{x}$ = 66.3, σ = 18.8) demonstrated no significant difference in overall assessment grade. The error bars indicate the standard deviation from the mean of each data set. Results were achieved by students in 2018 (n=20) and 2019 (n=16) enrolled in the unit Biology and Society.

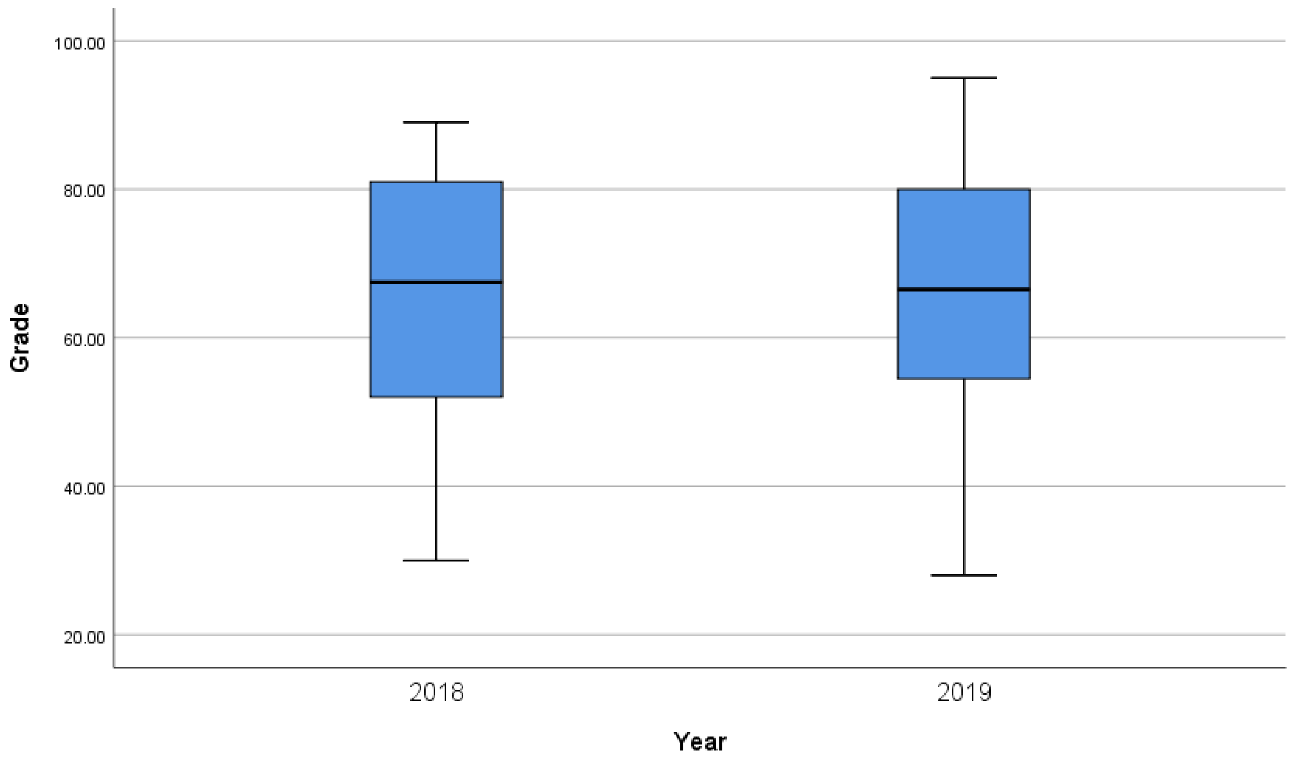

Figure 3.16. Mean scores of Discussion Paper. The bold horizontal line indicates the sample median. The blue areas indicate the upper and lower quartiles and the error bars indicate the upper and lower extremes of the samples.

To further explore individual aspects of the assessment criteria and determine whether any differences between cohorts occurred, further detailed analysis was undertaken. The mean and standard deviation was calculated for each individual criterion of the assessment task and comparison between the cohorts was made. Figure 3.17 describes the mean +/- standard deviation of each of the criterion listed in the assessment rubric in order to determine if there was any impact of the e-learning module on particular aspects of student writing. To compare means between the cohorts an independent samples nonparametric Mann-Whitney U test was performed to accommodate the grading scale that resulted on non-normal distribution at the level of individual criteria. The result of this analysis indicated that there was no significant difference in the distribution of grades in all areas of the assessment criteria except for a small yet significant improvement in performance observed in the 2019 cohort in the criteria of Referencing (sources) $U = 230$, $z = 2.501$, $p < .026$. The results of the Mann-Whitney U test indicated that null hypothesis was accepted for all other assessment criteria as differences observed between years were not statistically significant. The data described here indicate that the impact of the e-learning module on the assessment scores of students is variable and complex as seen in the Scientific Writing Assessment data analysed above, and there are likely to be several factors that contribute to the impact of the e-learning module rather than just the module itself. Interestingly the mode of DP was novel to the students in both cohorts, however this genre displays similarity to Persuasive Expositions, which many students had previous experience with writing, and which shares sections of similar style of introduction and conclusion statements. These sections which shared similar structural patterns may explain why there was no observable difference between cohorts that completed the e-learning module and those who did not. While students are often required to include a range of reference materials, the improvement noted in this section may be related to reading a range of examples included in the module and noting the types of resources used, rather than a direct effect of being advised to do so within the module. In the previous year's cohort of students, they regularly incorporated references unsuited to the task, such as websites and opinion articles, while in the cohort that completed the e-learning module this behaviour was less prevalent.

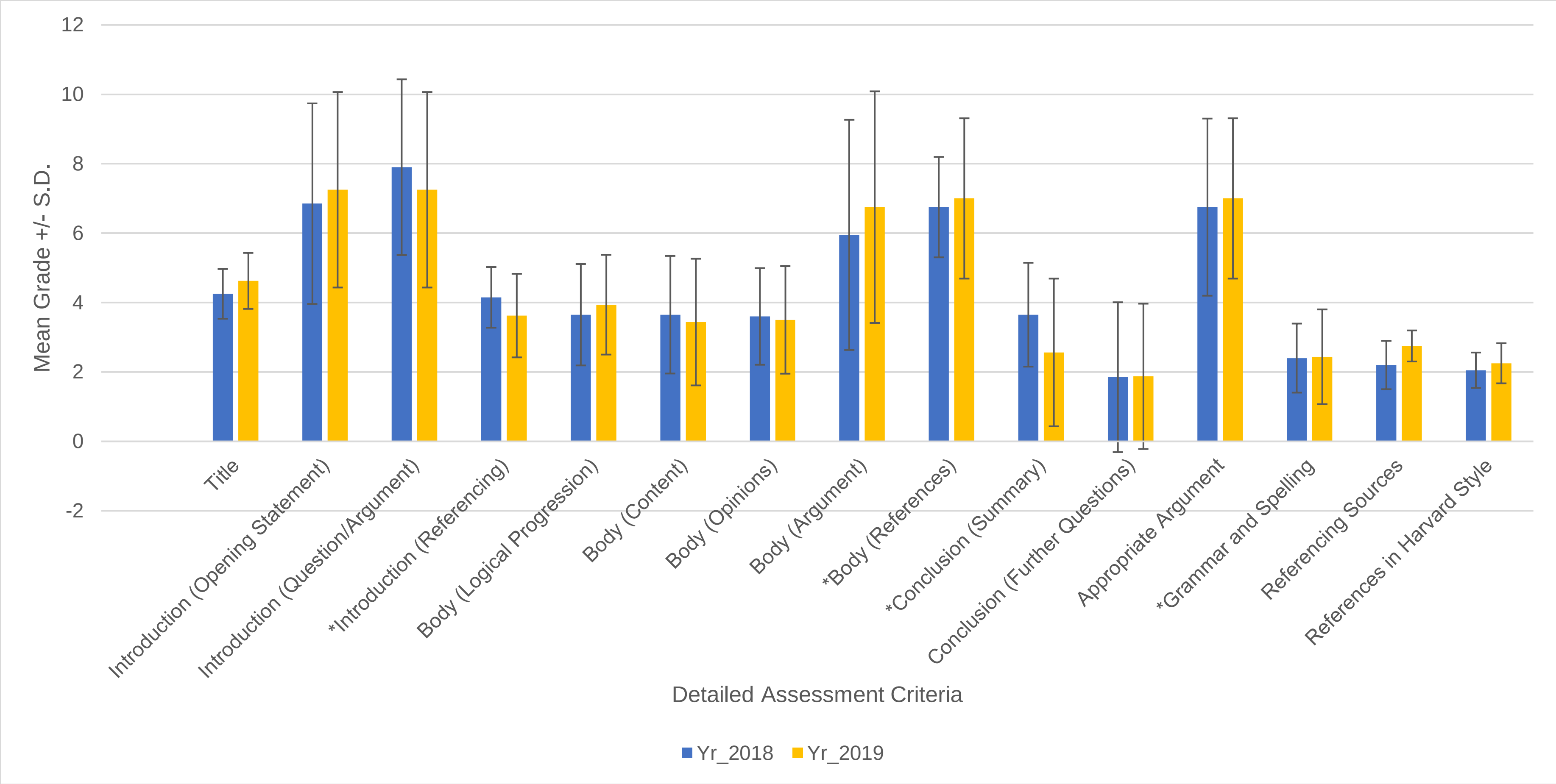

Figure 3.17. Mean scores characterised by section headings in the Discussion Paper.

Impact of e-Learning Modules on Student Confidence

Assessment performance is one measure to evaluate the effect of a learning intervention on a student cohort. To investigate the role of e-learning modules on developing student confidence student survey responses were analysed from students undertaking a novel task that was introduced in 2019. Students reported diverging levels of confidence in performing the various scientific writing tasks which is depicted in Figure 3.18, with those most commonly appearing in undergraduate assessment rating the highest in confidence levels, including SWA, Scientific Poster and Laboratory Reports. Interestingly Scientific Journal Article/Manuscript was ranked lower than the SWA even though these types of scientific writing are closely linked and structured similarly. This data was gathered from students in first year Biology units Molecular Basis of Life and Evolution of Biological Diversity at Flinders University before (n=148) and after (n=50) introduction of new assessments. However, as previously discussed in section 3.5 the name given to the assessment tasks plays an important role in the way students consider them and as these survey responses relate to only first year students it is unlikely that they have experienced this form of assessment previously. In almost all examples of writing provided the experienced students (those who had undertaken at least one semester of study, indicated by S2) indicated a higher level of confidence than inexperienced students (students that had recently completed only one semester of study, indicated by S1). Statistical analysis of differences between S1 and S2 students was conducted using a Chi-square analysis. Notably the reported confidence in students completing the Impact Statement differs significantly X^2 (5, N=183) = 29.161, p < .001 between the S1 and S2 cohorts. This result reflects the introduction of the e-learning module and associated assessment task in 2019 that had previously not been included in the unit design. There were no significant differences between cohorts for any of the other assessment tasks.

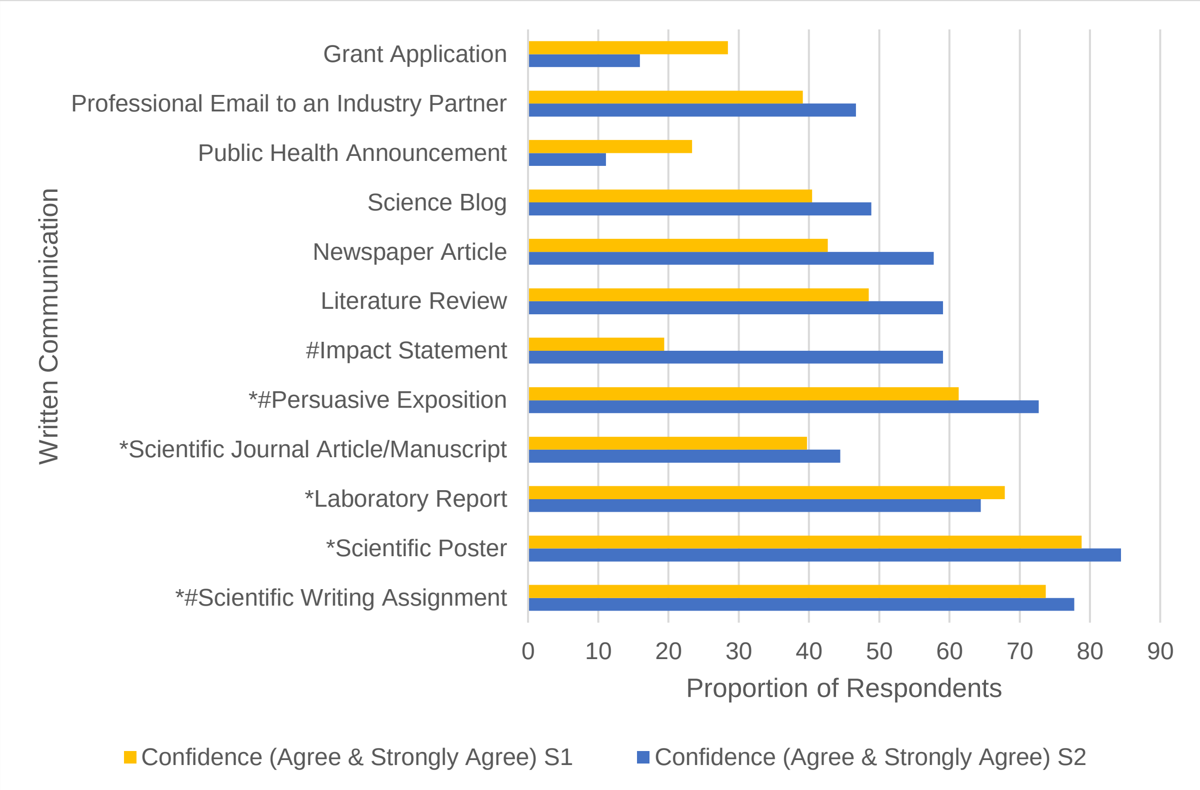

Figure 3.18. Proportion of students confident in scientific writing assessments.

The items in Figure 3.18 marked with * indicate that the assignment type is regularly included in science curriculum in Australian higher education institutions and is present in multiple instances in the first year Biology units surveyed as part of this research project. Items marked with # indicate assignment types targeted in this research project and included in the e-learning modules developed for this project.

Upon investigation of the differences between the S1 and S2 groups responses to confidence in undertaking an assessment in the form of an Impact Statement, Figure 3.19 clarifies this relationship, showing that the majority of students that had undertaken this mode of assessment task (S2) reported higher levels of confidence than those who had not (S1). Inexperienced students were considered to have completed one semester of study (S1, n=134) and experienced students were considered to have completed at least two semesters of study (S2, n=44).

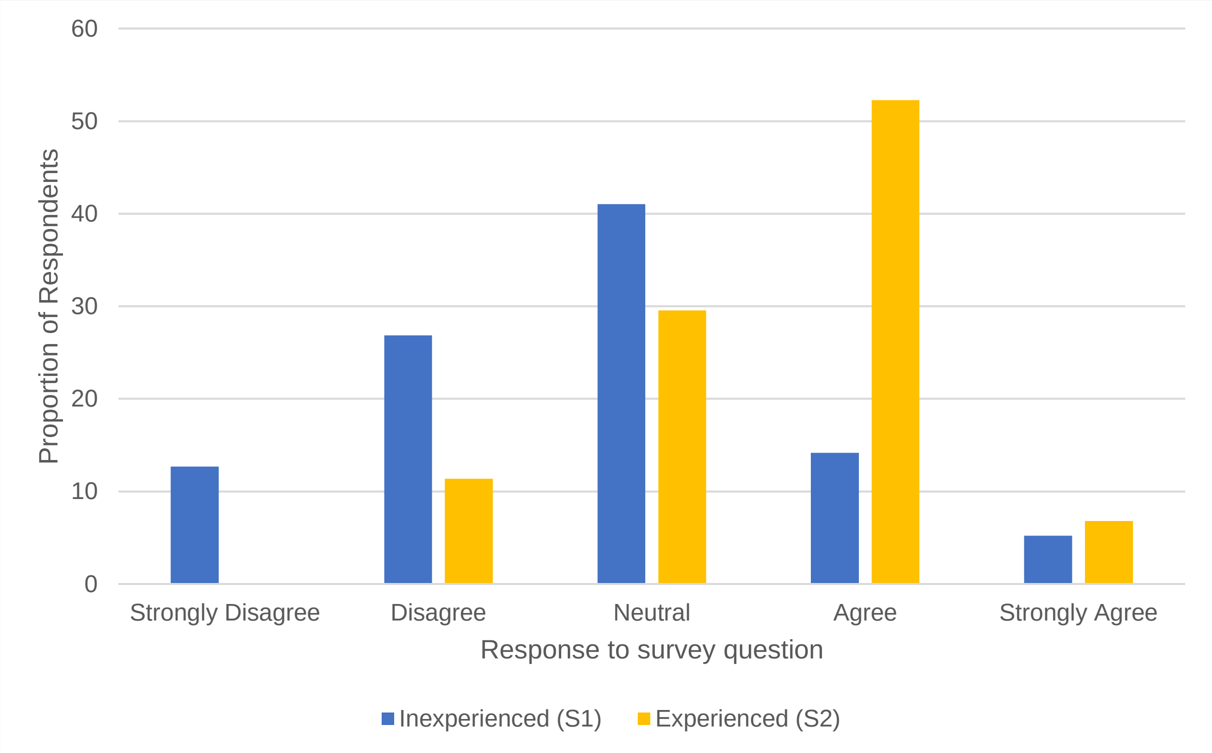

Figure 3.19. Survey responses regarding confidence in ability to write an assignment in the format of an impact statement in their specific field.

Further analysis indicated that survey responses between S1 and S2 differed significantly only for the Impact Statement item. X^2 (5, N = 183) = 30.872, p < .001, all other assessment items showed no statistically significant difference in student confidence. As the data were not paired observations, they were analysed using a Chi-squared analysis however, the sample size adequacy assumption of the Chi-Square test of homogeneity was violated thus, a Fisher's Exact test was performed to determine whether students reported confidence in assessment tasks differently. Students were categorised as either first or second semester of their first year of an undergraduate degree program. This analysis tested the null hypothesis that student confidence was the same between semesters. The results of the Fisher's Exact test indicated a statistically significant difference between the proportion of students reporting to agree with the statement 'I feel confident in my ability to write an assignment in the format of an impact statement in my specific field' ($p < .001$). Post hoc analysis involved pairwise comparisons using the z-test of two proportions with a Bonferroni correction. Statistical significance was accepted at $p < .016667$. Table 3.7 describes the statistical differences between first and second semester students who reported significantly different levels of confidence in writing an Impact Statement. The results presented in Table 3.7 indicate that significantly fewer first-semester students (13.8%) reported agreeing with the statement than did second-semester students (51.1%). The results of the post hoc analysis indicated that the null hypothesis was accepted for all other forms of assessment as differences observed between cohorts were not statistically significant.

Table 3.7 Descriptive statistics of the differences between reported confidence of students undertaking an assessment in the form of an Impact Statement.

			Semester		
			1	2	Total
Impact_Statement		Count	4a	1a	5
		% within Semester	2.9%	2.2%	2.7%
	Agree	Count	19a	23b	42
		% within Semester	13.8%	51.1%	23.0%
	Disagree	Count	36a	5b	41
		% within Semester	26.1%	11.1%	22.4%
	Neutral	Count	55a	13a	68
		% within Semester	39.9%	28.9%	37.2%
	Strongly agree	Count	7a	3a	10
		% within Semester	5.1%	6.7%	5.5%
	Strongly disagree	Count	17a	0b	17
		% within Semester	12.3%	0.0%	9.3%
Total		Count	138	45	183
		% within Semester	100.0%	100.0%	100.0%

Each subscript letter denotes a subset of Semester categories whose column proportions do not differ significantly from each other at the .05 level.

To understand the impact of the e-learning modules in relation to the overall experience of students developing confidence by undertaking an undergraduate degree program a comparison between confidence in first-year undergraduate students and postgraduate students was performed. These results are presented in Figure 3.20 below, which depicts the proportion of students that indicated that they either agreed or strongly agreed they were confident in their ability to write in the form of written communication described.

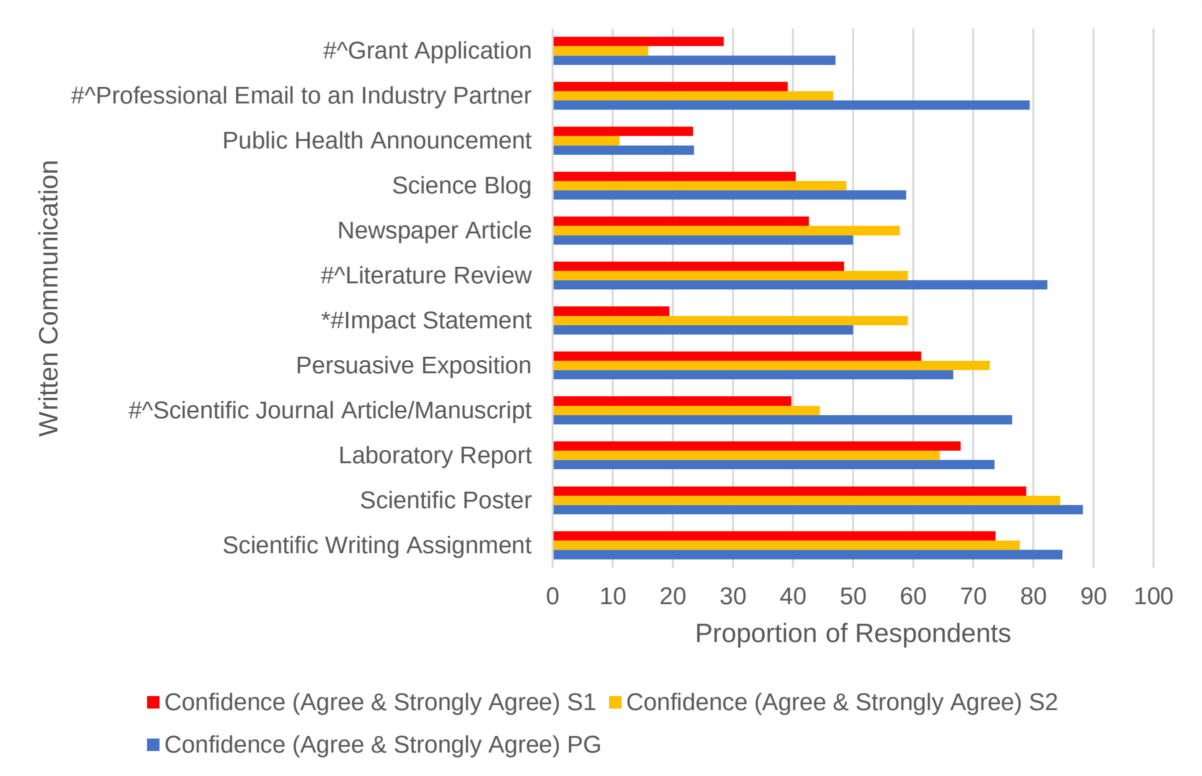

Figure 3.20. Proportion of students confident in scientific writing assessment.

In Figure 3.20 the notation * indicates a statistically significant difference between S1 and S2 students. The notation # indicates a statistically significant difference between S1 students and postgraduate students, and the notation ^ signifies a statistically significant difference between S2 students and postgraduate students. This data was gathered from students in first year Biology units Molecular Basis of Life and Evolution of Biological Diversity at Flinders University before (n=148) and after (n=50) introduction of new assessment in comparison to Postgraduate students reported confidence (n=34).

Data was examined using a Chi-squared analysis and the sample size adequacy assumption of the Chi-Square test of homogeneity held. Students were categorised as either first-semester (S1), second-semester (S2) or postgraduate students (PG). This analysis tested the null hypothesis that student confidence in performing assessment tasks were the same across all cohorts. Students reporting to agree or strongly agree with the statement ‘I feel confident in my ability to write an assignment in the format of [task] in my specific field’ were taken as a high level of confidence in performing the assessment task, where the term ‘task’ was replaced with the assessment task described in Figure 3.20. The results of the Chi-square test indicated a statistically significant difference between the proportion of students reporting confidence in the assessment tasks of Impact Statement ($p < .001$), Journal Article/Manuscript ($p < .001$), Grant Application ($p = .003$), Literature Review ($p < .001$), and Professional Email to an Industry Partner ($p < .001$). Post hoc analysis involved pairwise comparisons using the z-test of two proportions with a Bonferroni correction. Statistical significance was accepted at $p < .016667$. Table 3.8 describes the statistical differences between undergraduate and postgraduate students who reported significantly different levels of confidence in performing scientific writing in the form of an Impact Statement. The results presented in Table 3.8 indicate that significantly fewer S1 students (16.6%) reported high confidence in their ability to undertake an assessment in the form of an Impact Statement than did S2 students (52%) and postgraduate students (50%), indicating that undertaking the novel task of the Impact Statement in semester two improved confidence in performing a similar task in first-year students to similar levels experienced by students undertaking postgraduate studies.

Table 3.8 Descriptive statistics of respondents reporting agreement in confidence undertaking an assessment in the form of an Impact Statement. Agreement is indicated as 1 and neutral responses and disagreement is described by 0.

			Year			
			PG	S1	S2	Total
Impact_statement	.00	Count	17_a	131_b	24_a	172
		% within Year	50.0%	83.4%	48.0%	71.4%
	1.00	Count	17_a	26_b	26_a	69
		% within Year	50.0%	16.6%	52.0%	28.6%
Total		Count	34	157	50	241
		% within Year	100.0%	100.0%	100.0%	100.0%

Each subscript letter denotes a subset of Year categories whose column proportions do not differ significantly from each other at the .05 level.

The results in relation to the Journal Article/Manuscript, Grant Application, Literature Review, and Professional Email to an Industry Partner show that significantly more postgraduate students reported high levels of confidence in writing these types of scientific communication compared to either S1 or S2 students and the proportion of these responses are depicted in Table 3.9 below.

Table 3.9 Proportion of respondents that indicated high confidence in performing various scientific writing tasks.

Year Level	***Journal Article/Manuscript***	***Grant Application***	***Literature Review***	***Professional Email***
S1	34.4%	24.8%	42.0%	34.6%
S2	40.0%	14.0%	52.0%	42.0%
PG	76.5%	47.1%	82.4%	79.4%

The results of the post hoc analysis indicated that null hypothesis was accepted for all other types of resources as differences observed between undergraduate and postgraduate groups were not statistically significant.

In almost all instances, postgraduate students reported higher levels of confidence in completing the various forms of written communication tasks, except for Newspaper Articles and Impact Statements, which was reported at a slightly lower level in both instances than second-semester students. Of note are the statistically significant differences observed between responses of undergraduate and postgraduate students in relation to communication tasks that are associated with writing that occurs commonly in the workplace, including Scientific Journal Article/Manuscript, Grant Application, Literature Review and Professional Email to an Industry Partner. It is likely that opportunities arise throughout both an undergraduate degree program and postgraduate studies to prepare students to perform these tasks and these results reflect the increase in opportunities. Thus, these findings are not surprising. However, of most notable interest are the results regarding the Impact Statement. These results suggest that there is a significant difference between confidence reported in writing an Impact Statement between first-semester students and postgraduate students, which is not unexpected. Yet, no significant difference between second-semester undergraduate students, who had completed a task of this nature and the postgraduate cohort is found. This indicates that students who completed the Impact Statement task in their first year of study reported confidence levels equivalent to those who had completed their undergraduate studies and progressed to a postgraduate research degree. This has significant implications for improving student confidence in approaching writing tasks, both by introducing a novel task and providing appropriate support in doing so to aid in the development of confidence in students in approaching future disciplinary tasks.

3.7.6 Discussion

E-learning and digitised materials have much to offer in developing written communication in a tertiary environment. The ability to build confidence in one's own abilities may be strengthened using e-learning resources that are designed to allow multiple attempts in a low-risk setting prior to assessment tasks. The results presented here describe small improvements in student confidence in assessment items that are commonly found in science classrooms (SWA and DP), and a large increase in student confidence in students that experienced a new mode of writing for the first time (Impact Statement).

Student confidence and thereby student performance can be impacted by the choice of assessments in an undergraduate degree program as student's beliefs about themselves are strong predictors of their performance, effort and perseverance with a task (Bandura, 2006; Pajares, 2003, 2007; Zimmerman & Bandura, 1994). Students initially unfamiliar with this task after being introduced to it expressed confidence in performing a similar activity.

In order to understand why students report decreased confidence in preparing a Scientific Journal Article/Manuscript compared to a SWA, student perceptions of the task must be considered. Even though these types of scientific writing are closely linked, and similarly structured students do not appear to be making this connection. The wording of the survey was carefully constructed to ask students to reflect on their perceptions of performing the task as an assessment item, not a task in the workplace. Therefore, we can be reasonably certain that any differences observed are not due to perceptions of differences in difficulty between performing the task as an assignment or a real-world task in the workplace. These perceptions instead may be nested in the inexperience of the students and lack of explicitness in educators in making the link between these forms of writing clear and overt. This may be alleviated with a simple change in name of the assessment item, clearly identifying these characteristics and making explicit the relationship to the tasks carried out as a professional in the workplace.

To explain the decrease in mean grades for some aspects of the SWA and the DP criteria we must consider students experience of writing. The criteria for which performance decreased are those that are common among other assessment tasks, for example laboratory reports, which student survey data indicated was a common assessment with high student experience. Basing learning on imitation rather than more challenging thought processes may be limiting student development in areas that they are already experienced in. Rather than seeking further understanding students may be taking the easier path of simple imitation provided to them, which is to be expected as student engagement with learning materials has been shown to be closely related to perceptions of value of those materials in assessment and a lack of interest in seeking additional resources to support their learning (Karaksha, Grant, Anoopkumar-Dukie, Nirthanan, & Davey, 2013; Kenwright et al., 2017). Students without this example provided in 2018 still had clear instructions on how to complete the task yet were required to develop their own understanding of which specific aspects to include in their own submissions. A process that appears to have been inhibited in the 2019 cohort. This behaviour is not surprising when considered in context of modern students, surrounded by a glut of information. It is easier to email the coordinator to find out information that is available by reading (Brabazon, 2016a) as it is enough to complete the minimum standard without taking extra effort to develop an understanding of content or genre. This is not to say that students are lazy, merely that whilst developing at a novice level they do not know what they do not know, thus are not appropriately framed for further investigation and cannot present this in written assessment tasks that are overly prescriptive. In cases where students have some experience, providing too many supporting materials may limit their capacity to learn the skills necessary to decipher information.

The criteria for which an increase in mean grade was recorded correlate to new assessment criteria, which are not common among traditional assessment activities. Therefore, the impact of the e-learning modules is complex and multi-faceted. When students have not encountered an assessment activity before examples or imitation may improve results. However, if students have seen these assessment activities previously imitation may limit or inhibit their performance at a task. The act of writing requires engagement with knowledge that is more than simply replicating ideas, rather as a process writing enables learners to construct their knowledge in a way to demonstrate understanding (Hand, 2017). The impact of the e-learning modules on how students demonstrated their understanding and construction of knowledge cannot be ignored.

The balance of providing instruction and supporting materials that are just prescriptive enough while still encouraging writing development is a delicate task in undergraduate education. These results suggest that the provision of supporting materials should be carefully managed, and consideration given to student experience. When introducing novel tasks, high quality examples may provide clear guidance for students to orient themselves within a discipline or genre. Additionally, students can only be expected to develop a sense of what ‘high quality’ literature is by being introduced to it during their learning experiences. However, in instances where students have experienced similar types of assessment, less support may provide learning opportunities beyond content understanding, encouraging students to explore real-world examples outside of provided materials. Perhaps the notion that "the Internet is ruining the quality of students' research papers" (C. Thompson, 2003, p. 1), is less about the technology itself and more related to the expectations that educators and students place on how it is to be used. As the results demonstrate when students were in a disruptive environment, those that accessed the e-learning modules performed significantly better than those who did not use the resources, demonstrating that this type of support has a valuable place is supporting students to understand the requirements of their assessment.

Additionally, the data indicated that student behaviour in seeking resources to assist in completing assessment activities does not change significantly over their undergraduate degree program. This is very troubling considering the provision of additional learning assistance provided to students by teaching and other support staff, including librarians. The implications of this in providing e-learning materials such as described here beyond the first year are that students may limit their learning strategies. By over-provisioning students, educators run the risk of dumbing-down the curriculum. E-learning materials have a place in supporting students in the initial stages of orienting themselves within a discipline and genre, however they should not be relied upon for deeper learning of written skills.

The increase in reported confidence in performing novel tasks indicate that student confidence can be developed through scaffolding of appropriate assessment tasks. In this example students in their first year of study, with limited experience of scientific writing were able to perform scientific written communication in a way that they had previously not experienced through an Impact Statement. Prior to this task students were not initially confident as the indicated by the low reported confidence depicted in Figures 3.18-3.20. Yet, after completing this task students reported confidence levels similar to that of postgraduate students. While confidence is not a substitute for skill, research indicates a link between the two (Bandura, 1986, 1993, 1994) and it is likely to play a role in the development of disciplinary literacy in terms of engaging with disciplinary tasks.

3.7.7 Limitations

E-learning modules were selected for this project for several reasons. First-year university students experience the greatest challenges around transition to their new landscape, with an increased focus on learning discipline specific literacies. With a widening participation agenda and a decrease in the number of students engaging in face-to-face interactions during their undergraduate degree program an e-learning module enables a greater number of students to access teaching resources. E-learning tools are increasingly offered to assist students in the development of a variety of literacy practices, including writing (Willems-Jones et al., 2019), however to date they have not utilised a combined approach that embeds a wider variety of scientific genre. The limitations of the artefact design are significant. The e-learning modules can only act as a model of how disciplinary literacy may develop in students, bounded by the genres that are explored and the student cohort they are delivered to. Data collected has been treated in such a way to acknowledge this significant limitation. However, the benefits of selecting this platform are also significant. Students must practise their writing in order to improve. Multiple drafting is not feasible with large cohorts of students, so review is built-in to the e-learning modules, allowing review of key concepts without additional instruction from the assessor. Additionally, the importance of context is not lost, with students able to select context specific options in a flexible module to suit their specific area of interest.

Further limitations of the e-learning materials as they are presented here is in the modalities incorporated. As described in section 1.7 of this thesis multimodality is critical in widening the access to the broader community, and this includes students from a range of backgrounds. The e-learning modules that form part of this thesis address multimodality only in part, incorporating a narrow range of modes in their design. Upon reflection, the e-learning modules could be re-designed to include a broader range of modes such as sound and movement that are found in video recordings. This would be especially beneficial for students who are hearing or vision impaired. Additionally, it has the ability to drive engagement, both with students and with staff in the creation of material for use in the e-learning modules.

3.7.8 Future Development

Several aspects of the e-learning modules lend themselves to improvements for measuring student engagement in the future, such as tracking of student performance in the modules and the amount of time spent on various sections throughout. This information could be very useful to educators in the development of further support for students in their writing and will be considered in future iterations of the e-learning modules to improve instructors' ability for analysis of impacts on student learning.

3.8 Translating the Language of Science

The results presented in this chapter have a wide range of implications for both educators and learners. Educators have a responsibility to deliver high quality and relevant material to their students, providing opportunities to develop a wide range of skills applicable to the variety of work they will go on to do. Current practice in undergraduate science degree programs does not reflect the diversity in skills that will be required by graduates in the workplace, yet addressing this while retaining discipline specific content presents challenges. While the responsibility of rectifying this does not solely rest with educators, we are in a unique position and have the capacity to make changes to the way science education is delivered that will have ongoing impact for our students and the broader community. By carefully considering the way assessment is designed educators can foster transferable communication skills in our students, preparing them to work with a range of disciplines and forging stronger relationships between disciplines built upon shared language and understanding.

Based on the results of using e-learning modules to guide the development of writing skills in first year students we can begin to understand how to design supporting materials for students. Careful design with consideration of prior experience will enable educators to support students to transfer existing skills into current assessment tasks, encouraging cross-disciplinary learning and a broader understanding of the context and relationship of their discipline with others. By fostering connections based on a variety of genre within and between disciplines, students can be supported in their development of disciplinary literacy, moving them from novice towards expertise.

CHAPTER 4 : FRAMING DISCIPLINARY LITERACY

4.1 The Learner's Experience

Among school leavers in Australia, participation rates in higher education have significantly increased in the last 20 years, more than doubling since the uncapping of undergraduate places (Norton, Cherastidtham, & Mackey, 2016). The undergraduate higher education student cohort is more diverse than ever before, bringing a variety of experiences and expectations to universities. The student experience has been linked to factors including motivation, level of preparedness, personal resources and social networks (Baik, Naylor, Arkoudis, & Dabrowski, 2019) much of which is formed prior to entering the higher education space. During this time attempts have been made to understand the needs and experiences of students entering the higher education space (Brinkworth, McCann, & McCann, 2013) and align expectations of students and educators for a more successful outcome. These efforts have seen an increase in focus in transition and support for commencing students with many institutions having a 'Transition Officer' and team of staff. This has resulted in more positive experiences in first year cohorts as indicated by Baik et al. (2019, p. 531) "Over the past two decades of Australian FYE studies, students' views about the quality of teaching have become significantly more positive, from 66% agreeing in 1994 that the quality of teaching in their courses was generally good, to 78% in 2004 and 89% in 2014. The vast majority of students in the 2014 study also believed that staff were enthusiastic about the subjects they were teaching (80%), good at explaining things (73%), and put great effort into make the subjects interesting (74%)". While Huffmyer and Lemus (2019) suggest that these influences are highly varied and act at a local level in individual units as students interact with various teaching staff. Additionally Gravett and Kinchin (2020) note that increasing diversity in student cohorts creates a challenging space to measure student experiences and that many learners consider themselves intruders in the institutional space, particularly in performing academic writing. Thus, with an increasingly diverse student body it is difficult to make clear comparisons of such long-term approaches to improving the student experience. Debates in these areas are slow, dependent on interpreting large data sets and understanding the influence of many complex changes in the higher education system. Thus, I will not try to jump to conclusions beyond that which can sensibly be inferred. Efforts from educators to engage with students do not necessarily translate to a student connection with their studies or with their discipline, which is typically more pronounced in students from non-traditional backgrounds (Willans & Seary, 2018). This type of responsiveness to the changing student cohort is a step in the right direction in improving student outcomes, however this approach is merely a band-aid solution to a growing problem. Educators must approach the issue of aligning student expectations and experience by addressing the cause rather than the symptoms of this issue. Instead of students simply enjoying their learning experience they must be truly engaged in it. Immersion in the discipline allows students to gain experiences needed to develop disciplinary literacy that produces engaged graduates. Rather than treating the external symptoms of poor engagement, educators must respond to the cause of the problem, which is poorly developed disciplinary literacy.

Students sense of self and belonging are deeply connected to the discipline they are part of (Shanahan & Shanahan, 2012) and are closely tied to feelings of empowerment to contribute towards and engage with their discipline (Eccles & Wigfield, 2002). This is vitally important to how students develop confidence in engaging in the learning process and if well-scaffolded will address many of the issues that students experience with disconnection. Strong connections are important both within an academic discipline, where the learner sees themselves as capable and valued as well as within an institution more broadly, having a capacity to contribute. Lizzio (2006, p. 2) noted that “students with stronger connections are more likely to be successful learners, effective colleagues and happy people. A student’s sense of connectedness depends on the quality of relationships with peers, with staff and their feelings of identification or affiliation with their School or University. We can help develop connectedness by providing opportunities for students to form good working relationships with their fellow students and with staff and encouraging them to get involved with the university.” And these measures seem to have impacted students experience in higher education with the majority of students reporting that they are more engaged and satisfied with the quality of teaching they are receiving (Baik et al., 2019) yet there is a long way to go in ensuring a more positive outcome for the range of students entering higher education and providing the strong connections to the discipline that are needed.

Still much of the teaching experienced by learners in higher education follows a traditional didactic model using lectures and practical materials designed to impart information from an expert to a novice. While these methods may be useful for learners developing basic understanding during the initial stages of learning literacies, they are less effective for developing a strong understanding of advanced discipline content that empowers them to wield deep expertise with 21st century skills of communication, critical thinking and problem solving. Didactic teaching methods place the focus of the interaction on the teacher, rather than the learner, and can lead to low levels of engagement in learning. Over the last two decades there has been a shift towards engaging learners with teaching experiences that not only develop their discipline content knowledge but cultivate an understanding of research processes. However, few students understand the complex relationship between research and teaching within higher education institutions. Those that do hold a view consider the relationship a negative one, with research valued more highly than teaching (Kandiko & Mawer, 2013). This issue is further compounded by naturally unequal power relations between academics and students. While academics position themselves as experts and students as novices unable to understand research or to have sufficient capability to participate in research (Kinchin & Howson, 2019) any potential to recentre learning will be hampered. The shift towards research-led education has been embraced particularly amongst science disciplines (Smyth et al., 2016) and provides an opportunity for students to engage in research in a meaningful way. Through the process of performing and communicating authentic research students develop skills that are essential for all scientists and include a wider range of skills than could otherwise be taught in a traditional didactic model. Yet in traditional undergraduate curricula these opportunities are limited and not widely accessible to aid in student engagement.

Student engagement with content is critical and occurs in a variety of ways, but writing is perhaps the most complex to research and crucial to understand. The development of knowledge through writing occurs through the cognitive processes of evaluation and generation of ideas described by the cognitive process dimensions proposed by Anderson and Bloom (2001) that builds upon Bloom’s taxonomy of hierarchical models classifying educational learning objectives. The act of writing involves creative processes where writers generate understanding and synthesise meaning from information. They must evaluate information rather than simply remember or understand it, thus when performing writing learners must use higher order thinking skills to bring together what they already know into a coherent model that can be expressed through written text, using writing to construct knowledge, developing new ideas based on prior experiences. Writing provides an opportunity to synthesise understanding and thought “because writing, after all, is the material expression of our immaterial thinking” (Hogsette, 2019, p. 1). Through writing we discover knowledge and incorporate it into our understanding of the world around us.

Writing in the sciences is linked to the development of critical thinking and conceptual understanding (Gunel, Hand, & McDermott, 2009) enabling learners to make connections between concepts as they clarify meaning with writing. Students perform this task reasonably well within the narrow bounds defined by their audience, usually their assessor. However, writing tasks designed to focus on an audience of peers or younger students results in increased understanding of discipline content than writing for teachers or an older audience (Hand, 2017). Through the act of distilling concepts and redefining them for younger audiences’ students must actively engage with the material, considering the critical aspects to relay understanding they must first understand the concepts themselves. Previous research has focussed on primary and middle school writing to learn programs where a less experienced audience is naturally younger (Gunel et al., 2009; Hand, 2017; Prain & Hand, 2013). However, it is unlikely that age is the significant factor in this relationship, rather the experience of the intended audience. Thus, writing tasks that focus on communication with others outside of the discipline are likely to be equally important to learners developing deeper understanding of concepts and context of their discipline. “Audience awareness is a critical component of all good writing. Effective writers develop an understanding that the language and content they use and create are interactive and that these must be taken into account by analyzing who their audience is” (Gunel et al., 2009, p. 356). It is up to educators to guide students and frame the learning experience in writing to communicate with a range of audiences appropriate for the discipline. The artefacts and the interpretation of how they impact student learning presented in the previous chapter can inform how educators can best guide their students in communicating with a range of audiences. First and foremost, educators have a responsibility to introduce their students to audiences outside their discipline and these artefacts demonstrate it is possible to do so without sacrificing content.

4.2 The Educator's Experience

Educators in higher education come from a wide range of knowledge bases and thus bring with them a variety of approaches to teaching and learning. Views on involving learners in the research process are broad and are well described by Kinchin and Howson (2019, p. 289) "The 'knowledge-first' versus the 'knowledge through research' perspective may represent a reflection of the academics' conceptions of teaching, with the more positivist colleagues requiring the students to be given the facts in advance and the more constructivist teachers allowing for the understanding to emerge."

Whilst academic faculty in higher education institutions are considered experts in their specific fields based on their specialised training and involvement in current research, there is often speculation that in the classroom they simply "teach the way they were taught", without formal training or instruction in educational practice and theoretical understanding (Oleson & Hora, 2014). This notion is supported by Mazur (2009, p. 50) in his commentary regarding his own practices early in his career in Physics education. He stated that, "The traditional approach to teaching reduces education to a transfer of information. Before the industrial revolution, when books were not yet mass commodities, the lecture method was the only way to transfer information from one generation to the next. However, education is so much more than just information transfer, especially in science. New information needs to be connected to pre-existing knowledge in the student's mind. Students need to develop models to see how science works. Instead, my students were relying on rote memorization." Mazur's experience of teaching is not unusual, however perhaps his response is. Instead of persisting with traditional approaches he is seeking to solve the perceived issues using novel and engaging practices (Mazur & Hilborn, 1997).

This does not mean that the vast majority of higher education faculty are relying solely on their observations and experience of teaching to develop their own pedagogies. In fact as Oleson and Hora (2014, p. 30) describe "it assumes a causal and linear relationship between past experience and behaviour, and it overlooks other sources of professional knowledge and expertise that may influence teaching." Excellent examples of teaching practice are abundant in higher education, and in much the same way that disciplinary literacy is deeply embedded in and influenced by one's experience in a disciplinary community (Shanahan & Shanahan, 2012), a teacher's professional identity is also deeply influenced by their discipline, with "knowledge of the subject matter, social and political context, family influences, and especially the knowledge that they develop over time about how to teach particular topics (i.e., pedagogical content knowledge)" (Oleson & Hora, 2014, p. 30) forming the basis of their relationship with teaching and learning.

Given that Piaget's (1973) ground breaking work in learning theory demonstrated that learning occurs in relation to experiences and already existing understanding, and Vygotsky (1980) theory of social constructivism described how the importance of relationships with knowledgeable adults and peers contributes towards developing the learner's own skills, it is not surprising that many academics will fall back on what they have experienced themselves, an educational comfort zone of sorts, where they teach in the way that has been modelled to them, either as a student themselves or by their colleagues. However, relying on this method of information transfer is no-longer appropriate. Past practices that encouraged educator-focused interactions may have worked for them as students but are not suited to a wider and more varied audience of which our current cohorts are comprised.

The challenge lies in how to promote a change in teaching practice when academic staff are under increasing pressures from their institutions. Summarised in the following statement from a senior lecturer reported by Cleary (2013, p. 21), “To do research well I think you have got to be incredibly selfish … the motivational drive for any researcher has to be themselves … ultimately it’s their own progression up the research hierarchy (that motivates them)…that doesn’t necessarily come across in teaching, where the rewards don’t come from their progression, but from the progression of others”. In a time where teaching is becoming commodified to manage the increasing massification of higher education, research and teaching are being driven further apart than ever before. With teaching specialist and part-time academic positions being used as cost-cutting exercises (Altbach et al., 2019) the nexus between teaching and research will not only continue to be difficult to foster in student learning, but increasingly so. This is only exacerbated by the increasing demand to focus on the preparation of graduates for the workplace and devaluing of traditional intellectual research. Whilst we cannot change those past experiences, we can impact the future of science education by examining our teaching practices closely, ensuring that education practices encompass a range of practice-based, practice-led and learner-led approaches. Teaching staff are limited in the time available to devote to the re-development of curriculum thus modules like those presented in the artefacts here provide an opportunity to maintain traditional structures while embedding communication skills without the needs to re-write entire teaching units. The ability of artefacts like these to move between modes and adapt to a variety of teaching models is also important, with the focus on context of writing critical to student learning.

The discipline of Science, and more broadly STEM (Science, Technology, Engineering and Mathematics), is an area of intensive research and rapid growth in knowledge. The nexus between science research and science education is complex, with many scientific researchers also involved in science education. Advancements and achievements in science are often used as the basis of content delivery in higher education, ensuring students are kept abreast of the latest developments in technology and scientific discovery. However, this ever-increasing volume of highly complex material presents a challenge to educators. How are they to enable learners to access current and relevant content while developing scientific literacy and critical thinking skills required by employers? Perhaps the answer lies in the notion of authenticity. Authentic science, authentic experiences and authentic examples provide meaningful learning that is relevant and contextually rich and diverse. The literature explored in Chapter 2 of this thesis provided clear evidence that multimodality and multiliteracies are crucial in providing a rich context for learning to occur. Authentic experiences combine the variety of forms and literacies necessary to engage multimodality, multiliteracies and context into a single meaningful learning experience. In the following section I will describe a way of viewing how authenticity can provide these opportunities to students enabling them to move from novice to expertise within a discipline using carefully scaffolded experiences to support the development of disciplinary literacy.

4.3 Theory, Lenses and Disciplines

I am a scientist at heart. Biology is in my bones. This deep connection that I have to my discipline is not unusual (Davis & Wagner, 2019), with research indicating that a strong identity is tied to a sense of belonging, self-efficacy and confidence within the discipline (Robnett et al., 2015). These deep connections to an academic discipline form a disciplinary identity and develop through disciplinary socialisation (A. Wilson et al., 2012). As we learn how to perform within our discipline, we become enmeshed within it. Immersed in and transformed by our discipline, we can lose sight of the constructs that underpin the way we value and produce knowledge. Constructs such as scientific methods become part of our everyday thinking within a discipline, however it is easy to forget that they are a single way of viewing, interpreting and understanding the world around us. Wolfe (2017, p. 75) suggests that, "to begin to address this issue … you have to have a theory of disciplinarity, and in particular of how knowledge production happens in the contemporary university." In my interpretation of the research presented in this exegesis I acknowledge two disciplines that frame and inform my thinking. If Biology is in my bones, then Education is in my blood. The intersection of these two disciplines has provided a perspective of theory that has significantly impacted the way I think and move in the theoretical space. The word 'theory' no-longer describes one thing and at this point it is important to dissect the two ways in which I am using the term and why.

Stephen Grimm (2016, p. 1) described the innate differences in how we understand humans and the natural world when he wrote "When it comes to human beings, the thought seems to be, our goal is not simply to explain or predict their behavio[u]r, as we might explain or predict the behavio[u]r of rocks or stars. Rather, our goal is to understand why people act the way they do, and in order to understand their actions we need to adopt a different stance—a different methodology—than we find in the natural sciences." However, there is division amongst philosophers regarding this notion with more recent movements towards a naturalistic view "that denies that there is something special about the social world that makes it unamenable to scientific investigation" (Kincaid, 2012, p. 1). As a scientist of the natural world, I appreciate the similarities in pattern recognition that can be found between biological and human populations. Whilst there may be a profound impact of disciplines on human thinking and behaviour, there appears to be consistency in how this develops that transcends disciplines themselves. Therefore, I have difficulty in accepting the notion that the social world behaves in such a way that is incompatible with scientific investigations. In this vein I have brought a scientific lens through which to investigate the development of disciplinary literacy and acknowledge that this places value on the way that empirical evidence has been collected, analysed and interpreted.

As a scientist, the term theory brings about a range of emotions strongly tied to the misuse of the term in the wider population. With the phrase 'it's just a theory' or 'I have a theory' commonplace among the broader community and persistent high levels of confusion around scientific meanings even among science school teachers (Williams, 2013). A theory in the scientific sense explains the world around us by applying a strict set of criteria to measure and evaluate empirical evidence. It is not simply an idea but rather is formed only after many observations and measurements that show a consistent trend. A scientific theory is defined by a vast body of supporting evidence that explain phenomena around us. Incorporating many hypotheses, scientific theories are based on the careful examination and interpretation of facts. Empirical data or facts in the context of justification are balanced in the context of discovery by interpretation in relation to the theory "The core idea behind this distinction is that there comes a moment in your research when you develop your main insight. This insight, however, cannot be presented in the form in which it occurs; it is much too intuitive and underdeveloped for this (i.e. 'context of discovery'). For this insight to become acceptable to the scientific community, it has to be translated into a different language, often in the form of hypotheses that are confronted with data (‘context of justification’)” (Swedberg, 2016, p. 8).

Kincaid (2012, p. 2) suggests that key tenets of positivist philosophies of science are that “a mature science ideally produces one clearly identifiable theory that explains all the phenomena in its domain. In practice, a science may produce different theories for different subdomains, but the overarching scientific goal is to unify those theories by subsuming them under one encompassing account.” And that in practice “scientists certainly can act as philosophers, but the philosophy and the science are different enterprises with different standards. The corollary is that philosophy of science is largely done after the science is finished.” However, as Kincaid (2012, p. 3) reminds us “often we find no one uniform theory in a research domain, but rather a variety of models that overlap in various ways but that are not fully intertranslatable.” Theories may complement or oppose, or simply not fit context. A theory that may explain phenomena at a molecular level may not hold at the ecological level, context is sensitive, and viewpoint is crucial. Additionally science is not fixed, theories and methods are debated as philosophers of science consider the nature and purpose of scientific investigations, in contrast to the widely-held perceptions that scientific methods are set and theory does not change over time. Kincaid (2012, p. 5) also points out that “philosophy of science is something that scientists themselves do, and in a sense, science is something that philosophers of science do. Contemporary philosophy of biology is a paradigm case in this regard. Philosophers of science publish in biology journals and biologists publish in philosophy of biology venues. The problems tackled are as much biological as philosophical or conceptual.” Whilst scientists are clarifying theoretical concepts, they are doing so using empirical methods, verifying how we think and practice science. The nature of the questions asked and answered in scientific exploration limiting the type of knowledge that can be developed.

A scientific theory is influenced by the lens through which it is viewed. The discipline controls which facts are valued over others and how these should be interpreted. While scientific methods attempt to reduce the influences of the observer they can never be fully removed. Science has long stood on the building blocks of facts as described by Ivan Pavlov in his final work “No matter how perfect a bird's wing may be it could never make the bird airborne without the support of the air. Facts are the air of the scientist. Without them you will never be able to take off. Without them your theories will be barren” (Green, 2016). As a scientist research is viewed as the tool with which to support or refute a theory, the theory itself independent of influencing the scientist. Within the discipline the lens is invisible, facts are facts, there is no alternate view. So deeply is the practice of being a scientist entangled within the person and the practice that it becomes indistinguishable “it is not the practice of science itself that understands, but instead the individual practitioners—i.e., scientists ....scientists themselves understand by “taking up” or cognitively appropriating these relationships in the right way—by being able to apprehend how these relationships work, and by being able to put them to good use, for instance, in making accurate predictions….. Meanings are therefore only properly appreciated from the “inside.” The distinctive nature of the object—meanings—therefore gives rise to the distinctive way in which these meanings are taken up or appropriated, namely by participating in certain forms of life.” (Grimm, 2016, p. 1). The notion that there is a single version of a fact, or truth, is the foundation of scientific research and thus separates scientific and educational theorising such that “scientific knowledge was seen as general and abstract in form:

consisting of laws that capture relations operating across all times and places" (Hammersley, 2012, p. 23). Thus, scientific knowledge is viewed as independent from the subjectivity of the researcher, an objective and singular fact or truth. However, this viewpoint is itself an example of a singular version or fact, insinuating that an Educational Theory is based on something other than developing meaning from observation, rather a feeling or 'vibe' a theorist uses to explain phenomena.

Within educational philosophy, the term theory has a different meaning. Rather than a theory developing from a body of evidence based on empirical data, a theory may not be able to be empirically tested. Educational theories provide multiple lenses through which meaning can be made about phenomena. Educational theorists recognise the existence of these multiple lenses which are often ignored in scientific research. Unlike in the natural sciences where one (or rarely, a few) theory(ies) help to explain a series of events, in the field of education there are many and varied theoretical ways of understanding teaching and learning.

As educators, we often turn to theory to explain and justify our practices. We are guided by theory in understanding how students learn and use theory to develop a set of principles that we can apply to curriculum design. What we design, what we observe and the evidence we collect is all interpreted through the lens of theory. While there are practitioners that view educational theory as simply a way to "explain and justify" educational practices (Carr, 2006, p. 137) this perspective is not common. However, I include this sentiment here as a basis for discussion around those educators that are disconnected from theory in everyday practice. In tertiary education settings many educators find themselves teaching without formal qualifications to do so, and thus through their ignorance are disconnected from educational theory. They are experts in the discipline they teach, but ill-equipped to enact educational theory in a classroom.

Unless we see sweeping policy changes requiring tertiary educators to undertake additional training it is unlikely that practices will change. Therefore, educational research must be made accessible to practitioners or more effort made to connect practitioners to this research. Why should educational theory be wrapped up in language that is difficult to understand by those outside the discipline of education? Instead I seek to make connections across disciplines enabling educators to focus on their specialty content, while understanding good practice that is supported by research and theory alike.

In the late 1990s and through to the early 2000s, there was much debate about the role of theory and methodology within the discipline of education (Berliner, 2002) stemming from the introduction of the No Child Left Behind policy implemented in the USA in 2001. A focus on evidence based practices that aim to identify which educational practices work well in classrooms (Biesta, 2007) appears to have surfaced to placate policy makers at the time, largely unsatisfied with a perceived lack of evidence in teaching practices. Unlike the natural sciences, education is embedded with peculiarities of individual teachers, schools, and societal groupings (socioeconomic, parental etc) that influence students' achievement far more than educational pedagogy (House, Glass, McLean, & Walker, 1978). Thus, the natural diversity observed in educational settings is far greater than we would accept within a scientific one. There is a long-standing controversy that has existed between Education and the Sciences for a very long time. As Berliner (2002, p. 18) confirmed,

> Educational research is considered too soft, squishy, unreliable, and imprecise to rely on as a basis for practice in the same way that other sciences are involved in the design of bridges and electronic circuits, sending rockets to the moon, or developing new drugs.

The disciplinary bridges are difficult to build and maintain. Therefore, quantitative results alone will not do justice to this research, we must equally consider the qualitative information associated with educational settings as this will add strength and flexibility to our understanding and interpretations. The evidence presented in this thesis are overwhelmingly weighted towards qualitative data and this does provide limitations on the interpretations that can be drawn. Educational researchers have the added complexity of managing the individual influences of their student cohorts, including those that vigorously reject research findings, students that insist that they do not fit typical behaviour patterns or learning strategies. This project is not immune to such effects, with a wide range in attitudes and approaches from student participants from high engagement and excitement at being able to access supporting materials designed to encourage their understanding, through to those who deemed such resources as useless, declaring that "these things might work for others, but I just don't learn that way". The variation that we find in an educational setting is enormous, and if present in a traditional scientific study would likely render the results non-sensical, unable to be interpreted due to unacceptable levels of 'noise'. As Berliner (2002, p. 18) describes "we have the hardest-to-do science of them all! We do our science under conditions that physical scientists find intolerable. We face particular problems and must deal with local conditions that limit generalizations and theory building—problems that are different from those faced by the easier-to-do sciences". Yet persevere we must, bridging the gap and rendering education research to be interpreted by all.

In order to understand and interpret educational theory, researchers must understand the concept of interpretivism that describes how a researcher must draw on their own social experiences. Interpretivism underpins the uptake and embedding of educational theory into educational design because individuals will naturally draw on their social experiences to inform their practice. Hammersley (2012, p. 26) describes this as when

> studying the social world it is essential to draw upon our human capacity to understand fellow human beings ‘from the inside’ – through empathy, shared experience and culture, etc – rather than solely from the outside in the way that we are forced to try to explain the behaviour of physical objects.

For those outside of the education disciplines educational enquiry may be a confronting proposition filled with “unfamiliar paradigms, language, research approaches and methods and perhaps also may challenge … understandings of ‘validity’ (Cleaver, Lintern, & McLinden, 2018, p. 5). The matter of evidence and what can and should be considered appropriate evidence (Kvernbekk, 2016) is a key difference between scientific and educational theories that impact the research presented here.

My goal in this chapter is to define the theoretical space that this research is bound by and to enable the reader to transfer this framework to a variety of learning environments. Whilst this research is deeply nested within a scientific context, the process of performing this research and engaging with a trans-disciplinary space has transformed the result. Disciplinarity is crucial for learner development, and formation of learner identity, yet “disciplines are calcifying, rigid and reifying. Post disciplinarity is creating space and opportunities for innovation” (Redhead, 2018, p. 40). To be aware of disciplinary constraints and limitations is ultimately freeing and will enable this research to be truly transformative in the post disciplinary space. In the sections that follow I will explore how written text is crucial to the development of Disciplinary Literacy.

4.4 Literacy studies

Written text continues to form a central element to the way in which scholars communicate, encompassing both reading and writing. Literacy in both reading and writing is strongly linked and research indicates that by teaching writing skills, reading ability will also be enhanced (Graham, 2000; Graham & Hebert, 2011). Galbraith (1999) describes writing as 'discovery' and as a process of constructing knowledge, where writing enables a learner to explore their understanding of a concept and link it to existing content. Expertise in content can be developed by writing (in conjunction with reading) as the act of writing is in fact thinking as summarised by Hand (2017, p. 17) "By having to construct text, a learner is required to connect to existing knowledge in ways that he/she had not previously done, and thus knowledge is constituted in a new way. Writing could be viewed as a process by which knowledge is engaged with in a way that was much more than replication of existing ideas given to students, but rather as a process by which students themselves could construct their own understanding of these ideas".

However, traditional science education pedagogy has emphasised the importance of writing to communicate scientific understanding to a narrow and highly specialised group of similarly literate individuals (Stevens et al., 2019) and ignored the varied forms of communication that scientists conceivably practice. In order to promote scientific literacy more widely amongst society our science graduates must learn how to communicate with family, friends, children, teachers, policy makers, and industry in a way that is sensitive to their audiences' background and understanding. These experiences must be authentic and meaningful, preparing our graduates to perform these activities throughout their careers. Our graduates can only hope to succeed if educators have a theoretical framework from which to base science communication education upon. One that is presented in a way that speaks their language.

Science education will continue to exclude minorities from participating in science if we do not transform the notion of what scientific literacy is. Norris and Phillips (2003, p. 224) argue “that nothing resembling what we know as western science would be possible without text…… because of the dependence of western science upon text, a person who cannot read and write is severely limited in the depth of scientific knowledge, learning, and education he or she can acquire.” They go on to describe “reading and writing when the content is science as the *fundamental* sense of scientific literacy, and being knowledgeable, learned, and educated in science as the *derived* sense.” Whilst much of science education focuses on the *derived* sense of scientific literacy (Kohen, Herscovitz, & Dori, 2020; Roth & Lee, 2016) exclusive participation will be the norm. Science and scientific knowledge can and should be used to tackle real world problems and issues, and if higher education science graduates can’t communicate their knowledge in a way that the broader community can understand then we have failed as science educators.

Through the science education literature, scientific literacy is defined as “being constructed from the following components: (1) understanding the core concepts of the natural sciences, (2) the ability to understand and critically evaluate scientific content, and (3) enabling members of society to cope with situations they are likely to encounter in real-life scientific and technological contexts” (Kohen et al., 2020, p. 250), thus focussing on the knowledge held by an individual about scientific concepts rather than the ability to construct knowledge based on reading and writing of scientific content. As Hand (2017, p. 20) confirmed, “While students are perceived as being active in doing science, there is a need to address the question of doing what?

Replication of the structures of argument is different from requiring involvement in the justification of claims as a critical element of learning the big ideas of the topic. It is at the intersection of these three acts – learning about language, using the language and living the language of science – that students are required to fully engage with the epistemic nature of language". In today's context of climate change denial, where scientific language is used against scientific arguments and promotes political inaction with respect to the environmental and social impacts of the science (Herrando-Pérez et al., 2019), it is critical that we have an understanding of how to engage and develop *fundamental* scientific literacy in our students and beyond into the wider community.

4.5 Universal design

It is important for educators and students to recognise that simply providing digital access to learning material is not sufficient to produce a multimodal curriculum, nor a well-supported scaffold to lean on when one accesses their own 'knowledge'. Many students think and act as if access to 'Google' alone is enough to tackle any problem they encounter, and this notion is becoming more widespread. In our digitally transformed educational landscape, simply digitising material without considering the educational reasoning behind doing so and incorporating this into the design brings with it a wide range of issues. As Douse and Uys (2018, p. 8) describe "the young inhabit – indeed own – a digital world embracing social interaction, entertainment, gaming, music, pictures, information gathering and friendships." We are surrounded by digital platforms and more learners than ever before are familiar with digital modes. In this research project the digital mode was integral in increasing access to a large cohort and was used to enable low-risk trial and error by learners, rather than a main driver of learning.

I have previously discussed the problems of accessibility of science to minority groups in section 3.5.5 and indicated that encouraging and enabling wider participation will ensure that more people from a variety of backgrounds are able to contribute to scientific solutions as well as feel as though they are part of the scientific community. To actively encourage and enable widening participation within science disciplines educators may find solutions in the concept of Universal Design described by Ronald Mace (1998). Initially based on housing accessibility the notion of universal design recognises that "because most of the features needed by people with disabilities were useful to others, there was justification to make their inclusion common practice" (Mace, 1998, p. 22), resulting in services and products that are usable by all. By designing curricula with universal design at the forefront, it becomes accessible to all because the focus becomes shifted from the syllabus content to the learner. Once the learner becomes the centre of the learning experience, then access is not limited. Educators must address the ongoing issues that impact the accessibility of science to minorities, enabling learners agency (Segura & Mohorn-Mintah, 2019) over their contributions to the broad discipline of science. The following model of the learning and teaching processes has been conceived by investigating, observing and recording how learners proceed through structured learning activities specifically designed to provide universal access. Whilst presented here within the context of scientific literacy, these theoretical models are not limited to this specific discipline and may be explored in other disciplinary spaces.

4.6 Developing a theoretical model

In the following sections I will describe the theoretical models that have been born from the preceding research. The development of the models presented here has involved an exploration of the processes involved in both teaching and learning, with the researcher being positioned as both teacher and learner at the same time, a crucial element to the model itself. Only by participating in the learning process and analysing the similarities in my students and in myself was I able to describe the processes involved.

The models presented have been developed through the many years of observation of students within my classrooms and began to solidify into a cohesive framework during the Artefact design phase and through reflection of teaching practices to ensure the e-learning modules were inclusive of the necessary elements needed to support the development of disciplinary literacy. Through the analysis of assessment related to the e-learning modules the distinct elements that are required of teaching and learning for disciplinary literacy development were able to be clarified and combined into the models described here.

4.7 A theoretical model of the learning process

Developing literacy amongst science students involves a combination of factors including ample opportunities to practise reading and writing and is not developed in isolation of other experiences. Thus, it is important to ensure that any theoretical model that attempts to explain the processes involved in learning scientific literacy address the student holistically and in context. I propose that a student's learning experience can be described as comprising of three central elements: Context, Expectations and Engagement which is represented in Figure 4.1, and only when all three aspects are considered during curriculum design can the student's learning experience be transformative, resulting in the development of disciplinary literacy. The context is critical in this model as it describes the element over which educators have the most influence and determines the relationship between both other elements; accordingly, it is positioned at the top of the model. By designing the context with past experiences and expectations in mind educators can provide opportunities to align both the learning environment and student expectations. A student's expectations of a task include not only what achieving the task might look like but also whether they are confident in their ability to do so. As confidence is a predictor of success this directly impacts the student's ability to complete the task. Additionally, if the student has experience of a similar task, then confidence in achieving the new task will be greater. However, unless students are also engaged in the learning process then neither positive expectations nor context alone are sufficient for learning to occur. In this model Experience is considered both prior experiences of learning and the learning context that students are exposed to, thus can be viewed as the sum of elements that have contributed towards learning as well as what should be considered in curricula design. The term experience is important here as it encompasses both past and future learning environments and thus enables this model to be used by both educators and learners.

By applying a disciplinary literacy approach to curricula design these elements are brought together, providing alignment to student's expectations and engagement through authenticity in context. This results in a model where *Context* + *Expectations* + *Engagement* = *Experience*, and this is where learning occurs.

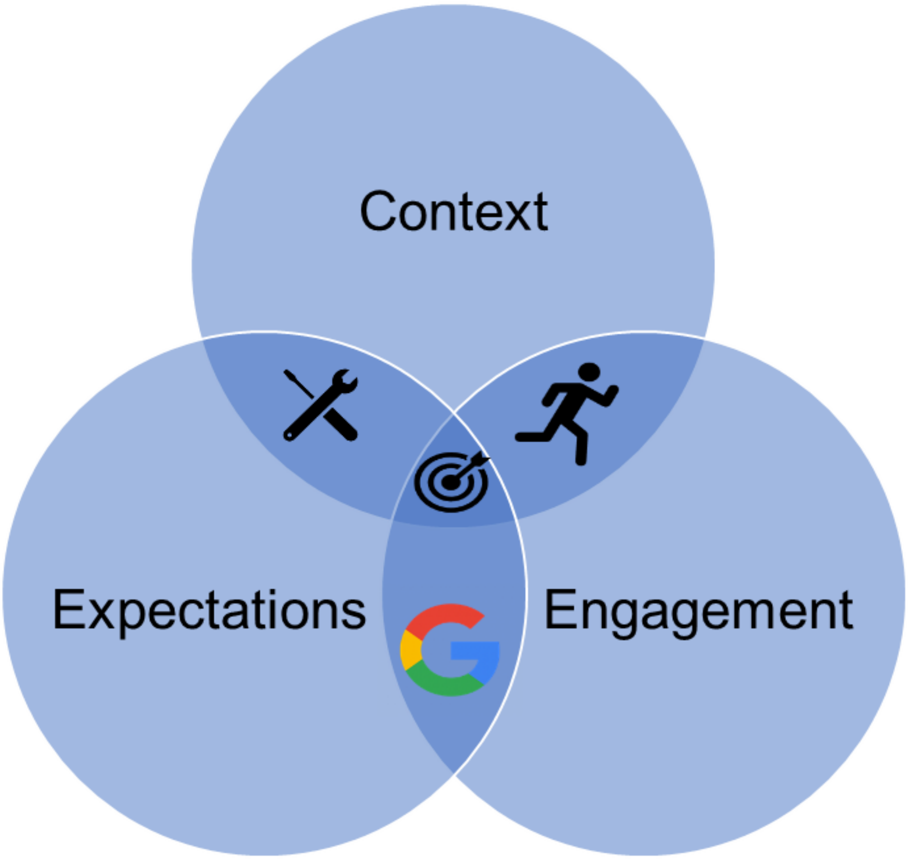

Figure 4.1. The relationship between the three central elements of student learning. The transformative learning experience is represented by the central target.

Learners may move between the elements resulting in varying levels of learning. The service learner has clear expectations and context for their learning, however, lacks engagement. This type of learner is unlikely to see the relevance of the learning to their long-term learning goals, such as a biologist undertaking organic chemistry, the links between the subject areas being viewed as only notional rather than providing a source of engagement and interest. The runaway learner understands the context of their learning and is engaged but lacks clearly defined and reasonable expectations thus finds it difficult to determine the boundaries of their discipline. The Googler has clear expectations and engagement, but this is not tied to a purposeful context, thus their learning behaviours are characterised by their own interests rather than guided by context. The Googler is more likely to rely on non-academic sources of information for learning. This model suggests that students may shift between learning elements over time and with discipline. Thus, educators must scaffold opportunities to direct students to maintain all three elements in order to experience transformative learning.

Shanahan and Shanahan (2008) described a model for disciplinary literacy development (Figure 4.2) in which they describe how disciplinary literacy can be scaffolded based on basic and intermediate literacies. I have adapted this model to consider the effects of student expectations of a discipline as well as their engagement in learning within a discipline area. A student is unlikely to engage with a task if they have feelings of discomfort (Efklides, 2006), which may include a lack of confidence in achieving a task, inexperience or having previously experienced failure. Thus, engagement is a crucial indicator of whether a student will experience learning and must be monitored in an ongoing fashion. In both cases, authenticity provides the landscape for engagement and learning to occur, with experience and expectations being embedded in authentic examples in the learning environment.

This process can be seen in the artefact development and analysis in the previous chapter, where providing opportunities for students to develop clear expectations of assessment tasks that aligned with previous experience of the learning environment resulted in increased engagement and confidence in task performance. By modelling task expectations students can be guided through the development of skills while developing confidence in performance. Using this model will result in higher student engagement and learning without sacrificing content.

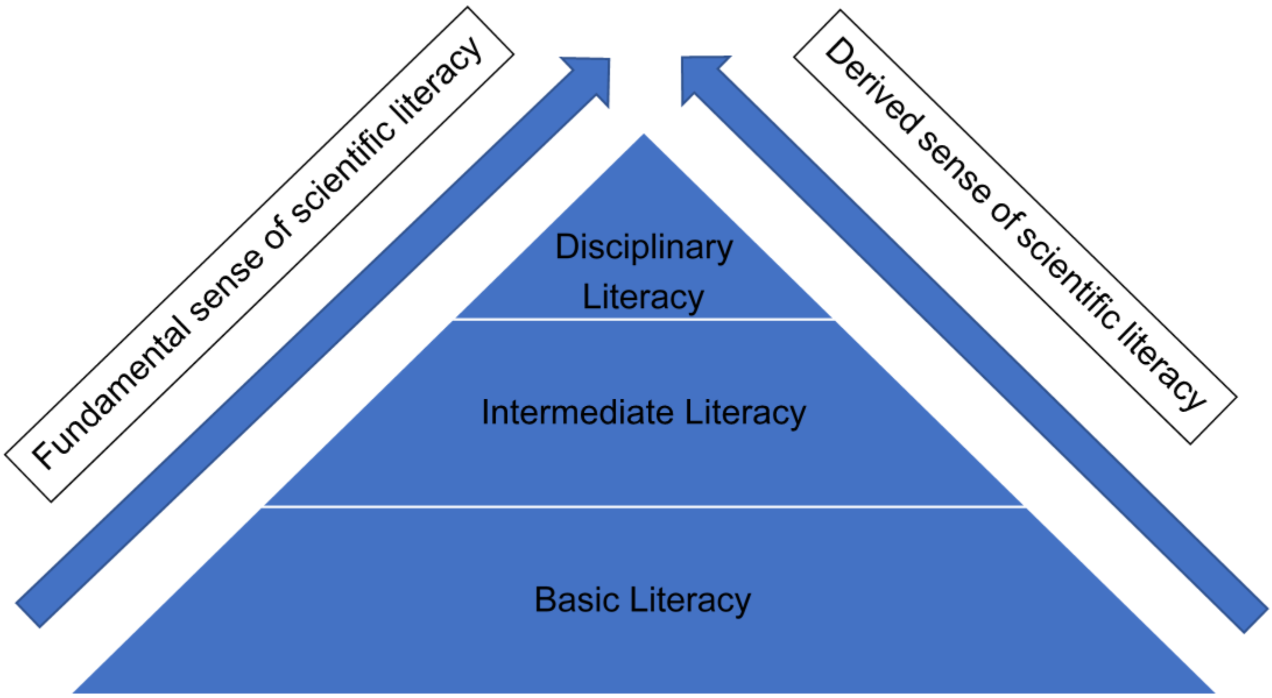

Figure 4.2. The increasing specialization that accompanies literacy development.

This structure depicted in Figure 4.2 is modified from Shanahan and Shanahan (2008), where narrowing of the pyramid stages occurs as a learner moves through the stages of literacy, indicating increasing specialisation along with decreasing instructional support provided/needed. The fundamental sense of scientific literacy is regarded as reading and writing when the content is science while the derived sense of scientific literacy is being knowledgeable, learned, and educated in science. Basic literacy skills are traditionally developed early in life and relate to the decoding and understanding of high frequency words found in virtually all reading tasks, while intermediate literacy refers to fluency and generic comprehension found in many reading tasks and results in the understanding of common texts in everyday life.

While fundamental and derived literacy are represented as separate skills in this example, it is unlikely that they develop independently. In developing foundational disciplinary literacy, students develop the core knowledge they need to become a prolific learner in their discipline. As they progress higher in the pyramid, they learn more specialised and less generalisable skills in reading and writing and therefore authentic expertise within the disciplinary genre, where developing derived disciplinary literacy involves gaining more subtle conceptual understanding and knowledge of the discipline that may be beyond most learners, or inconsistent with previous experiences. These skills must be developed in conjunction with one another in order to result in disciplinary literacy as they provide the foundational structure to move towards increasingly complex disciplinary content. Most instructions in reading and writing instruction are forgotten, embedded or marginalized by the time a learner has achieved an intermediate level of literacy. Especially in higher education, where we see highly specialised and compartmentalised curricula, learners are left to manage this obstacle themselves. All literacies are based on previous literacies. All literacies are resurfaced by new skills, masking the layers of meaning that preceded it. So how can a teacher help create a learning environment that fosters development in the student, so that they can progress up the pyramid? This theoretical model describes the elements that educators must consider to enable learners to make the leap in their expertise from intermediate to disciplinary literacy. The combination of these elements results in the model presented in Figure 4.3 that describes the development of disciplinary literacy in a stepwise fashion, where each step can be considered an integral aspect of the discipline. Progression up the steps towards disciplinary expertise involves learner engagement in a variety of authentic disciplinary activities, which results in the disciplinary identity of the learner.

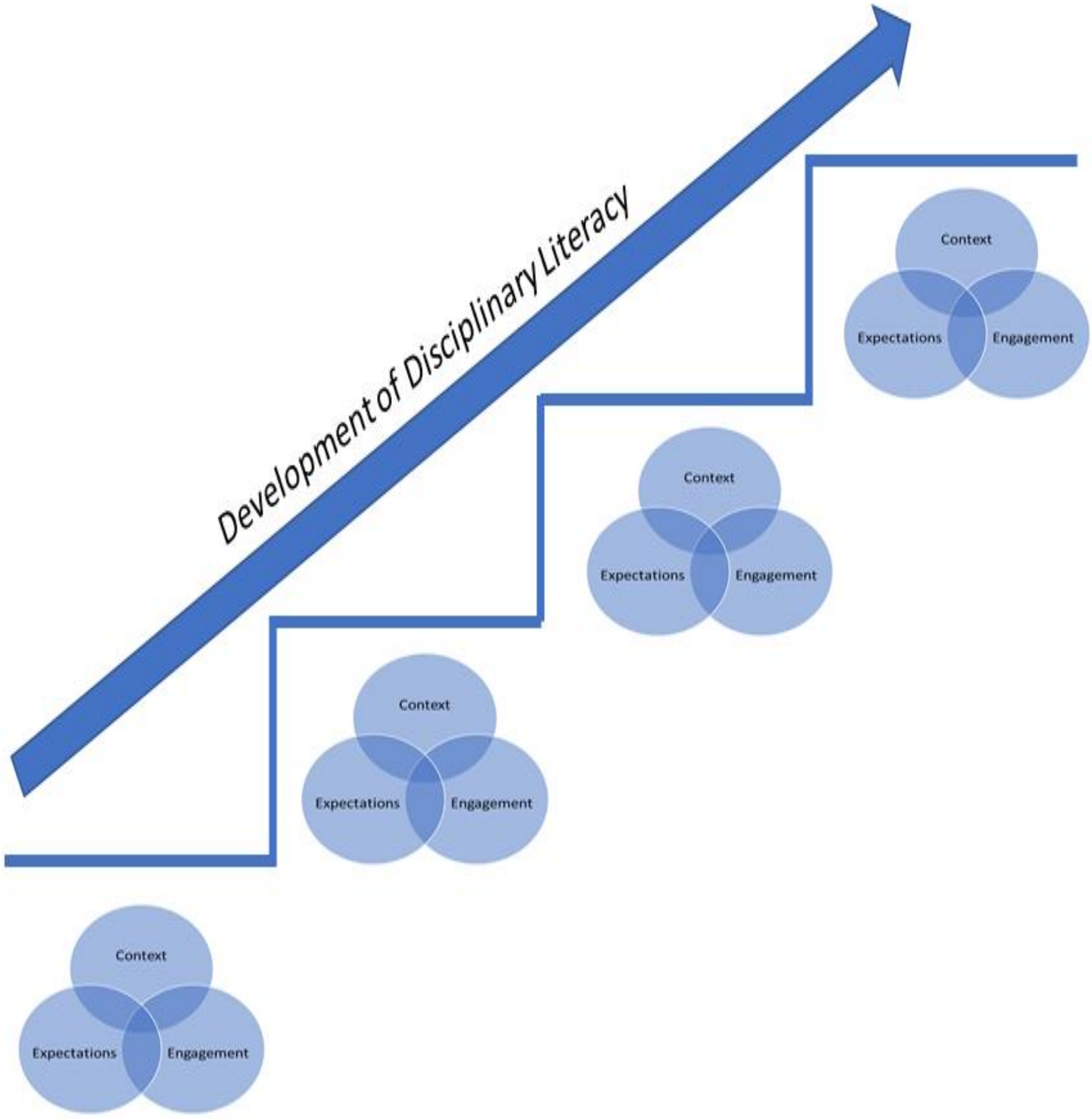

Figure 4.3. Theoretical model of disciplinary literacy development.

Gunther Kress (2003, 2009) was instrumental in understanding the importance and value of multimodality to language and to education, and building upon his perspectives I have come to understand the power of applying multimodality in teaching and learning. The model proposed so far indicates stepwise learning, dealing with individual academic challenges. However, with the use of multimodal teaching it is possible to reduce the size or even flatten the steps (Figure 4.4) and provide a learning environment that is increasingly accessible to learners, meaning that moving towards disciplinary literacy is no-longer a series of quantum leaps represented by potentially unattainable objectives or achievements.

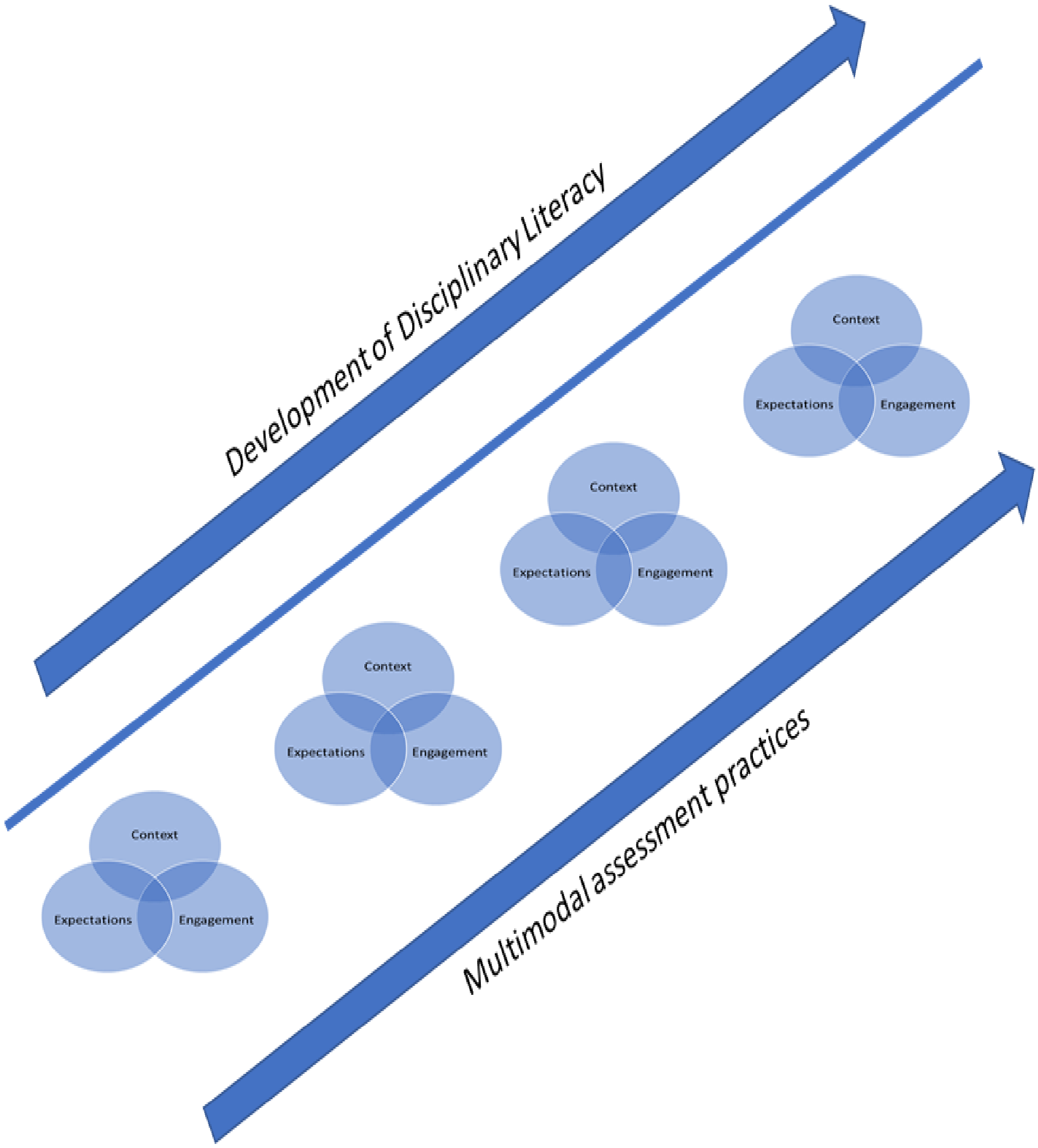

Figure 4.4. Model of student learning with the inclusion of multimodal assessment practices.

In her paper discussing the doctoral learning space, Tara Brabazon (2018, p. 64) describes multimodality as "the capacity to select, interpret and manage diverse platforms. The many platforms and channels that are now the nature of our reality, a way of experiencing information, ideas and life." By incorporating a multitude of modes in the learning environment and recognising the educational importance of non-traditional modes (such as video, audio, blogs, Facebook, Twitter etc) not only do we enable learners to engage with material that has meaning for them, we invite them into academic conversations based in modes that they understand and have expertise in, we provide authentic environments and experiences for them.

In this model, multimodality provides context that enables learners to access academic content that would otherwise be unavailable to them. Multimodality takes existing knowledge in one mode and uses that expertise to improve it in other modes (Brabazon, 2018). Thus, learners that engage with a wider range of modalities within a discipline will be more easily able to transfer their knowledge to another discipline. In deploying the methodology of this project with a focus on multimodality and the impact it has on the transfer of skills, I have chosen to present this research in a disruptive and creative way. In considering the appropriate form to present this doctoral research the concept of multimodality was integral, with the artefacts and exegesis I am embodying the creative modes described in my research, providing an opportunity to enact multimodality in my own practice. By presenting the research in this form I have provided an opportunity both for myself as the learner in this process, but also for the reader as an example of how the choice of modes for delivering content to the learner can be used to enact and enable knowledge transfer. For many readers this will be an unusual and uncomfortable read, and that is important in the exploration of why mode is critical in knowledge transfer. Only by disrupting the way we read and write within a discipline can we hope to challenge those ideas and build upon our understanding of how disciplinary knowledge functions, allowing us to move between disciplines with those skills. This will be the key to effective science communication, as learners make connections with a wider variety of modes and contexts meaning that they will be able to develop an understanding from multiple perspectives, thus encompassing a wider community voice. The artefacts aligned with this exegesis were designed with these elements in mind, ensuring that students were encouraged to build upon previous experience, scaffold clear expectations and engage in the development of relevant contextual content. Additionally, the artefacts (see exemplar excerpts in Appendix A) can be considered a foundation for a multimodal curriculum designed to be accessible to a diverse range of students. Whilst the most prevalent mode used in the artefacts is based in a text form, the delivery is both text and image based, with the use of varied genre delivering the diversity in form. In relation to the artefacts discussed in this exegesis, the key design elements were modelled on the features described earlier in Figure 4.1 reflecting the student learning elements of *Context, Expectations* and *Engagement* of *Situated Practice, Modelling* and *Community* (Figure 4.5). Situated practice provides the environment which enables learners to connect their own experiences of the discipline to how experts function within the discipline, while modelling provides clear examples of expectations of the discipline including the type of writing that is commonly used to communicate within and between other disciplines. By incorporating authentic aspects of discipline community learners are encouraged to engage with that community, performing the tasks that will be expected of them within the discipline.

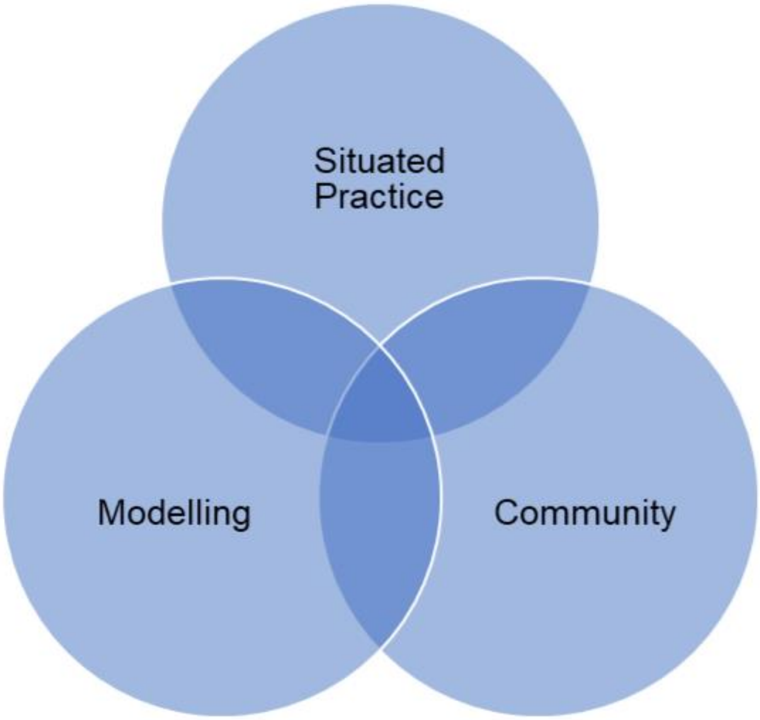

Figure 4.5. The relationship between the three central elements employed in the artefacts that promote student learning.

The elements of Situated Practice, Modelling and Community relate to each of the elements necessary for learning to occur: Context, Expectations and Engagement.

Human cognition is situated, whereby learning is linked closely to the context in which it is learned and the experiences of the learner (Gee, 2004) thus learners can develop stronger links and enjoy further learning if the contexts clearly relate to what they already know. While situated practice focuses on the learner developing meaning in ways that are relevant to them in their own lives (Cope & Kalantzis, 2015). Both educational techniques describe ways of connecting with learners' experience. Within a learning environment this can mean tailoring assessment and scaffolding activities to make these links clear, in turn valuing both existing knowledge and experience of the learner.

Learner engagement is linked to student success (Groccia, 2018) and relates directly to the student effort in meaningful educational tasks (Kuh, 2001). Educators have long understood the importance of engagement in higher education and the elements proposed by Chickering and Gamson (1987) and described in section 1.14 are particularly relevant the characteristics of the learning environment and the educator interactions with students. Through the model described in Figure 4.1 it can be seen that the combination of these elements is critical, demonstrating that engagement alone will not result in learning.

While these factors emphasise the learning environment, they exclude the internal factors such as learner disposition. Here we can learn from alternate theoretical models of human behaviour, including the model of critical thinking disposition developed by Peter Facione (1990, p. 11) where "there are dispositional components to critical thinking….. each cognitive skill, if it is to be exercised appropriately, can be correlated with the cognitive disposition to do so." Similarly, there are dispositional components to engaging in any kind of learning. "In each case a person who is proficient in a given skill can be said to have the aptitude to execute that skill, even if at a given moment the person is not using the skill" (Facione, 1990, p. 11).

Affective dispositions in critical thinking can be influenced by the learning environment (Butler, 2020) it is a reasonable expectation that learner disposition is also influenced by the learning environment they find themselves in. In the model presented here, disposition is defined as the combination of a learners' confidence and willingness to attempt a task. Baird and Dilger (2018, p. 21) suggest that “in the case of writing transfer, [disposition] shape[s] decisions writers make regarding prior skills, experience, and knowledge as they move between contexts”. Disposition and therefore engagement can be influenced by the expectations and context of the learner. The more closely aligned the expectations and context are the more confident and willing a learner is to attempt a task. In the pictorial representation of the model of the learners’ experience, disposition can be described as *factors acting to increase learner engagement* and is influenced by the alignment of expectations and context of the learner.

Engagement Theory was developed by Kearsley and Shneiderman (1998) to understand and provide a framework for teaching and learning using technology. However, the concepts are broadly applicable to teaching and learning and can be used to understand how collaborative and interactive teaching promotes learning engagement, with a focus on worthwhile tasks. Depicted in Figure 4.6 is the situation where poor alignment of factors contributes to poor engagement. A student who has poorly developed learner disposition that is not well aligned with the discipline will result in poor engagement with their learning. By addressing the issue of engagement through aligning the context and expectations learner disposition can also be improved. This can be related to the model described in Figure 4.1 to address students that find themselves positioned as service learners. By realigning the context of learning so that the student can see how it relates to long term learning goals, increased engagement can be achieved. In this example the learner disposition works to distance the expectations and context of the learner, resulting in a lack of confidence and willingness to undertake tasks, which translates to a poor learning experience. However, by providing opportunities for engagement in authentic contexts, confidence and willingness to undertake tasks also develop. This stage of learner disposition represents students who are in the early stages of developing their disciplinary literacy skills. At this stage educators must provide ample opportunities for students to easily access the disciplinary environment to help them align their context and expectations and therefore engagement, resulting in a more positive learning experience. By incorporating meaningful and relevant authentic tasks educators can promote learner engagement.

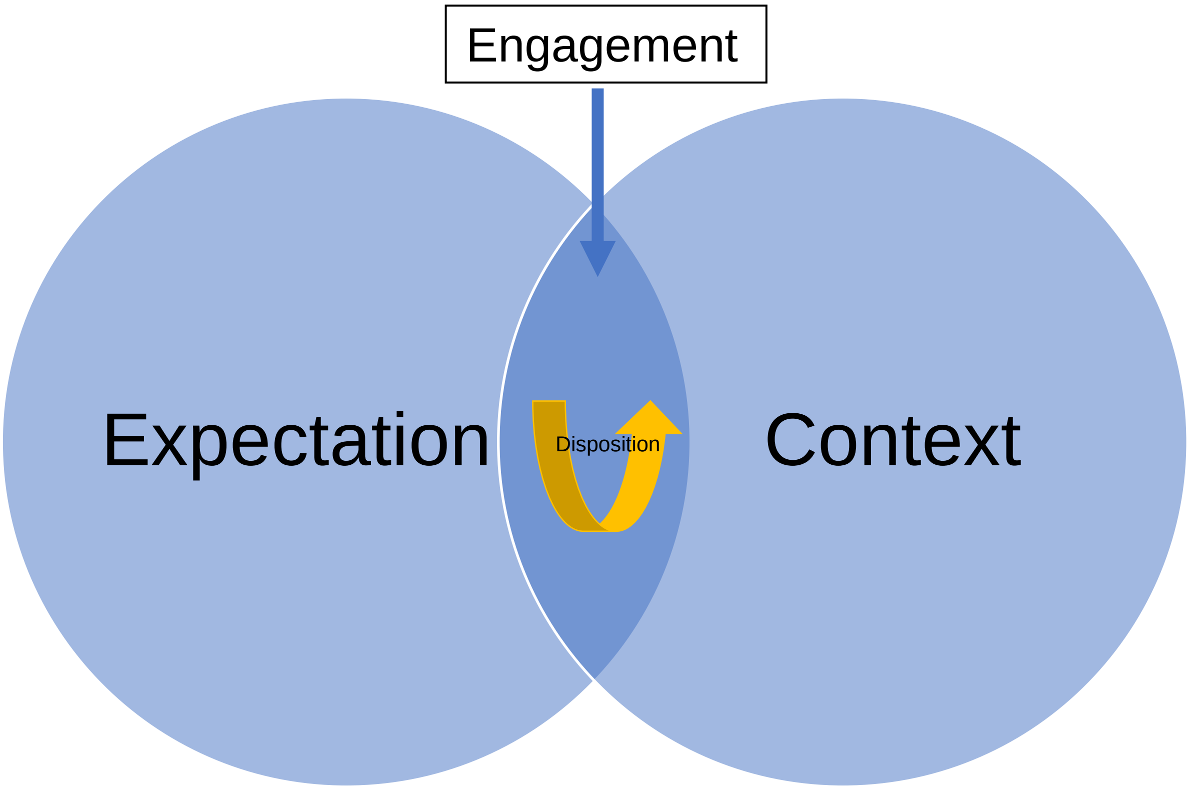

Figure 4.6. Representation of the engagement of a student whose expectations and context are not closely aligned.

By providing supportive curricula where expectations and context align, for example providing clear guidelines and ample opportunities for practise and feedback in a low risk setting, then learners can be supported to move towards the model described in Figure 4.7 of high engagement.

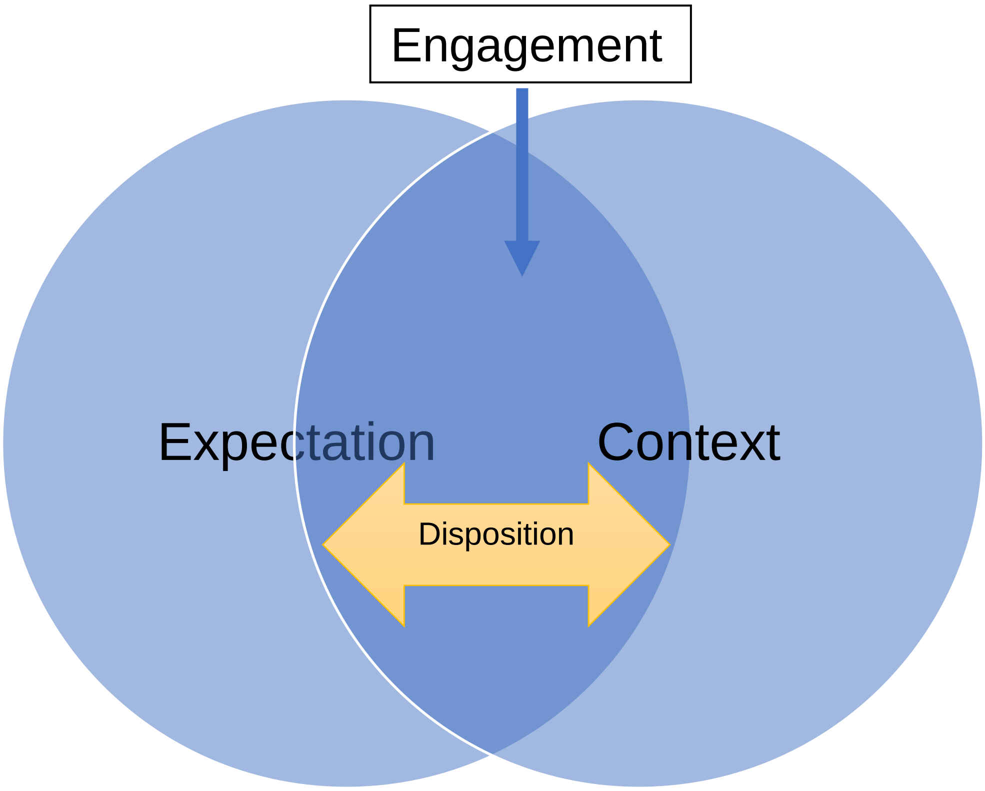

Figure 4.7. Representation of the opportunity for engagement of a student whose expectations and context are closely aligned.

A student who is likely to have a high level of engagement in their own learning and who has a well-developed learner disposition will further benefit, as these traits act to align both expectations and context. This represents students who have a well-developed disciplinary literacy skill set.

4.8 A theoretical model of the teaching process

Just as learners cannot be considered in isolation of their experiences, so too must science education researchers examine the teaching process and teachers within the context of their discipline and broader experiences that they bring. We must also acknowledge how the teaching process is impacted by intrinsic problems that exist in current higher education institutions where separation of teaching and research is increasing. Higher education teachers often have individual discretionary control over the communication skills that are included in a particular unit of study (Bath, Smith, Stein, & Swann, 2004) and these skills may not be clearly mapped throughout an undergraduate degree program. Consequently, skills develop haphazardly with conflicting evidence that educators feel confident in teaching students written communication skills in an undergraduate classroom (De la Harpe & David, 2012; Ferns, 2012). Therefore, it is crucial that we grow our understanding of *how* and *why* educators teach in the way that they do. Support needs to be provided in the most beneficial way to improve outcomes, both for teachers and learners.

There are a variety of ways that higher education institutions have addressed the need to improve the teaching of communication skills in the sciences. These include compulsory communication units, elective communication units or postgraduate programs, and strategies to embed communication skills into disciplinary units of study (Stevens et al., 2019). However, whilst strategies to embed communication skills within a discipline appear to be most effective for student learning (Harris, 2016; Jaidev & Chan, 2018) educators may not themselves be confident of how to so in the context of their discipline. Understanding the relationship between an educator's own disciplinary literacy and their confidence in teaching within the discipline are integral to developing a model that explains teaching practices and provides a framework that enable educators to move beyond their own experiences of teaching and learning. The model that is described here demonstrates how teachers move through the development of their teaching practices. The model has been devised using key research terminology to encompass the interdependence of teaching and research.

4.8.1 Practice-based teaching

Educators undertaking practice-based teaching focus the experience of the learner on authentic experiences, encouraging the learner to form ideas and understanding from real-world situations and context. Practice-based teaching ranges from short exposure to realistic contexts to immersive experiences where the learner develops an in-depth understanding of the complexity of real-world situations and is involved in complex problem solving. While the learner is important in this process, it is the process and experience that is valued in practice-based teaching. Practice-based teaching allows little room for alternate views and experiences, potentially leading to situations of othering where students' sense of understanding (personal/cultural/family experiences) are not aligned with experiences in the classroom. In the frame of disciplinary literacy this means that educators base the curriculum and practice around the disciplinary norms they have experienced themselves. Thus, limiting the range of experiences available to students.

Practice-based teaching relies on an immersive environment enabling the learner to experience a range of real-world challenges within their discipline. Practice-based teaching ranges from providing learners with modified examples of authentic experiences through to genuine field or industry experiences. If implemented to its full extent, Greece, Dejong, Gorenstein Schonfeld, Sun, and McGrath (2019) suggest that practice-based teaching can provide an educational environment equivalent to the real world. However, this relies on developing relationships with industry stakeholders, which in many circumstances is not feasible.

Practice-based teaching is common amongst professional disciplines including health and education, being closely linked to professional practice and competencies (Koo & Miner, 2010; Wrenn & Wrenn, 2009). In the sciences practice-based teaching is also a deeply embedded practice, especially in disciplines that involve laboratory based techniques and applications (O'Neill & Polman, 2004). Greece et al. (2019) propose the following relationships and outcomes of practice-based teaching experiences, noting the significant emphasis of technical and professional skills developed through the learning process.

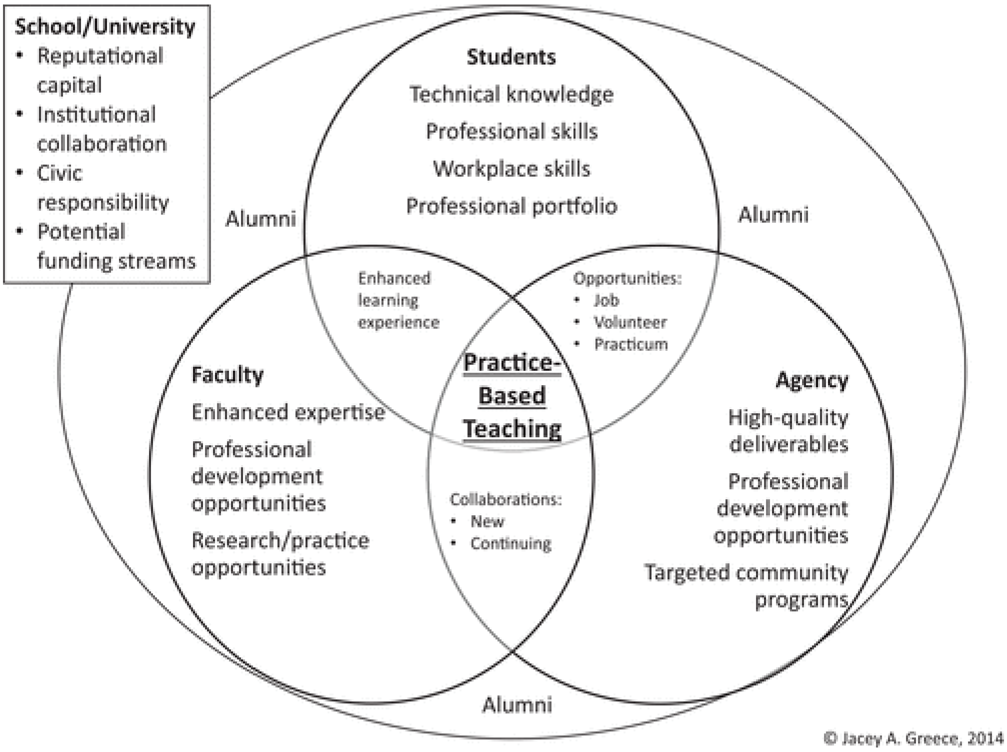

Figure 4.8. Relationships and outcomes of practice-based teaching experiences. Modified from Greece et al. (2019)

The artefacts that accompany this thesis demonstrate how practice-based teaching can be used to align the disciplinary needs of students, faculty, and industry by considering the needs of all and designing assessment tasks that are authentic. The artefacts do this by bringing authentic examples of writing into the classroom and making them accessible by unpacking the structure of various genre, linking the writing to the intended audience. In this way the traditional goals of higher education and the needs of industry can be brought together while improving the student experience and engagement with learning.

Using the disciplinary lens in the context of the sciences, limitations of practice-based teaching emerge. Specifically, practice-based teaching has great potential to develop disciplinary literacy in learners as it is based on a disciplinary-specific immersive experience. However, providing an experience that is a true representation is challenging and even if attempted, will still be framed by the educator's own experiences. Indeed, the artefacts presented here are framed by my own experiences through learning, teaching and engaging with industry partners.

4.8.2 Practice-led teaching

Throughout the process of teaching and learning, experienced educators regularly identify problems and challenges associated with their practice. In the higher education context this can be a significant challenge in that many educators are not well-equipped to recognise and respond to these issues as there are no expectations of formal education qualifications (Harland, 2017; Mcnamee et al., 2004). This is an important limiting factor in that it leaves many higher education teachers without the disciplinary literacy needed to observe, understand and respond to their own teaching practices. Tertiary educators are particularly vulnerable in this circumstance as they are likely to have a good understanding of the content and context of their discipline yet are unable to articulate perceived problems in pedagogy.

Practice-led research involves the conceptualisation of how we understand our experiences in the world (Hawkins & Wilson, 2017). In the same way practice-led teaching involves understanding how students make meaning of their learning experiences as well as the educator involvement in the learning process. The very notion of this thesis began as a practice-based exercise as I reflected on the experiences of my students in learning to write, examining practice and considering the theoretical basis of the pedagogies employed.

Practice-led research is becoming increasingly common in scientific research (Main, Weeks, Buller, MacAllister, & van Dijk, 2017; van Dijk, Buller, MacAllister, & Main, 2017) with increasing recognition of the importance of involving industry stakeholders that have a wealth of knowledge about practice and context. The “practice-led collaborative learning processes, which involve but are not led by scientists” (Main et al., 2017, p. 1) can provide an excellent example of how the process can be adapted to the formal education experience. Practice-led teaching centres on the collaboration of teachers and learners in exploring the learning experience, valuing both perspectives and knowledges that they bring. Personal knowledge and lived experiences inform the teaching practices of educators and in the context of practice-led teaching become the basis for reflective practices that inform pedagogy. Practice-led teaching holds opportunities to address the limitations described in practice-based teaching, by examining the relationship of practice and learning we can develop an understanding of the interplay and address the narrow lens individual educator experience provides.

4.8.3 Learning-led teaching

Learning-led teaching differs from other teaching practices, as the educator becomes the learner in a position of power over their own learning. By re-positioning the educator as a learner their context is reframed enabling them to have a more meaningful understanding of the learning process. Learning-led teaching incorporates reflective practice by the educator/learner to explore and understand the process of learning. Learning-led teaching involves the educator developing an identity as a learner, allowing them to understand the learning process by performing it (Brabazon, Knight, & Hills, 2020).

Learning-led teaching offers something that no other mode of education can provide, the opportunity to experience the process from the learners' perspective. It is only from this perspective that educators can learn with authenticity about the learning process and therefore truly focus on the learner. This has been confirmed by my own experiences throughout this PhD research, positioning myself as the learner and developing my understanding through writing. By performing learning through writing, I have a far deeper appreciation of the experience from the learner's perspective and have therefore been able to offer a unique understanding of the learning process, reflecting on both my experience as a learner and an educator.

4.9 Theory in Teaching Practice

In practice, during curriculum design and in reflecting on teaching experiences educators engage in practice-based, practice-led and learning-led teaching not in a discreet manner but rather in combination. However, as I have come to understand through the practice of my own learning-led research presented in this exegesis, all these teaching modes are necessary to develop pedagogical practice that provides a dynamic, accessible and transformative curriculum.

Examples of good teaching practices can be found in each of the modes discussed here, however the strength in curriculum design lies in their combination. Bringing these modes together is a complex task and requires ongoing commitment from teaching faculty. Understanding how and why educators engage in each mode of teaching will build knowledge and support educators in developing their practice. Through reflection educators can identify which aspects of their teaching can be described by each component and therefore ensure a cohesive and complimentary curriculum designed to support a wide range of learners. The element that transforms practice-based, practice-led and learning-led teaching practices into high quality learning experiences is multimodality. Multimodality acts in several ways to make knowledge more accessible. Multimodality places value on multiple forms of knowledge. No-longer is knowledge bound in a single mode or form, thus enabling wider access. Transdisciplinary literacy is made possible by the application of multimodality.

Learning is challenging and uncomfortable (Bheekie & van Huyssteen, 2015; B. Brown, 2016). Pushing the boundaries of the learner's expectations and experiences is likely to lead to unpleasant feelings, making tasks seem more difficult and less satisfying (Efklides, 2006) and less likely to be sustained. The proposed model of learning and teaching presented here suggests that expectations and environment are aligned to establish an experience where learners are less likely to feel overwhelmed, uncomfortable and incapable of achieving. However, there is an element of productivity to struggling with a challenging concept where a learner is supported and encouraged to "figure something out that is not immediately obvious" and this "can help… in their thoughts and play an important role in deepening the student's understanding" (Permatasari, 2016, p. 95). It is critical that educators strike a balance between supporting and challenging students. Support must link the environment and expectations to develop engagement in students and challenge must be authentic and multimodal ensuring real connections form within the discipline.

While the models presented here have been based on observations in biology classrooms, they have potential for more far-reaching impact. Whether a student is learning about biology, law or education the importance of aligning expectations, context and engagement are the same. To become an effective learner and gain as much as possible from their education students must have a well-developed disposition to learning within their discipline. By providing clearly scaffolded opportunities for students to succeed within their disciplinary context teachers can enable all students to make meaningful connections and contributions.

CONCLUSION: TOWARDS EXPERTISE

Since first pondering how I could help students improve their writing, this doctoral research has uncovered a much deeper sense of the way students learn to write disciplinary texts and the relationship between writing, disciplinary literacy and expertise. In an environment driven by knowledge, where expertise provides learners with enhanced opportunities, educators are well positioned to prepare students. However, current practices suggest that the learning environment provides only a narrow version of the scientific landscape that will exist for graduates. With the experiences that I bring to this problem, I am in a strong position to reflect on how these practices should evolve to provide a more meaningful undergraduate environment for learners. I feel a responsibility to my fellow educators to share this knowledge so that the process of disciplinary literacy development is more widely accessible.

In the same way that I seek to develop disciplinary literacy with each science student and teach them to wield it and communicate to wider audiences, education researchers must also consider wider audiences as well. No longer can educational research be restricted to those who speak the specialised language necessary to understand and interpret the meaning of this knowledge. Instead, as I have attempted here, we must endeavour to cross the disciplinary boundaries and in the same way we want our learners to broaden their literacies and develop translatable skills, we educators need to connect with others to improve teaching practices more widely. Regardless of whether educators have the literacies required to design, configure and disseminate educational research, it is our responsibility to find a way to translate it into accessible forms that can be used to inform disciplinary practice.

This research has profound implications for how science education is enacted and how disciplinary literacy is developed. It also has meaning and resonance for how disciplinary literacy is developed in any discipline. By thinking critically about the way disciplinary literacy develops in the sciences, I have been able to move beyond the discipline and describe a way of understanding that transcends this single context. By examining writing through the lens of disciplinary literacy and applying a combination of approaches from educational and scientific disciplines this research has produced a powerful interpretation. The use of empirical data in combination with theory has resulted in the ability to evaluate classroom practices and understand how they contribute to disciplinary literacy development demonstrating that disciplinary literacy can be developed by providing authentic experiences that push the bounds of student learning.

At the beginning of this doctoral journey, I believed I held a strong understanding of learning processes involved in writing. Even though I was an experienced scientist and researcher I was naïve in my view of student learning. However, by reflecting on this journey I have come to appreciate how complex these processes are and the way they impact how we connect and relate to disciplinary practices. By performing the process of learning-led literacy I was able to recognise the transcendent nature of literacy development, enabling this research and myself to cross the bounds of the discipline.

This PhD research set out to answer three main questions. What was unexpected was that I - as the researcher - became part of the research. By implementing a disciplinary literacy framework to examine the development of communication skills in undergraduate students, and the relationship this has with improving accessibility of science education to minority groups, I discovered much about the way disciplinary literacy develops in students at any level. I became the student and developed my own disciplinary expertise. By employing a transdisciplinary approach, I was able to unpack the development of disciplinary literacy through my own experiences as well as that of undergraduate students. Whilst the focus throughout this PhD has been within the discipline of science, this research is not bounded by a single discipline. The answers to the questions I posed at the beginning of this journey might now hold the answers to developing disciplinary literacy and wider access in any discipline. The artefacts whilst based in a scientific context here could be designed and implemented in a variety of areas, the underlying educational theory the same in science and in law. This project addresses the broader issue of how educators are preparing university graduates for the world that is and will be. Well-developed transferrable and engaging communication skills in our future scientists is key to an informed and productive society. Where scientists, public, industry and politicians can have meaningful and informed discussions, leaving the lingo behind.

In uncovering how disciplinary literacy is developed during an undergraduate science degree program I also discovered why. Learning is a situated activity that cannot be separated from the social community in which it occurs. Learners are members of a community of practitioners, and through apprenticeship by experts develop an understanding of the sociocultural practices that form such a community. By incorporating social opportunities into the curriculum in a way that is reflective of authentic experiences, students develop an understanding of the cultural norms of that discipline. They can think, act, read and write as scientists do. Students develop disciplinary literacy by exposure to it, and this occurs best when instruction is explicit and authentic, because literacy skills and content are inextricably linked and defined by the discipline.

This research has aligned two fields that in many ways are opposed in their approaches to research. Scientific research is necessarily coloured by scientific methods and bounded by the physical environment in which it is conducted. Whereas educational researchers must more often deal with the enormous variation found in people, both educators and learners alike and the interactions that are produced from these relationships and experiences. This often limits the ability of educational researchers to develop robust theories that encompass the diversity of human experiences (Berliner, 2002) and therefore we cannot expect that empirical results from an educational study are able to be replicated in one context or another. To address these issues, I have approached this research as both a scientist and educational researcher, demonstrating that both have a place in science education. We must also ask ourselves to consider our own values as educators in the way we design and carry out educational research. Through this research I have focussed on assessment practices as this provides a point of comparison and measurable impact of an intervention. However, much learning occurs outside of assessment and it is important to recognise that restricting educational research to assessment excludes other equally valuable forms of learning outcomes. Educational researchers must carefully consider how we measure learning to ensure that it is not simply a measure of what we value, but more inclusive of wider educational outcomes. Because of these influences, I would caution against the use of the results presented here as a one-size-fits-all approach, instead ask that educators consider their own context and that of their students to use the theory proposed here as a set of guidelines to help foster disciplinary literacy development. These are not clearly defined rules by which to design curricula, rather they are intended to help educators focus on which aspects of their programme can be reconfigured to increase opportunities for a wider range of students, and an increasing audience.

The research presented throughout this exegesis has uncovered a lack of attention to the development of disciplinary literacy in the sciences, which has widespread consequences for both educators and learners. With an international shift towards valuing the needs of industry over the traditional purposes of education we have witnessed the loss of disciplinary identity that is crucial to learner development. Where once disciplinary expertise was highly valued, industry needs have overwhelmingly taken priority. However, recognising that both higher education and industry share the same goal of communication to translate knowledge is crucial to realign the sectors and forge a new relationship that values both academic endeavours and workplace preparation. Interestingly, through engaging deeply within a discipline, learners are not narrowly defined by it, rather they become more able to develop transdisciplinary skills, enabling communication between disciplines to become more effective. Thus, by understanding and reflecting on their own disciplinary literacy development, a learner can understand the needs of others, recognising links between other disciplines, resulting in a wider view rather than a narrow one.

This research has identified limitations in how learners access disciplinary texts and develop writing skills. As highlighted in section 3.6.5 reading is as much a part of learning as is writing and both should be encouraged in conjunction. Whilst reading was an essential component of the e-learning modules that form part of this thesis, it was neither explicit nor directly investigated and future research in this area would benefit our understanding of its contribution to how students develop disciplinary literacy. With the insight this research has afforded it would be appropriate to consider a different approach in investigating the involvement of reading in the development of student writing and how educators may encourage students to engage with a wider range of academic sources.

Understanding how learners develop specialist knowledge is not a recent area of research, with numerous studies in content area literacy investigating how children develop the necessary skills to read content specific texts. However, content area literacy focuses on being able to read disciplinary texts based on the premise that reading of all types uses essentially the same set of cognitive skills. Thus, by this view reading a scientific text or a history text require little difference in cognitive approaches, rather a shift in reading style in order to interpret each text. This notion has shaped much of the current teaching practices that have carried through into higher education in the sciences, with little time dedicated to discipline specific literacy development. Do educators consider that being literate enough to read and write ought to be sufficient for students to understand and interpret highly complex scientific text? Whilst highly technical content may be thought to be the main barrier in students' ability to engage with disciplinary texts, educators have largely ignored the specialist knowledge required to understand the language and structure of such texts, which is the focus of disciplinary literacy research. Without building these skills into curricula students cannot be expected to make sense of the world around them. With an increasing volume of information available at the click of a mouse, specialist knowledge and how to interpret it is becoming less valued. However, the ability to interpret the vast range of information is crucial in developing disciplinary literacy. Where once learners developed literacy skills under the guidance of specialist librarians, learning how to locate and read a range of high-quality texts available through their institution, increased electronic accessibility has reduced these skills to a simple CTRL + F function. With increased accessibility has come reduced quality as well as information literacy. All this is occurring in the background of many educational environments, without intervention of educators as they focus on the delivery of disciplinary content.

As scientific knowledge progresses and new techniques are developed, educators are under pressure to include even more disciplinary content than ever before, ensuring students have a strong foundation to understand the evolution of their discipline, whilst also incorporating generic skills. However, combined with a lack of professional development in delivering transferrable skills leaves educators unprepared for this challenge. This is relevant, not just in higher education, but across all levels of education. Teachers are prepared and focussed on their area of expertise, with less thought given to the translation of that specialist knowledge to other areas. However, higher education teachers are more at risk of focussing on content knowledge to the exclusion of other aspects of the discipline for two reasons, they are ill prepared to scaffold learning due to a lack of education specific training, and the content they deal with is often highly technical and specialised, justifying the need to stay within the confines of discipline specific language.

Currently, the development of disciplinary literacy is not well scaffolded and rarely considered throughout the undergraduate student experience. The value of communication through the written word is loaded towards disciplinary environments, focussing on communication between experts. Rarely are there opportunities for students to develop skills to communicate with someone outside of their field. Instead of this intentional intervention, educators see disciplinary literacy gradually developing over time by chance exposure, in many cases only emerging in the postgraduate space where learning experiences are highly individualised, and expertise is already somewhat developed. Yet very few students continue to postgraduate studies, meaning that most graduates will not be afforded the environment in which to develop adequate disciplinary literacy to establish transferrable skills. This research shows that the changes required to create a rich environment that supports the development of disciplinary literacy need not be difficult, in fact educators already possess the necessary skills to implement such change without undertaking any additional training. However, in order to enact change educators must see value in the outcomes, they must tip the balance in favour of how much work is required, they must be relatively easy to put in place. Thus, the use of the e-learning modules - the artefacts - is crucial. The artefacts demonstrate to educators that such a shift does not require an extraordinary amount of investment in curricula redevelopment. Instead, the artefacts highlight how to embed workplace practices into teaching, without squeezing out valuable disciplinary content. The artefacts demonstrate how what academics do daily through research and professional relationships can mesh into their educational practices. In this sense, the artefacts act as a key to unlock the door to disciplinary literacy, making accessible the skills that are already developed in educators.

There are many ways to develop literacies within a discipline, however reading and writing link them all, thus the artefacts presented here allow educators and learners to embark on a journey together, with a shared understanding of the destination, and with clear expectations of how to develop the skills needed to become a member of the disciplinary community. These circumstances are not unique to science education, indeed many of the educational practices explored here are embedded within a wide range of other disciplines, suggesting that the outcomes of this research have broader applications than solely within science education settings. Thus, the key principles to developing disciplinary literacy can be applied across all disciplines and are not unique to a particular developmental level. These educational principles will be equally effective in science as in arts, working with primary school-aged children or adult learners. In summary, these principles are:

1. Alignment of the three central elements of student learning: ***Environment, Expectations and Engagement*.** In designing curricula to develop disciplinary literacy educators should consider these elements, ensuring there are multiple opportunities for overlap to occur. Explore students' expectations and discuss how these have formed. Examine the learning environment and seek to embed authentic experiences that connect to students' expectations, and provide opportunities for meaningful engagement to occur, reflecting on the purpose of assessment and being explicit and open throughout educational practice.
2. Employ ***Situated Practice, Modelling and Community Connections*** where educators can provide opportunities for students to develop meaningful connections that are relevant to their own lives and authentically place the content they are to learn in disciplinary contexts. Educators should model what they expect from their students, providing examples of the expectations of the discipline demonstrating what is valued in the discipline and how to develop these skills, not only between disciplinary experts but beyond. Using authentic assessment, students should be provided with opportunities to become part of the disciplinary community, where their voice is valued and contributes to the discipline, working towards expertise.
3. Employ ***Multimodal Learning Mechanisms in Curricula***. Understanding the previous experiences of student learning is crucial in developing an environment that establishes connections with expectations and provides

opportunities for student engagement. In order to move students ever towards expertise and disciplinary literacy, the use of multimodal curricula allows increased opportunity for engagement, which is critical in addressing the accessibility of minorities, in science and in education more generally. Multimodal assessment practices provide genuine opportunities for students to connect their learning to their past experiences, and these connections promote deeper engagement and confidence in learners.

4. Promote and foster ***Engagement*** by providing clear guidelines and ample opportunities for practise and feedback in a low-risk setting so that learners are supported to engage.

To move beyond current practices, shifting how we view the purpose of teaching and learning and understand how disciplinary literacy develops I have explored the following three questions. These questions have been activated through the doctoral mode selected for this research: the artefacts and the exegesis.

1. *How can Disciplinary Literacy be applied to provide a framework to support the inclusion of a variety of communication skills?*
2. *How does Disciplinary Literacy develop during an undergraduate science degree program?*
3. *How can the application of a Disciplinary Literacy framework be used to address factors limiting the inclusion of minority groups in Science Education?*

In answering these questions, this doctoral research has provided a framework for educators on which to base high quality curriculum to include a wide range of communication skills in science education. By analysing current practice, we can focus attention on the areas of science communication that we have been ignoring, including authentic learning experiences that provide students an opportunity to develop communication skills for broader audiences. The artefacts act as a model for how educators can model disciplinary examples and situating assessment in authentic writing, providing learners with increased opportunities to develop disciplinary literacy. The analysis of the way the artefacts impacted student assessment allows us to consider the prior experience of our students, ensuring adequate opportunities to build on current understanding rather than stifle it or make assessment too prescriptive. This is apparent in how students responded to e-learning modules described in Chapter 3 where improvements in performance correlate with areas of inexperience and small but significant decreases in performance are seen when novice learning methods are encouraged in areas where students are already experienced.

Currently, opportunities for students to broaden communication skills are sparse in an undergraduate teaching program. The focus remains a narrow parameter of writing genres, with a focus on communicating with experts within the discipline. By incorporating a wider range of authentic communication activities students will develop stronger connections to the discipline and the content by exploring their understanding through writing. A crucial design element of the artefacts is the strong disciplinary links they have to writing that is performed in the workplace by experts in the field. This is a critical element in providing learners with an experience that aligns the learning environment, their expectations and provides opportunities for engagement through authenticity. Promoting change, not just in learners but in educators, makes connections beyond the classroom. Demonstrating that the learning environment reflects disciplinary practices more broadly by linking the two together.

These connections can be further strengthened by increasing accessibility using multimodal design, thus the issues surrounding inclusion of minority groups can be addressed. Communication in various forms is crucial to engagement within higher education but also more broadly. By teaching our graduates how to communicate with a wider audience, issues of accessibility are addressed both within and beyond the discipline. By improving the accessibility and thus the visibility of science to the broader community existing barriers to women and other minorities in science disciplines are reduced (Fogg-Rogers & Hobbs, 2019). The artefacts provide clear examples of how this can be done without sacrificing important disciplinary content, demonstrating to students the importance of communicating with a range of audiences and the value of language choices. With a stronger focus on communication in science education we can expect a variety of voices to be heard and contribute to the conversation of science and a shared understanding can be developed between scientists and the wider community.

Reflecting upon the processes of describing theories of learning and teaching, it seems that I have become a living case study of my own research. Having developed my original disciplinary literacy in the Biological sciences, I have now performed the scaffolding literacy theory that I have described in this exegesis in the discipline of Education. This scaffold has enabled me as a researcher and teacher to move between disciplines with confidence and clarity. Throughout this doctoral research, the design and development of the artefacts and in- depth reflection and understanding brought about in this exegesis my relationship with research, teaching and learning has changed. This process has taught me how to be comfortable in failure and confident to have another go, having learnt from my experiences. Through this process, I have discovered that having an educational environment where failure is seen as a learning opportunity rather than a disaster has been critical. I have been privileged to experience a sense of safety in falling over and picking myself up again. It is this safety that offers the comfort and confidence that educators strive to provide to our students. Through the process of my research I have come to understand the pivotal role this plays in the success of learners.

The mode of this thesis is important and relevant to my learning experience as a science educator. By pushing the boundaries of a traditional PhD thesis, I have been able to explore how the mode of information influences learner experience. The artefact and exegesis format are not only uncommon in the sciences, but also a rather challenging form due to the nature of empirical methods. By undertaking this mode of research, I have experienced my own development in disciplinary literacy, visible in the way I can bring together both disciplines to describe how disciplinary literacy develops. Scientific research requires creativity in order to tackle challenging problems in novel ways. The artefact and exegesis mode have facilitated the creative aspect of science education and enabled a creative approach to understand how to develop disciplinary literacy by combing the approaches of scientists and educators.

The development of the artefacts for this doctoral research provided an opportunity to explore the way learners learn, investigating why they develop particular skills in the way they do. Instead of focussing on disciplinary content rather on reading, writing and thinking in a variety of modes within a discipline, I was able to describe both how and why disciplinary literacy develops through assessment practices. This is critical in understanding the way learners engage with content, enabling the development of future resources that will help to prepare our learners for the challenging future ahead. At the beginning of this exegesis, I explored the dichotomy in purpose of university education, with student experiences shaped by either industry or the traditional objective of higher education. While these forces at first glance seem opposed, they need not be. Graduates who are provided with many opportunities to develop literacies in a variety of modes within a discipline will be able to move more easily between disciplines. The inquiry and philosophical openness that has traditionally been the goal of higher education (Allan, 2018) allows more people to transform their lives by being successfully employed in a variety of careers as these skills are precisely what employers say is lacking in graduates (Ferns, 2012; The Foundation for Young Australians, 2017). Instead of bringing the needs of society and industry together, higher education practices have inadvertently pushed them further apart. Extracting context specific skills from the curriculum under the guise of preparing students for the workplace has resulted in exactly the opposite. Science graduates in particular are no longer seeing the wider contexts of their learning experiences. They are ill-prepared for the range of work they will go on to perform. Yet, they must be prepared for a wide range of careers as many will find employment outside of traditional scientific fields (Palmer et al., 2018). The artefacts provide a mode for educators to reintroduce context into the curriculum, ensuring an authentic and relevant experience that is situated in their discipline but seeks to make connections beyond. Only by bringing context back into the classroom, engaging students with a wide range of opportunities to develop reading and writing skills within their discipline can we expect to align the goals of universities, employers and graduates resulting in better prepared graduates, productive industry and socially responsible universities.

Research Interrupted: The Value of Developing and Deploying Expertise in Challenging Times

Understanding how disciplinary literacy develops is essential in progressing as an individual learner. However, it is even more important in understanding the audience for science writing, teaching and research. While completing the final writing and drafting of this exegesis, the world is gripped by the global pandemic COVID-19. Educators and students alike are fearful of the future of online teaching and learning. Yet in a space that is dominated by hands-on practical experiences reflecting on the models of disciplinary literacy has enabled me to support a large group of first year students to transition to a fully online curriculum in under a week, without sacrificing learning outcomes and with minimal disruption. A large team of casual teaching staff will be retained and retrained in a virtual environment, ensuring continuous income during a time of precarious employment. By drawing on the models of disciplinary literacy I have been able to do all of this without skipping a beat in teaching, yes it has been challenging, but recognising the transferability of skills to new areas has been crucial and has provided a sense of calm and trust that is sorely needed in times like these and is highlighted by personal communications from teaching staff. These comments include, “Your experience and expertise really shine through in this time of crisis.” (G Norval 2020, personal communication, 19th March) and “I think you have done a wonderful job pulling together a thoughtful way to move these sessions online for students. I also really appreciate that you have found a way to include casual staff” (A Butler 2020, personal communication, 19th March). As well as students, “I really appreciate how easy this has been for me as a student, which means the Biology College/dept did a huge amount of work to make that seem easy” (S Haynes 2020, personal communication, 21st March).

By recognising how and why disciplinary literacy develops, we can reflect on the experiences of our students and provide meaningful modes of learning, no matter what the platform. In times of crisis like this it is important that society maintains a sense of normalcy. Continuing study for our students is one way to do this and will enable them to develop meaningful relationships with teaching staff and with each other from their own homes, adhering to social distancing measures. By designing and using online resources carefully we can enable our students to develop literacy within their discipline while physically distanced and socially supported.

During the COVID-19 pandemic and beyond there will be a need to be more flexible and agile in teaching practices than ever before. Scientists are experiencing ongoing challenges in communicating to a range of audiences and never has the need for greater scientific literacy amongst the public been clearer. These are unprecedented times in higher education where stress levels are at an all-time high for both students and staff alike. However, as educators we have both an opportunity and an obligation to support our students and colleagues to continue learning and teaching. Through innovative practices I have been able to provide a supportive learning environment using workable solutions to keep students and staff engaged and connected to a vibrant and supportive community that will help each other move through these challenging times. Throughout this doctoral research I have developed literacies that allow me to understand scientists and learning, bringing the disciplines together in a way that can benefit my students during a time of crisis, for that I will be eternally grateful.

Limitations and Future Directions

Whilst specific mention of the limitations of the research methods have been mentioned in previous sections (in particular section 3.7.7) consideration of broader limitations are needed. Higher education and more specifically science education shares characteristics across the globe, yet this research has focussed solely on data collected in the narrow frame of Australia. To compensate for this limitation the wider frame of international higher education has been overlaid, and there are commonalties between the way science is taught around the world. However, we must be careful in the interpretation of these findings as they may be indicative of peculiarities in the Australian education system.

The outbreak of COVID-19 during this PhD research highlighted the importance of such e-learning materials to support student learning. However, it also highlighted the limitations of their current design and provided areas for future improvement. The inclusion of a wider range of modes is certainly an area of interest for future development as well as providing a wider range of genres as examples of scientific writing.

Further research is most certainly needed to determine if the proposed theoretical model of the learning and teaching processes adequately describes what happens within a classroom setting. Furthermore, it remains to be seen how each of the areas identified interact with assessment and are implemented as a framework.

The Future of Science Education

The landscape of higher education has been permanently altered by recent events. Teaching and learning in higher education will unlikely ever be the same again no matter what the discipline, with a new focus on distance education and supporting a variety of students in a variety of modes. When students can return to classes on campus even then those classes are unlikely to look and feel the same as they once did. The relationship between students and staff has also changed, with it being clearer than ever the tenuous grasp that many academics have on their curriculum. The swift move to online delivery shone light on the deficits amongst higher education educators, in particular the reliance on didactic teaching methods and lack of scaffolded opportunities available for student learning (Adnan & Anwar, 2020;

Brabazon, Quinton, & Hunter, 2020). With students invited into our loungerooms via Zoom, Skype or Collaborate with children, spouses and pets in the background the relationship between teachers and learners is changed. By opening up our homes, students are seeing the reality of academia filled with late nights spent redesigning curriculum and managing a household at the same time, many educators are struggling. Kiser (2020 para. 4) suggests that, “in these trying times, the last thing that students need to see is their professional, highly educated professor falling apart at the seams” and whilst she has a point, I don’t think that it is our physical appearance that should be of such concern, but rather showing that we are able to support our students through challenging times with flexibility and grace, providing structure and continuing to develop meaningful curriculum. It is those connections that demonstrate to students the importance of their discipline. Those teachers that shone in challenging circumstances were successful not due to experience in online learning, but their ability to transfer existing skills to another mode of teaching and learning. Those that were experts within their discipline and able to move that knowledge through different modes have been best placed to continue to support their students online.

The most useful support that educators can provide to students for their long-term development is disciplinary literacy. Students with a strong understanding of their discipline and how ideas within the discipline are formed will be best positioned for future change, able to use that knowledge to understand and interpret the world around them. This has never been clearer in Science Education than it is right now. Millions of students worldwide are struggling to maintain focus on their studies feeling a lack of relevance, in a time when it has never been more important to understand the science. With academics across the globe concerned that science curriculum will be hardest hit by these changes and that “the worst affected programmes will be science and technology as students will be unable to access laboratories for their practicals" (Mohamedbhai, 2020 para. 12) teachers need innovative ways to continue to provide these learning opportunities to their students. My own disciplinary literacy within science and education has prepared me for this situation and enabled me to continue delivering a meaningful and engaging curriculum that includes practical components. Instead of being disadvantaged, students are using innovative techniques and discussions to explore issues that they previously would have glossed over in traditional practical classes. They now pay close attention to minute details to understand tricky concepts, they are seeing the connections between a single laboratory class and the bigger picture, communicating this to others and understanding concepts more broadly.

Educators can expect further changes to their student cohorts, not just in the way they will be engaging and interacting, but in who they are with predictions of increased enrolments of domestic students. As Hillman (2020 para. 8) confirms, "Recessions tend to mean that people want more education because the alternatives – underemployment or unemployment – are worse, and having more skills can protect you against the economic chill winds". Massification has already changed the landscape of higher education but these recent circumstances are likely to see more students seeking places in online courses particularly in the sciences, with the Minister for Education and the Minister for Employment, Skills, Small and Family Business announcing that "Australians will use their time social distancing to develop skills for new jobs in National Priority areas such as nursing, teaching, health, IT and science" with costs to study online short courses in these areas slashed. Educators can also expect changes in the expectations of curriculum delivery where "online education will be recognized as core to every school's plan for institutional resilience and academic continuity” (Kim, 2020 para. 10) meaning that swift action will be needed to cater to a growing need in the sector.

This disruption empowers educators to make changes. The opportunities to rethink and redesign curriculum will be widespread, and educators will have little choice but to embrace the opportunity. Educators have a chance to make a difference in the way science is taken up by the broader community, simply by enacting change in their students. The artefacts presented here combine two important aspects that will help guide students and staff through these challenging times and beyond. With attention to detail in discipline specific genre expectations students are supported to learn the importance of language choice and structure in their communications. Additionally, the choice of genre presented in the artefacts provides examples of communication with a variety of audiences including peers, industry, government and the public, emphasising the importance of reaching a wider audience with science communication. While the artefacts provide an example of how science education practice can be performed, they have much deeper meaning when considering the impact of developing disciplinary literacy in undergraduate students. In the current higher education environment, one that is dominated by industry expectations, educators can no longer deliver the traditional goals of a university education. However, by disrupting the approach and focussing on how students develop literacy within a discipline, educators will be able to provide both an informed and reflective experience to students, addressing both the traditional goals of higher education and the needs of industry. This will result in a community of scientists better prepared to work in a variety of fields and communicate with a wide range of people, which in turn will lead to increased engagement and understanding of science in the wider community. This revolutionary but seemingly simple shift in focus has the potential to change the way science is viewed, making it more accessible for all.

Not only is this shift in science education necessary, it is overdue. The increasing trend of science denial amongst a range of communities, citizens and stakeholders can only be addressed by improving science communication, not by saying or doing the same thing and expecting the public to listen as they are drowning in a myriad of mixed messages. Science educators around the world are currently experiencing a wake-up call to improve their practices and address the misinformation and misunderstanding amongst the public that has led to widespread anti-mask movements and COVID-denial. By focussing on how educators scaffold learning experiences to move students from novice to expert within a discipline, students will have the skills needed to communicate clearly and effectively with a rage of audiences, encouraging community input in scientific debates. Looking at this project through a wider lens, not only does disciplinary literacy relate to the realm of science. The development of disciplinary literacy and understanding how educators foster this through higher education is crucial to all disciplines. While universities should be a place of intellectual inquiry that are protected from dominant public opinions, they should be informed by them and inform them. Universities have a responsibility to give back to the community, improving the lives not only of its' students but the community as a whole.

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APPENDIX A : THE ARTEFACTS

What are the Artefacts?

The artefacts consist of three e-learning modules designed to support students to develop familiarity in reading and writing a variety of scientific genre. The genres included are *Journal Article*, *Discussion Paper* and *Impact Statement*. Each module is a stand-alone unit that students can work through independently, allowing flexibility in how they are deployed within curricula. Educators can select one or more of the modules to support assessment practices. The modules presented here were deployed in first year units at Flinders University and therefore include some details that are specific to the teaching practices there. However, as with many electronic resources their usefulness lies in the flexibility and ease in modifying to suit context. The modules were created using Articulate Storyline 3 software, which is an inexpensive and easy to use product, requiring no in-depth training. This allows the modules to be quickly modified by educators as needed to include or exclude content and link to assessment tasks without having to rely on technical support services. The modules are available as executable files that can be embedded within a LMS, provided independently via a webpage, or in a file that can be downloaded and opened without the need for additional specialised software.

Key design elements

The genre represented in the artefacts were selected based on an analysis of types of writing performed by scientists that could be incorporated into teaching practice within the context of this study. Even though there are many existing resources that demonstrate how to write a scientific journal article, this genre was still included to provide insight into the process of disciplinary literacy development. The scientific journal article is an important aspect of scientific writing which has an important place in science education. The discussion paper and impact statement were selected to represent communication with the general public and engagement with government policy, two forms of scientific writing that are lacking representation in most undergraduate curricula. All modules were designed in conjunction with a specified assessment task, thus refer to the requirements of assessment throughout. This method was chosen to drive student engagement with the resources and to enable empirical measurement of any influence they had on student writing development.

Each e-learning module begins by introducing students to the genre they have been asked to prepare for the associated assessment task. By doing so students are guided through how to read texts and they are prompted to consider the intended audience of the communication and its purpose. A combination of approaches was deployed to embed the development of writing skills within each module and ensure they were relevant to the wide range of students accessing them. Where possible the modules were created to have flexibility and choice so that students could self-select a context that best suited their own, including disciplinary specific examples to support their interests as demonstrated in Figure A.1 which is an excerpt of the impact statement module, providing students with a choice of five subject areas to begin their learning journey.

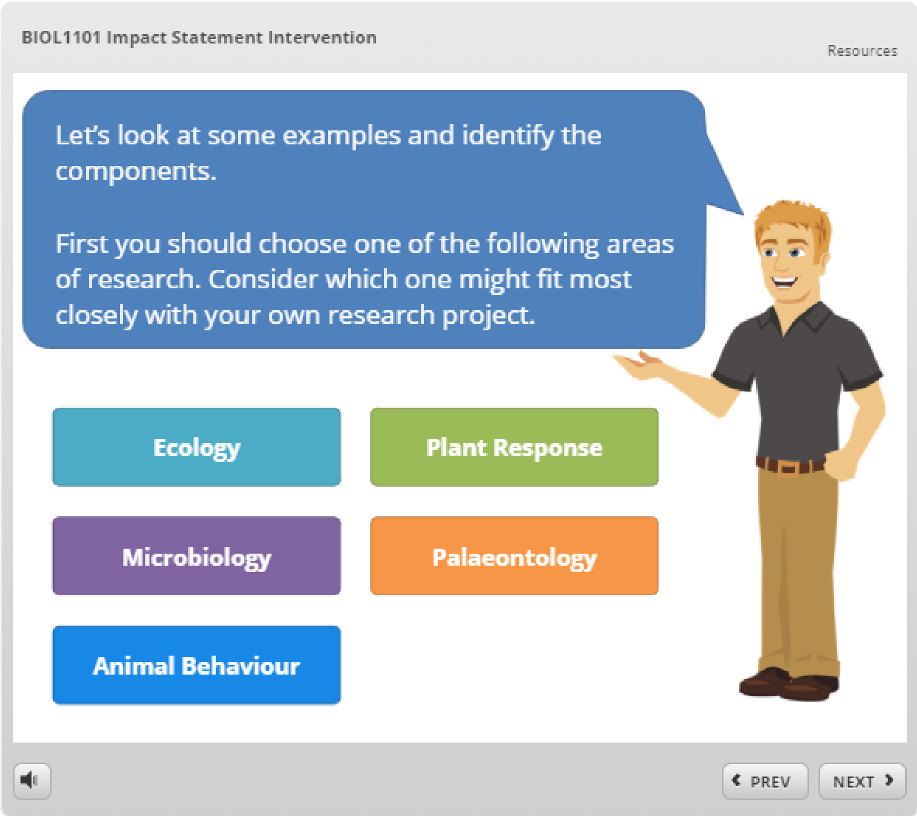


Figure A.1 Excerpt of the introductory section of the impact statement module.

Once students select the appropriate discipline to suit their learning context they are introduced to an expert within the field with an authentic example of their writing as depicted in Figure A.2. In the example depicted in Figure A.2 Professor James Stangoulis, an expert in plant physiology and biochemistry provided a genuine impact statement that was submitted as part of an ARC grant. Similar examples were also provided from a range of different disciplines to allow students to self-select an area of interest to them.

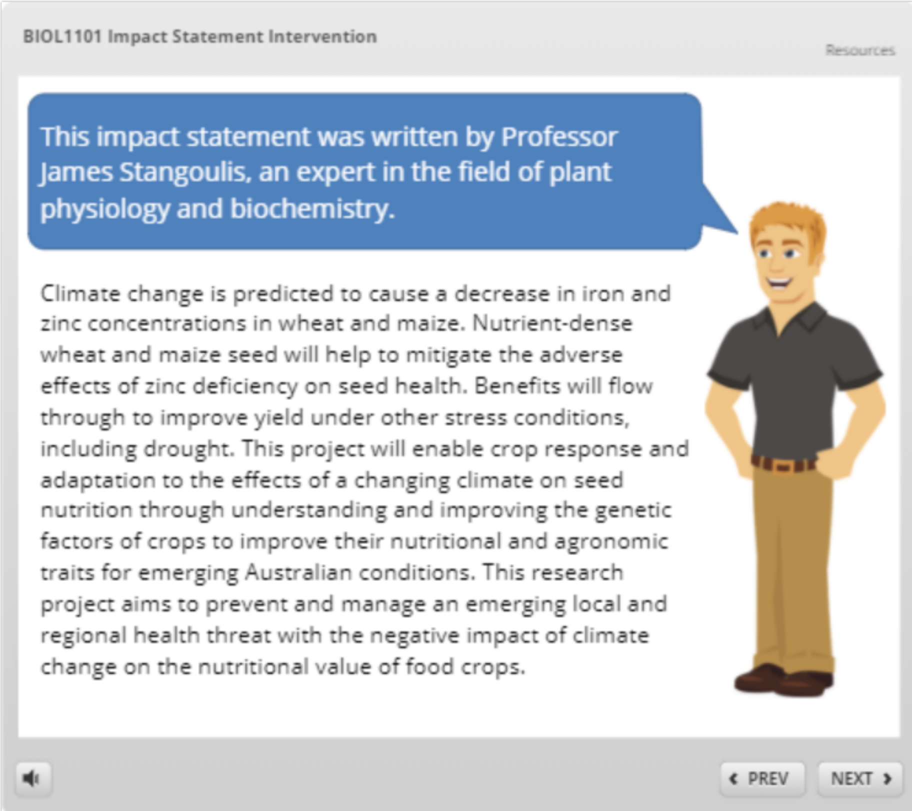


Figure A.2 Excerpt of the impact statement module depicting an example of authentic writing from an expert in the discipline.

In addressing explicit writing instruction, the e-learning modules employed three educational models and incorporated these together where possible. Product-based processes were used to model correct vocabulary and syntax specific to the discipline. This is depicted in Figure A.3, which shows an excerpt of the SWA module asking students to check their understanding of using the passive voice in describing their experimental methods.

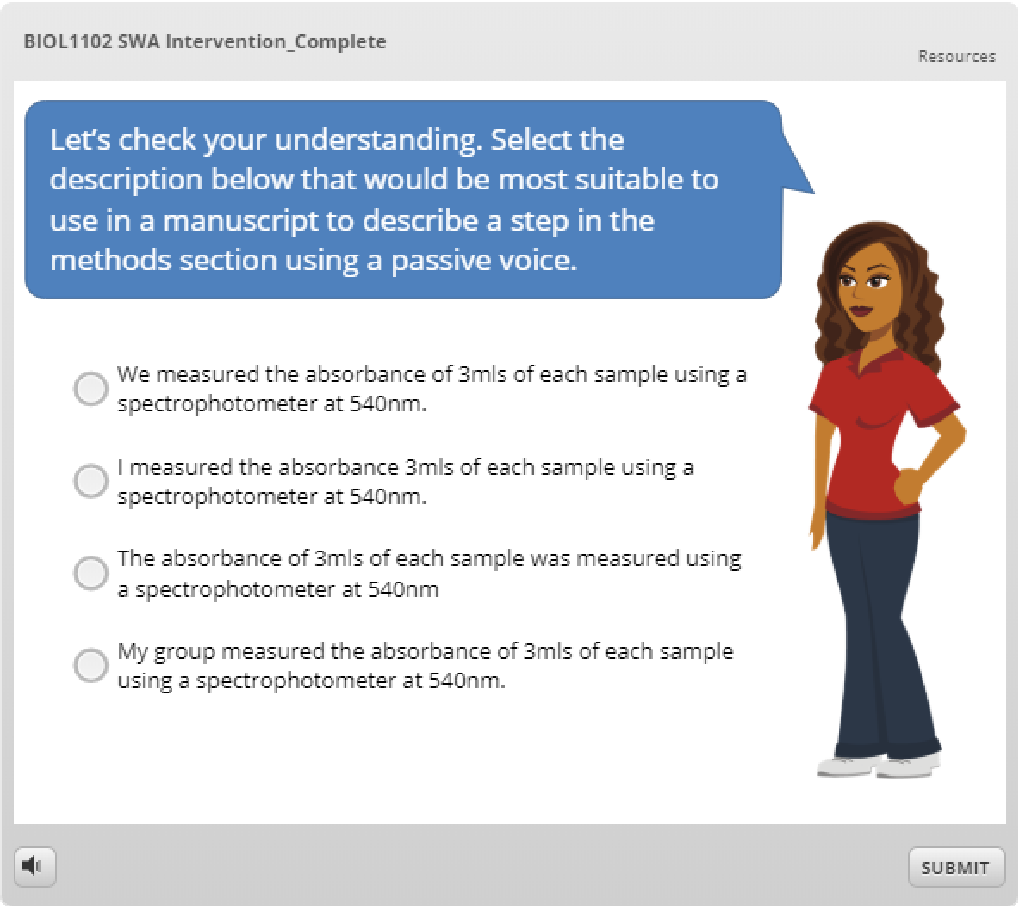


Figure A.3 An excerpt of the SWA module describing experimental methods.

Process based approaches were used to aid in the formation of texts and encourage learners to draft and revise their writing. This was done in several ways, firstly by incorporating sections as shown in Figure A.4 which depicts an excerpt from the discussion paper module reminding students of the overall structure of the text. Secondly, by providing opportunities for students to draft short sections of their own text within the modules as is shown in Figure A.5 and this is accompanied by an example of an expert summary for comparison depicted in Figure A.6, ensuring that if students are finding the material challenging they are supported with meaningful feedback and points throughout the module to compare their progress to the requirements of the assessment tasks.

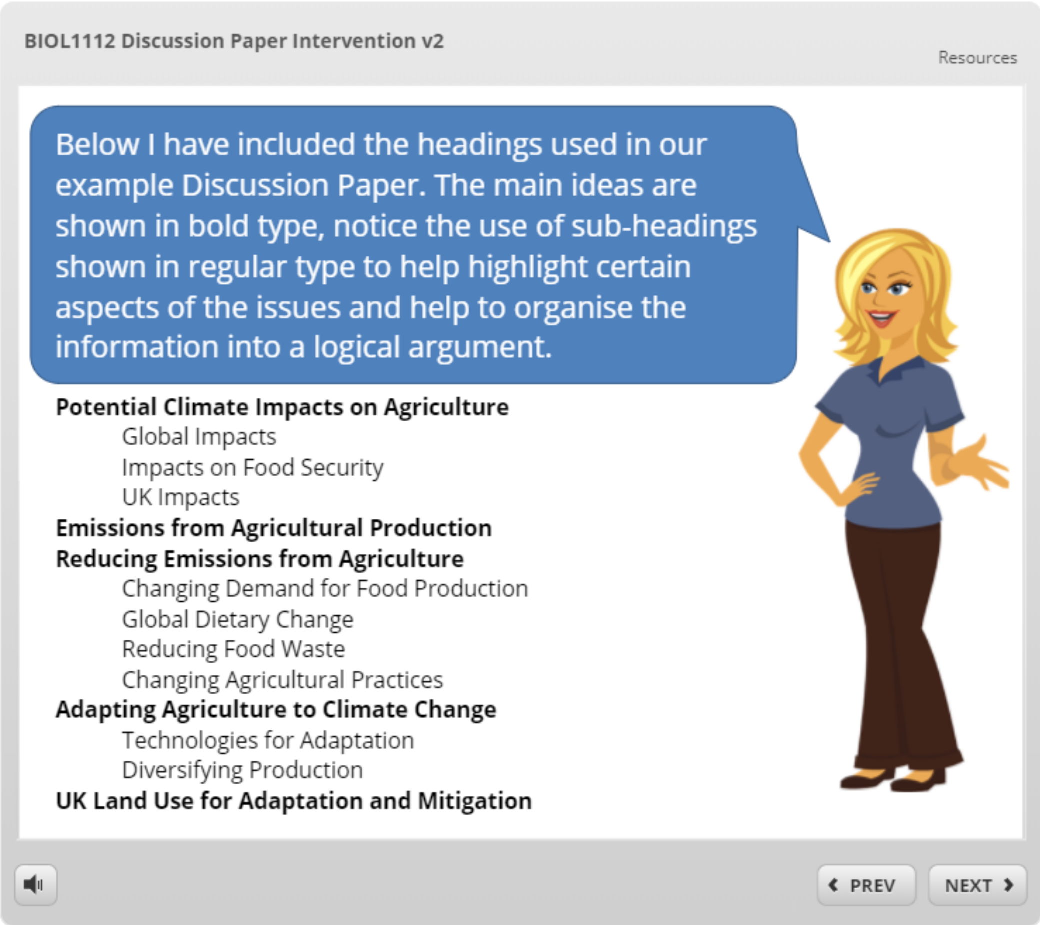


Figure A.4 An excerpt from the discussion paper module reminding students of the overall structure of the text.

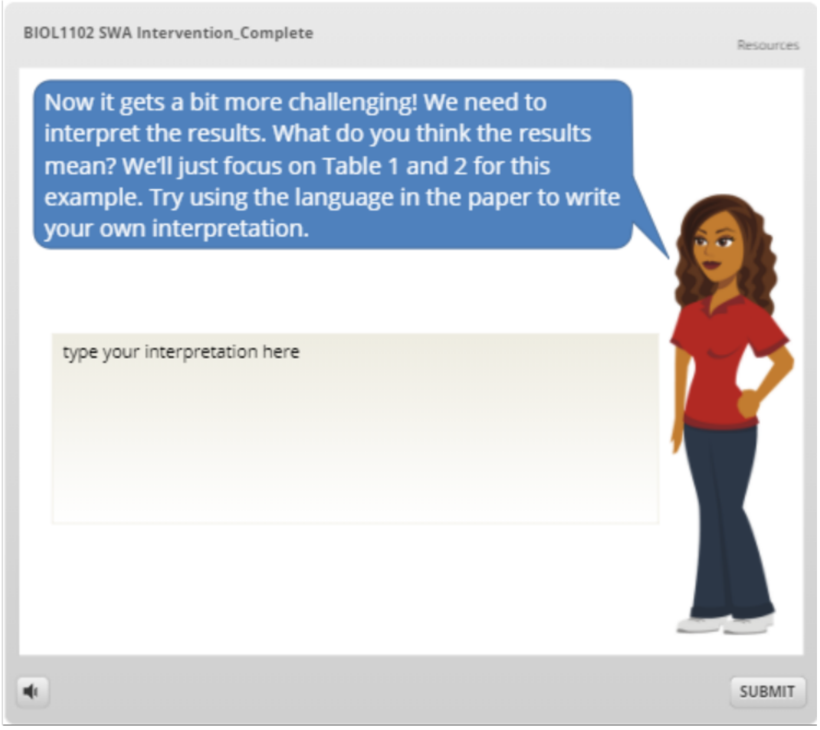


Figure A.5 An excerpt from the SWA module prompting students to draft a response.

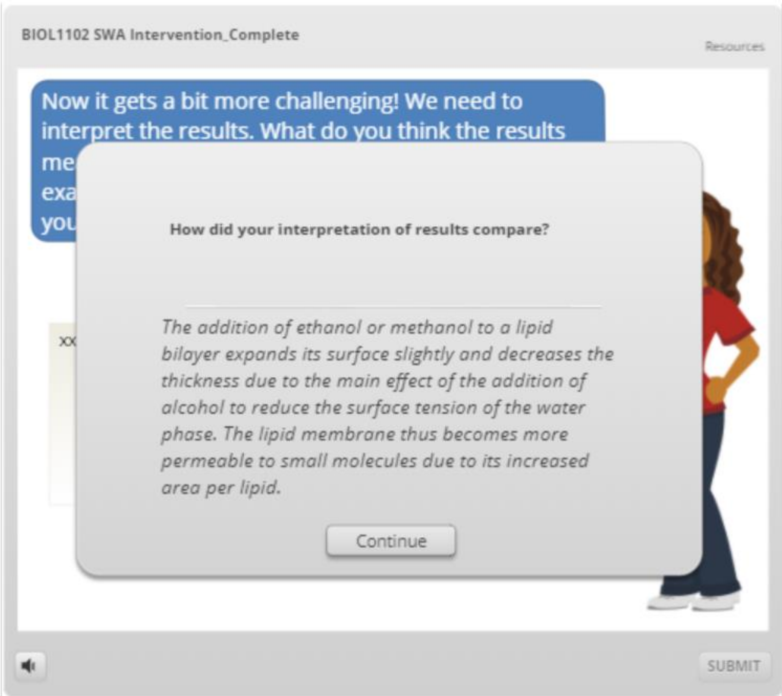


Figure A.6 An excerpt from the SWA module providing a comparison of an expert interpretation.

Finally, a genre-based approach was applied to each module centring the writing on the social context and making it clear who the intended audience was for the text. This is depicted in Figure A.7 which shows an excerpt of the discussion paper module introducing students to the genre. Each module employed a similar method to engage the learner with their audience using clear and overt terminology to provide context for the writing that was expected.

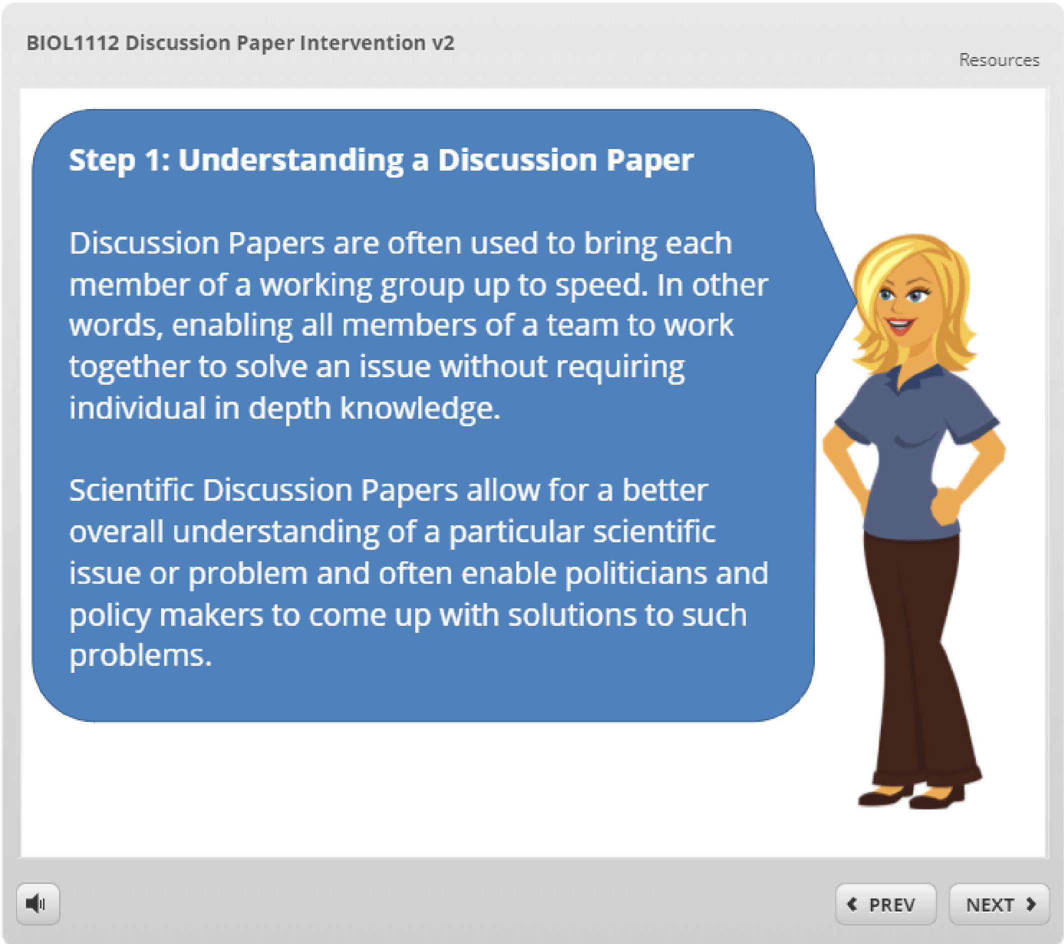
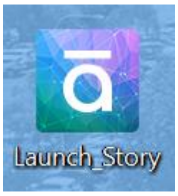


Figure A.7 An excerpt from the discussion paper module depicting the introduction to genre.

Accessing the Artefacts

The e-learning modules can be accessed by clicking on the links provided below. These links direct the user to a shared .zip file which should be downloaded in its entirety, and all files extracted to a suitable location on a desktop or laptop computer. Please note: a full download and extraction is required before "Launch Story" can be activated.

Once extracted, the Launch_Story icon 

will open the simulation upon double clicking. This process should be repeated for each of the three modules. This will allow the user to navigate the modules freely.

Scientific Writing Assignment e-learning module

Discussion Paper e-learning module

Impact Statement e-learning module

APPENDIX B : THE LANGUAGE OF SCIENCE ADDITIONAL DATA

Detailed data analysis for section 3.5 Current Assessment Practices

Data was analysed using a Chi-squared analysis however, the sample size adequacy assumption of the Chi-Square test of homogeneity was violated thus, a Fisher's Exact test was performed. Students were categorised as either first, second or third year of their undergraduate degree program (depicted as 1, 2 or 3). Post hoc analysis involved pairwise comparisons using the z-test of two proportions with a Bonferroni correction. Statistical significance was accepted at $p < .016667$.

Table B.1 Descriptive statistics and results of Fisher's Exact test of the differences between proportion of students completing assessment items during an undergraduate degree program.

Each subscript letter denotes a subset of each item category whose column proportions do not differ significantly from each other at the .05 level.

Bold values indicate significant differences between values.

		Year		
		1	**2**	**3**
Scientific writing assignment	Count reported	136a	98a	51b
	Count not reported	2a	2a	5a
	Count total	138	100	56
	% reported	47.7%	34.4%	17.9%
	% not reported	22.2%	22.2%	55.6%
	% total within category	46.9%	34%	19%
	Statistical test statistic	6.305		
	Statistical test: p-value	.033		
Scientific poster	Count reported	126a	94a	54a
	Count not reported	12a	6a	2a
	Count total	138	100	56
	% reported	46%	34.3%	19.7%
	% not reported	60%	30%	10%
	% total within category	46.9%	34%	19%
	Statistical test statistic	1.544		
	Statistical test: p-value	.441		
Lab notebook	Count reported	132a	99a	55a
	Count not reported	6a	1a	1a
	Count total	138	100	56
	% reported	46.2%	34.6%	19.2%
	% not reported	75%	12.5%	12.5%
	% total within category	46.9%	34%	19%
	Statistical test statistic	2.240		
	Statistical test: p-value	.329		
Lab report	Count reported	51b	74b	50b
	Count not reported	87a	26a	6a
	Count total	138	100	56
	% reported	29.1%	42.3%	28.6%
	% not reported	73.1%	21.8%	5%
	% total within category	46.9%	34%	19%
	Statistical test statistic	**61.138**		
	Statistical test: p-value	**<.001**		

Table continues next page

Journal article	Count reported	11b	9a	18b
	Count not reported	127a	91a	38a
	Count total	138	100	56
	% reported	28.9%	23.7%	47.4%
	% not reported	49.6%	35.5%	14.8%
	% total within category	46.9%	34%	19%
	Statistical test statistic	**18.732**		
	Statistical test: p-value	**<.001**		
Persuasive exposition	Count reported	3b	8a	5a
	Count not reported	135a	92a	51a
	Count total	138	100	56
	% reported	18.8%	50%	31.3%
	% not reported	48.6%	33.1%	18.3%
	% total within category	46.9%	34%	19%
	Statistical test statistic	5.937		
	Statistical test: p-value	.043		
Argumentative essay	Count reported	38a	30a	19a
	Count not reported	100a	70a	37a
	Count total	138	100	56
	% reported	43.7%	34.5%	21.8%
	% not reported	48.3%	33.8%	17.9%
	% total within category	46.9%	34%	19%
	Statistical test statistic	.841		
	Statistical test: p-value	.671		
Impact statement	Count reported	2a	4a	1a
	Count not reported	136a	96a	55a
	Count total	138	100	56
	% reported	28.6%	57.1%	14.3%
	% not reported	47.4%	33.4%	19.2%
	% total within category	46.9%	34%	19%
	Statistical test statistic	1.627		
	Statistical test: p-value	.422		
Literature review	Count reported	48b	64b	44b
	Count not reported	90a	36a	12a
	Count total	138	100	56
	% reported	30.8%	41%	28.2%
	% not reported	65.2%	26.1%	8.7%
	% total within category	46.9%	34%	19%
	Statistical test statistic	**38.730**		
	Statistical test: p-value	**<.001**		

Table continues next page

Newspaper article	Count reported	4a	2a	3a
	Count not reported	134a	98a	53a
	Count total	138	100	56
	% reported	44.4%	22.2%	33.3%
	% not reported	47%	34.4%	18.6%
	% total within category	46.9%	34%	19%
	Statistical test statistic	1.490		
	Statistical test: p-value	.544		
Science blog	Count reported	1a	3a	3a
	Count not reported	137a	97a	53a
	Count total	138	100	56
	% reported	14.3%	42.9%	42.9%
	% not reported	47.7%	33.8%	18.5%
	% total within category	46.9%	34%	19%
	Statistical test statistic	4.048		
	Statistical test: p-value	.121		
Public health announcement	Count reported	2a	2a	5b
	Count not reported	136a	98a	51a
	Count total	138	100	56
	% reported	22.2%	22.2%	55.6%
	% not reported	47.7%	34.4%	17.9%
	% total within category	46.9%	34%	19%
	Statistical test statistic	6.305		
	Statistical test: p-value	.033		
Professional email	Count reported	1b	5a	3a
	Count not reported	137a	95a	53a
	Count total	138	100	56
	% reported	11.1%	55.6%	33.3%
	% not reported	48.1%	33.3%	18.6%
	% total within category	46.9%	34%	19%
	Statistical test statistic	5.350		
	Statistical test: p-value	.070		
Grant application	Count reported	31a	25a	13a
	Count not reported	107a	75a	43a
	Count total	138	100	56
	% reported	44.9%	36.2%	18.8%
	% not reported	47.6%	33.3%	19.1%
	% total within category	46.9%	34%	19%
	Statistical test statistic	.238		
	Statistical test: p-value	.888		

Detailed data analysis for section 3.6 Student Resourcing

Data was analysed using a Chi-squared test and the sample size adequacy assumption of the Chi-Square test of homogeneity held. Post hoc analysis involved pairwise comparisons using the z-test of two proportions with a Bonferroni correction. Statistical significance was accepted at $p < .016667$.

Table B.2 Descriptive statistics and Chi-square test statistics of the differences between proportion of students reporting using various learning resource to develop writing skills.

Each subscript letter denotes a subset of each item category whose column proportions do not differ significantly from each other at the .05 level.

Bold values indicate significant differences between values.

		Year			
		1	**2**	**3**	**PG**
Written instructions	Count reported	113a	85a	45a	24a
	Count not reported	25a	15a	11a	13a
	Count total	138	100	56	37
	% reported	81.9%	85%	80.4%	64.9%
	% not reported	18.1%	15%	19.6%	35.1%
	% total within year	100%	100%	100%	100%
	Statistical test statistic	7.262			
	Statistical test: p-value	.064			
Rubric	Count reported	123a	81a	45a	15b
	Count not reported	15a	19a	11a	22b
	Count total	138	100	56	37
	% reported	89.1%	81%	80.4%	40.5%
	% not reported	10.9%	19%	19.6%	59.5%
	% total within year	100%	100%	100%	100%
	Statistical test statistic	**42.865**			
	Statistical test: p-value	**<.001**			
Consulting	Count reported	54a	49a	29a	13a
	Count not reported	84	51a	27a	24a
	Count total	138	100	56	37
	% reported	39.1%	49%	51.8%	35.1%
	% not reported	60.9%	51%	48.2%	64.9%
	% total within year	100%	100%	100%	100%
	Statistical test statistic	4.900			
	Statistical test: p-value	.179			

Table continues next page

Student learning centre	Count reported	23a	13a	3a	2a
	Count not reported	115a	87a	53a	35a
	Count total	138	100	56	37
	% reported	16.7%	87%	5.4%	5.4%
	% not reported	83.3%	13%	94.6%	94.6%
	% total within year	100%	100%	100%	100%
	Statistical test statistic	6.576			
	Statistical test: p-value	.087			
Q&A	Count reported	39a	38a	17a	6a
	Count not reported	99a	62a	39a	31a
	Count total	138	100	56	37
	% reported	28.3%	38%	30.4%	16.2%
	% not reported	71.7%	62%	69.6%	83.8%
	% total within year	100%	100%	100%	100%
	Statistical test statistic	6.564			
	Statistical test: p-value	.087			
Assignment examples	Count reported	103a,b	83b	48b	21a
	Count not reported	35a,b	17b	8b	16a
	Count total	138	100	56	37
	% reported	74.6%	83%	85.7%	56.8%
	% not reported	25.4%	17%	14.3%	43.2%
	% total within year	100%	100%	100%	100%
	Statistical test statistic	**13.446**			
	Statistical test: p-value	**.004**			
Online resources	Count reported	50a	30a	18a	9a
	Count not reported	88a	70a	38a	28a
	Count total	138	100	56	37
	% reported	36.2%	30%	32.1%	24.3%
	% not reported	63.8%	70%	67.9%	75.7%
	% total within year	100%	100%	100%	100%
	Statistical test statistic	2.293			
	Statistical test: p-value	.514			

Detailed data analysis for section 3.7 E-learning Modules

Scientific Writing Assignment Analysis

An exploration of the data from student assessment of performance on the SWA was undertaken to determine if it was homogeneous by creating a box plot using SPSS and investigating for values greater than 1.5 box-lengths from the edge of the box. Each outlier was individually inspected in further detail to understand any reasons for divergence from the data set. Each outlier was removed as they all were examples of incomplete submissions, thus did not represent the overall product for comparison to the rest of the cohort. Additionally, a Shapiro-Wilk's test was performed to determine if the samples were normally distributed and this indicated non-normal data ($p < .001$). Therefore, further analysis to compare means was performed using an independent samples nonparametric Mann-Whitney U test.

Table B.3 Descriptive statistics and Mann-Whitney U test statistic of student grades for the scientific writing assignment.

Bold values indicate significant differences between values.

	Year	
	2018	2019
Maximum	100	98
Minimum	39	45
Median	80	79
Mean	77.91	77.70
Standard Deviation	13.25	11.88
N	462	406
Mean rank	438.85	429.55
Statistical test statistic	91775.0	
Statistical test: p-value	.585	

Table B.4 Descriptive statistics and Mann-Whitney U test statistic of student grades for each assessment criteria of the scientific writing assignment.

Bold values indicate significant differences between values.

		Year	
		2018	2019
Title	Median	4	4
	Mean	3.54	3.53
	Standard deviation	.930	.882
	N	462	406
	Mean rank	436.68	432.02
	Statistical test statistic	92779.5	
	Statistical test: p-value	.702	
Introduction (area of study)	Median	5	3
	Mean	3.96	3.81
	Standard deviation	1.163	1.202
	N	462	406
	Mean rank	447.78	419.39
	Statistical test statistic	87652.5	
	Statistical test: p-value	.066	
Introduction (link between aims and background information)	Median	3	2
	Mean	2.29	2.16
	Standard deviation	.843	.798
	N	462	406
	Mean rank	456.00	410.03
	Statistical test statistic	**83851.0**	
	Statistical test: p-value	**.004**	

Table continues next page

Introduction (aims)	Median	2	2
	Mean	2.28	2.22
	Standard deviation	.824	.771
	N	462	406
	Mean rank	446.33	421.04
	Statistical test statistic	88320.0	
	Statistical test: p-value	.109	
Introduction (hypothesis)	Median	3	3
	Mean	2.68	2.57
	Standard deviation	.601	.624
	N	462	406
	Mean rank	455.38	410.74
	Statistical test statistic	**84138.5**	
	Statistical test: p-value	**.001**	
Methods (language)	Median	2	2
	Mean	2.38	2.33
	Standard deviation	.643	.667
	N	462	406
	Mean rank	441.38	426.69
	Statistical test statistic	90616.0	
	Statistical test: p-value	.341	
Methods (content)	Median	5	5
	Mean	5.49	5.29
	Standard deviation	1.284	1.251
	N	462	406
	Mean rank	451.75	414.87
	Statistical test statistic	**85817.0**	
	Statistical test: p-value	**.015**	

Table continues next page

Results (text and language)	Median	5	5
	Mean	5.25	5.33
	Standard deviation	1.576	1.447
	N	462	406
	Mean rank	431.69	437.69
	Statistical test statistic	95082.0	
	Statistical test: p-value	.702	
Results (reference of data)	Median	3	3
	Mean	2.43	2.54
	Standard deviation	.875	.761
	N	462	406
	Mean rank	423.97	446.48
	Statistical test statistic	98651.5	
	Statistical test: p-value	.117	
Results (table)	Median	5	5.45
	Mean	5.35	5.45
	Standard deviation	1.293	1.298
	N	462	406
	Mean rank	426.81	443.25
	Statistical test statistic	97340.5	
	Statistical test: p-value	.278	
Results (figure)	Median	5	5
	Mean	5.01	5.32
	Standard deviation	1.451	1.426
	N	462	406
	Mean rank	412.86	459.12
	Statistical test statistic	**103783.0**	
	Statistical test: p-value	**.003**	

Table continues next page

Discussion (aim)	Median	3	3
	Mean	2.36	2.52
	Standard deviation	.940	.762
	N	462	406
	Mean rank	421.81	448.94
	Statistical test statistic	99650.0	
	Statistical test: p-value	.064	
Discussion (hypothesis)	Median	3	3
	Mean	2.41	2.46
	Standard deviation	.733	.714
	N	462	406
	Mean rank	427.57	442.39
	Statistical test statistic	96987.5	
	Statistical test: p-value	.328	
Discussion (previous research)	Median	5	5
	Mean	5.32	5.52
	Standard deviation	1.908	1.560
	N	462	406
	Mean rank	429.37	440.34
	Statistical test statistic	96157.0	
	Statistical test: p-value	.488	
Discussion (limitations)	Median	3	3
	Mean	3.46	3.36
	Standard deviation	1.467	1.261
	N	462	406
	Mean rank	443.00	424.82
	Statistical test statistic	89857.0	
	Statistical test: p-value	.258	

Table continues next page

Conclusion (summary)	Median	3	3
	Mean	3.81	3.77
	Standard deviation	1.251	1.187
	N	462	406
	Mean rank	438.90	429.49
	Statistical test statistic	91752.0	
	Statistical test: p-value	.545	
Conclusion (application of research)	Median	3	3
	Mean	3.46	3.24
	Standard deviation	1.552	1.491
	N	462	406
	Mean rank	452.35	414.19
	Statistical test statistic	**85541.5**	
	Statistical test: p-value	**.018**	
References (Harvard style)	Median	5	5
	Mean	5.19	5.23
	Standard deviation	1.390	1.394
	N	462	406
	Mean rank	431.87	437.50
	Statistical test statistic	95003.0	
	Statistical test: p-value	.715	
Language	Median	3	3
	Mean	3.64	3.33
	Standard deviation	1.134	1.037
	N	462	406
	Mean rank	464.02	400.91
	Statistical test statistic	**80147.5**	
	Statistical test: p-value	**<.001**	

Table continues next page

Layout	Median	3	3
	Mean	2.58	2.78
	Standard deviation	.669	.466
	N	462	406
	Mean rank	406.65	466.19
	Statistical test statistic	**106651.0**	
	Statistical test: p-value	**<.001**	

Table B.5 Descriptive statistics and Mann-Whitney U test statistic of student grades for the final exam in 2018 and 2019.

Bold values indicate significant differences between values.

	Year	
	2018	2019
Median	63.8	62
Mean	63.16	62.37
Standard deviation	16.42	15.46
N	810	684
Mean rank	758.61	734.35
Statistical test statistic	268022	
Statistical test: p-value	.279	

Scientific Writing Assignment Analysis – E-learning through a pandemic

An exploration of the data from student assessment of performance on the SWA was undertaken to determine if it was homogeneous by creating a box plot using SPSS and investigating for values greater than 1.5 box-lengths from the edge of the box. Each outlier was individually inspected in further detail to understand any reasons for divergence from the data set. Each outlier was removed as they all were examples of incomplete submissions, thus did not represent the overall product for comparison to the rest of the cohort. A Shapiro-Wilk's test indicated that the samples were not normally distributed, thus an independent samples nonparametric Mann-Whitney U test was used to determine any differences between the mean grade of each group.

Table B.6 Descriptive statistics and Mann-Whitney U test statistic of student grades for the scientific writing assignment across three years.

Bold values indicate significant differences between values.

		Year		
		2018	2019	2020
Complete student cohort	Median	80	79	77
	Mean	77.83	78.03	75.37
	Standard deviation	12.56	11.72	12.52
	Statistical test: p-value	**<.001**		
2020 student cohort that used the e-learning module	Median	80	79	80
	Mean	77.83	78.03	78.80
	Standard deviation	12.56	11.72	11.99
	Statistical test: p-value	.526		

Table B.7 Descriptive statistics and Mann-Whitney U test statistic of student grades for the scientific writing assignment in 2020 between groups that had/had not completed the e-learning module.

Bold values indicate significant differences between values.

	e-learning module completion	
	completed	Not completed
Median	80	73
Mean	78.80	72.97
Standard deviation	11.99	12.45
Statistical test: p-value	**<.001**	

Table B.8 Descriptive statistics and Mann-Whitney U test statistic of student grades for each assessment criteria of the scientific writing assignment in 2020.

Bold values indicate significant differences between values.

		Module completion	
		Without module	With module
Title	Median	3	3
	Mean	2.57	2.54
	Standard deviation	0.69	0.82
	N	304	205
	Mean rank	253.49	257.25
	Statistical test statistic	31620.5	
	Statistical test: p-value	.730	
Introduction (area of study)	Median	2	2
	Mean	2.15	2.33
	Standard deviation	0.80	0.77
	N	304	205
	Mean rank	241.88	274.45
	Statistical test statistic	**35147.5**	
	Statistical test: p-value	**.008**	
Introduction (link between aims and background information)	Median	3	3
	Mean	3.56	3.82
	Standard deviation	1.23	1.16
	N	304	205
	Mean rank	242.79	273.10
	Statistical test statistic	**34871.0**	
	Statistical test: p-value	**.013**	

Table continues next page

Introduction (aims)	Median	5	5
	Mean	4.75	4.93
	Standard deviation	1.08	0.60
	N	304	205
	Mean rank	251.44	260.28
	Statistical test statistic	**32241.5**	
	Statistical test: p-value	**.038**	
Introduction (hypothesis)	Median	5	5
	Mean	4.78	5.51
	Standard deviation	1.55	1.32
	N	304	205
	Mean rank	229.05	293.48
	Statistical test statistic	**39048.5**	
	Statistical test: p-value	**<.001**	
Methods (language)	Median	3	3
	Mean	2.94	3.50
	Standard deviation	1.53	1.43
	N	304	205
	Mean rank	235.43	284.01
	Statistical test statistic	**37108.0**	
	Statistical test: p-value	**<.001**	
Methods (content)	Median	3	3
	Mean	3.71	3.85
	Standard deviation	1.17	1.21
	N	304	205
	Mean rank	248.32	264.91
	Statistical test statistic	33191.0	
	Statistical test: p-value	.170	

Table continues next page

Results (text and language)	Median	3	3
	Mean	3.14	3.53
	Standard deviation	1.21	1.30
	N	304	205
	Mean rank	238.03	280.16
	Statistical test statistic	**36318.5**	
	Statistical test: p-value	**.001**	
Results (reference of data)	Median	5	5
	Mean	4.72	5.43
	Standard deviation	1.82	1.72
	N	304	205
	Mean rank	231.78	289.44
	Statistical test statistic	**38219.5**	
	Statistical test: p-value	**<.001**	
Results (table)	Median	3	3
	Mean	2.35	2.50
	Standard deviation	0.89	0.74
	N	304	205
	Mean rank	247.16	266.62
	Statistical test statistic	33542.5	
	Statistical test: p-value	.096	
Results (figure)	Median	5	5
	Mean	4.92	5.22
	Standard deviation	1.47	1.41
	N	304	205
	Mean rank	244.27	270.90
	Statistical test statistic	**34420.5**	
	Statistical test: p-value	**.027**	

Table continues next page

Discussion (aim)	Median	5	5
	Mean	5.19	5.41
	Standard deviation	1.23	1.20
	N	304	205
	Mean rank	245.86	268.55
	Statistical test statistic	**33937.5**	
	Statistical test: p-value	**.049**	
Discussion (hypothesis)	Median	2	2
	Mean	2.22	2.41
	Standard deviation	0.63	0.56
	N	304	205
	Mean rank	238.89	278.90
	Statistical test statistic	**36058.5**	
	Statistical test: p-value	**.001**	
Discussion (previous research)	Median	2	2
	Mean	1.99	2.22
	Standard deviation	0.85	0.78
	N	304	205
	Mean rank	240.06	277.15
	Statistical test statistic	**35701.5**	
	Statistical test: p-value	**.003**	
Discussion (limitations)	Median	3	3
	Mean	3.19	3.43
	Standard deviation	0.98	1.04
	N	304	205
	Mean rank	241.52	274.99
	Statistical test statistic	**32257.5**	
	Statistical test: p-value	**.003**	

Table continues next page

Conclusion (summary)	Median	5	5
	Mean	5.09	5.29
	Standard deviation	1.30	1.30
	N	304	205
	Mean rank	247.02	266.83
	Statistical test statistic	33585.0	
	Statistical test: p-value	.090	
Conclusion (application of research)	Median	2	3
	Mean	2.25	2.40
	Standard deviation	0.81	0.77
	N	304	205
	Mean rank	244.25	270.94
	Statistical test statistic	**34428.5**	
	Statistical test: p-value	**.028**	
References (Harvard style)	Median	3	3
	Mean	2.38	2.51
	Standard deviation	0.89	0.84
	N	304	205
	Mean rank	246.77	267.20
	Statistical test statistic	33660.5	
	Statistical test: p-value	.074	
Language	Median	5	5
	Mean	5.25	5.68
	Standard deviation	1.25	1.16
	N	304	205
	Mean rank	237.24	281.34
	Statistical test statistic	**36560.5**	
	Statistical test: p-value	**<.001**	

Table continues next page

Layout	Median	4	4
	Mean	3.31	3.47
	Standard deviation	1.01	0.94
	N	304	205
	Mean rank	246.96	266.92
	Statistical test statistic	33604.5	
	Statistical test: p-value	.058	

Table B.9 Descriptive statistics and Mann-Whitney U test statistic of student grades for the mid-semester exam in 2020.

Bold values indicate significant differences between values.

	Module completion	
	Without module	With module
Median	18	20
Mean	17.34	19.17
Standard deviation	4.34	4.04
N	301	202
Mean rank	226.67	289.75
Statistical test statistic	**38025.5**	
Statistical test: p-value	**<.001**	

Discussion Paper Assignment Analysis

An exploration of the data from student assessment of performance on the DP was undertaken to determine if it was homogeneous by creating a box plot using SPSS, there were no outliers in the data as assessed by investigating for values greater than 1.5 box-lengths from the edge of the box. Additionally, a Shapiro-Wilk's test determined normal distribution of the data ($p > .05$). Therefore, further analysis to compare means was performed using an independent samples t-test.

Table B.10 Descriptive statistics and independent samples t-test statistic of student grades for the discussion paper assignment between years.

Bold values indicate significant differences between values.

	Year	
	2018	2019
Median	67.5	66.5
Mean	65.65	66.25
Standard deviation	16.57	18.79
Statistical test statistic	.111	
Statistical test: p-value	.741	

Table B.11 Descriptive statistics and independent samples t-test statistic of student grades for each assessment criteria of the discussion paper.

		Year	
		2018	2019
Title	Median	4	5
	Mean	4.25	4.63
	Standard deviation	.716	.806
	Statistical test statistic	.267	
	Statistical test: p-value	.608	
Introduction (opening statement)	Median	7	6
	Mean	6.85	7.25
	Standard deviation	2.889	2.817
	Statistical test statistic	.036	
	Statistical test: p-value	.851	
Introduction (questions/argument)	Median	8.5	6
	Mean	7.9	7.25
	Standard deviation	2.532	2.817
	Statistical test statistic	.473	
	Statistical test: p-value	.496	
Introduction (referencing)	Median	4	3
	Mean	4.15	3.63
	Standard deviation	.875	1.204
	Statistical test statistic	**4.713**	
	Statistical test: p-value	**.037**	
Body (logical progression)	Median	4	5
	Mean	3.65	3.94
	Standard deviation	1.461	1.436
	Statistical test statistic	<.001	
	Statistical test: p-value	.984	

Table continues next page

Body (content)	Median	4	4
	Mean	3.65	3.44
	Standard deviation	1.694	1.825
	Statistical test statistic	.336	
	Statistical test: p-value	.566	
Body (opinions)	Median	4	3
	Mean	3.6	3.5
	Standard deviation	1.392	1.549
	Statistical test statistic	.26	
	Statistical test: p-value	.874	
Body (argument)	Median	7	6
	Mean	5.95	6.75
	Standard deviation	3.316	3.337
	Statistical test statistic	.052	
	Statistical test: p-value	.821	
Body (references)	Median	7	6
	Mean	6.75	7
	Standard deviation	1.446	2.309
	Statistical test statistic	**7.321**	
	Statistical test: p-value	**.011**	
Conclusion (summary)	Median	4	2
	Mean	3.65	2.56
	Standard deviation	1.496	2.128
	Statistical test statistic	**8.325**	
	Statistical test: p-value	**.007**	

Table continues next page

Conclusion (further questions)	Median	1	1
	Mean	1.85	1.88
	Standard deviation	2.159	2.094
	Statistical test statistic	<.001	
	Statistical test: p-value	.985	
Appropriate argument	Median	7	6
	Mean	6.75	7.00
	Standard deviation	2.552	2.309
	Statistical test statistic	<.001	
	Statistical test: p-value	1.000	
Grammar and spelling	Median	3	3
	Mean	2.40	2.44
	Standard deviation	.995	1.365
	Statistical test statistic	**4.935**	
	Statistical test: p-value	**.033**	
Referencing sources	Median	2	3
	Mean	2.20	2.75
	Standard deviation	.696	.447
	Statistical test statistic	2.812	
	Statistical test: p-value	.103	
References in Harvard style	Median	2	2
	Mean	2.05	2.25
	Standard deviation	.510	.577
	Statistical test statistic	2.122	
	Statistical test: p-value	.154	

Impact of e-Learning Modules on Student Confidence

Statistical analysis of differences between S1 and S2 students in 2019 was conducted using a Chi-square analysis. As the data were not paired observations, they were analysed using a Chi-squared analysis however, the sample size adequacy assumption of the Chi-Square test of homogeneity was violated thus, a Fisher's Exact test was performed to determine whether students reported confidence in assessment tasks differently. Students were categorised as either first or second semester of their first year of an undergraduate degree program. Post hoc analysis involved pairwise comparisons using the z-test of two proportions with a Bonferroni correction. Statistical significance was accepted at $p < .016667$.

Table B.12 Descriptive statistics and Chi-square test statistics of the differences between proportion of students reported confidence in assessment tasks.

Each subscript letter denotes a subset of each item category whose column proportions do not differ significantly from each other at the .05 level.

Bold values indicate significant differences between values.

		Semester/Year		
		1	2	PG
Persuasive scientific writing	No response count	1a	1a	1a
	Strongly disagree count	2a	0a	0a
	Disagree count	9a	3a	4a
	Neutral count	42a	9a	7a
	Agree count	68a	25a	13a
	Strongly agree count	16a	7a	9a
	Total count	138	45	34
	No response %	0.7%	2.2%	2.9%
	Strongly disagree %	1.4%	0.0%	0.0%
	Disagree %	6.5%	6.7%	11.8%
	Neutral %	30.4%	20.0%	20.6%
	Agree %	49.3%	55.6%	38.2%
	Strongly agree %	11.6%	15.6%	26.5%
	Total %	100%	100%	100%
	Statistical test statistic	10.922		
	Statistical test: p-value	.294		
Scientific writing assignment	No response count	1a	0a	1a
	Strongly disagree count	2a	0a	0a
	Disagree count	5a	4a	1a
	Neutral count	29a	6a	4a
	Agree count	73a	24a	13a
	Strongly agree count	28a	11a,b	15b
	Total count	138	45	34
	No response %	0.7%	0.0%	2.9%
	Strongly disagree %	1.4%	0.0%	0.0%
	Disagree %	3.6%	8.9%	2.9%
	Neutral %	21.0%	13.3%	11.8%
	Agree %	52.9%	53.3%	38.2%
	Strongly agree %	20.3%	24.4%	44.1%
	Total %	100%	100%	100%
	Statistical test statistic	13.300		
	Statistical test: p-value	.140		

Table continues next page

Scientific poster presentation	No response count	1a	0a	0a
	Strongly disagree count	1a	0a	1a
	Disagree count	4a	0a	0a
	Neutral count	24a	7a	3a
	Agree count	82a	23a	14a
	Strongly agree count	26a	15a,b	16b
	Total count	138	45	34
	No response %	0.7%	0.0%	0.0%
	Strongly disagree %	0.7%	0.0%	2.9%
	Disagree %	2.9%	0.0%	0.0%
	Neutral %	17.4%	15.6%	8.8%
	Agree %	59.4%	51.1%	41.2%
	Strongly agree %	18.8%	33.3%	47.1%
	Total %	100%	100%	100%
	Statistical test statistic	15.942		
	Statistical test: p-value	.053		
Peer reviewed scientific journal article	No response count	2a	0a	0a
	Strongly disagree count	9a	2a	1a
	Disagree count	24a	7a	2a
	Neutral count	49a	16a	5a
	Agree count	42a	17a	13a
	Strongly agree count	12a	3a	13b
	Total count	138	45	34
	No response %	1.4%	0.0%	0.0%
	Strongly disagree %	6.5%	4.4%	2.9%
	Disagree %	17.4%	15.6%	5.9%
	Neutral %	35.5%	35.6%	14.7%
	Agree %	30.4%	37.8%	38.2%
	Strongly agree %	8.7%	6.7%	38.2%
	Total %	100%	100%	100%
	Statistical test statistic	**23.379**		
	Statistical test: p-value	**.005**		

Table continues next page

Impact statement	No response count	4a	1a	0a
	Strongly disagree count	17a	0b	1a,b
	Disagree count	36a	5b	4a,b
	Neutral count	55a	13a	12a
	Agree count	19a	23b	13b
	Strongly agree count	7a	3a	4a
	Total count	138	45	34
	No response %	2.9%	2.2%	0.0%
	Strongly disagree %	12.3%	0.0%	2.9%
	Disagree %	26.1%	11.1%	11.8%
	Neutral %	39.9%	28.9%	35.3%
	Agree %	13.8%	51.1%	38.2%
	Strongly agree %	5.1%	6.7%	11.8%
	Total %	100%	100%	100%
	Statistical test statistic	**36.565**		
	Statistical test: p-value	**<.001**		
Grant application	No response count	1a	1a	0a
	Strongly disagree count	33a	11a	3a
	Disagree count	35a	15a	9a
	Neutral count	30a	11a	6a
	Agree count	27a	6a	9a
	Strongly agree count	12a	1a	7a
	Total count	138	45	34
	No response %	0.7%	2.2%	0.0%
	Strongly disagree %	23.9%	24.4%	8.8%
	Disagree %	25.4%	33.3%	26.5%
	Neutral %	21.7%	24.4%	17.6%
	Agree %	19.6%	13.3%	26.5%
	Strongly agree %	8.7%	2.2%	20.6%
	Total %	100%	100%	100%
	Statistical test statistic	14.239		
	Statistical test: p-value	.126		

Table continues next page

Literature review	No response count	2a	1a	0a
	Strongly disagree count	9a	3a	0a
	Disagree count	22a	7a	2a
	Neutral count	39a	8a,b	4b
	Agree count	47a	20a	12a
	Strongly agree count	19a	6a	16b
	Total count	138	45	34
	No response %	1.4%	2.2%	0.0%
	Strongly disagree %	6.5%	6.7%	0.0%
	Disagree %	15.9%	15.6%	5.9%
	Neutral %	28.3%	17.8%	11.8%
	Agree %	34.1%	44.4%	35.3%
	Strongly agree %	13.8%	13.3%	47.1%
	Total %	100%	100%	100%
	Statistical test statistic	**22.712**		
	Statistical test: p-value	**.006**		
Newspaper article for the general public	No response count	2a	0a	0a
	Strongly disagree count	8a	1a	1a
	Disagree count	23a	8a	5a
	Neutral count	47a	10a	11a
	Agree count	43a	22b	13a,b
	Strongly agree count	15a	4a	4a
	Total count	138	45	34
	No response %	1.4%	0.0%	0.0%
	Strongly disagree %	5.8%	2.2%	2.9%
	Disagree %	16.7%	17.8%	14.7%
	Neutral %	34.1%	22.2%	32.4%
	Agree %	31.2%	48.9%	38.2%
	Strongly agree %	10.9%	8.9%	11.8%
	Total %	100%	100%	100%
	Statistical test statistic	6.224		
	Statistical test: p-value	.789		

Table continues next page

Science blog for the general public	No response count	2a	0a	0a
	Strongly disagree count	7a	1a	0a
	Disagree count	26a	8a	4a
	Neutral count	48a	14a	10a
	Agree count	42a	19a	16a
	Strongly agree count	13a	3a	4a
	Total count	138	45	34
	No response %	1.4%	0.0%	0.0%
	Strongly disagree %	5.1%	2.2%	0.0%
	Disagree %	18.8%	17.8%	11.8%
	Neutral %	34.8%	31.1%	29.4%
	Agree %	30.4%	42.2%	47.1%
	Strongly agree %	9.4%	6.7%	11.8%
	Total %	100%	100%	100%
	Statistical test statistic	6.507		
	Statistical test: p-value	.758		
Public health announcement	No response count	1a	0a	0a
	Strongly disagree count	23a	7a	2a
	Disagree count	42a	20a	15a
	Neutral count	40a	13a	9a
	Agree count	24a	3a	5a
	Strongly agree count	8a	2a	3a
	Total count	138	45	34
	No response %	0.7%	0.0%	0.0%
	Strongly disagree %	16.7%	15.6%	5.9%
	Disagree %	30.4%	44.4%	44.1%
	Neutral %	29.0%	28.9%	26.5%
	Agree %	17.4%	6.7%	14.7%
	Strongly agree %	5.8%	4.4%	8.8%
	Total %	100%	100%	100%
	Statistical test statistic	9.561		
	Statistical test: p-value	.479		

Table continues next page

Laboratory report	No response count	1a	0a	0a
	Strongly disagree count	2a	1a	1a
	Disagree count	13a	5a	3a
	Neutral count	29a	10a	5a
	Agree count	67a	17a,b	10b
	Strongly agree count	26a	12a,b	15b
	Total count	138	45	34
	No response %	0.7%	0.0%	0.0%
	Strongly disagree %	1.4%	2.2%	2.9%
	Disagree %	9.4%	11.1%	8.8%
	Neutral %	21.0%	22.2%	14.7%
	Agree %	48.6%	37.8%	29.4%
	Strongly agree %	18.8%	26.7%	44.1%
	Total %	100%	100%	100%
	Statistical test statistic	12.318		
	Statistical test: p-value	.215		
Professional email to an industry partner	No response count	0a	0a	0a
	Strongly disagree count	6a	1a	0a
	Disagree count	22a	10a	3a
	Neutral count	56a	13a,b	4b
	Agree count	38a	17a	12a
	Strongly agree count	16a	4a	15b
	Total count	138	45	34
	No response %	0.0%	0.0%	0.0%
	Strongly disagree %	4.3%	2.2%	0.0%
	Disagree %	15.9%	22.2%	8.8%
	Neutral %	40.6%	28.9%	11.8%
	Agree %	27.5%	37.8%	35.3%
	Strongly agree %	11.6%	8.9%	44.1%
	Total %	100%	100%	100%
	Statistical test statistic	**27.339**		
	Statistical test: p-value	**<.001**		

APPENDIX C : ASSIGNMENT RUBRICS ANALYSED IN THIS STUDY

BIOL1102 Scientific Writing Assignment Rubric page 1 of 2

MANDATORY Turnitin statement	Satisfactory statement of how Turnitin report was used to improve the assignment.		Turnitin statement missing.	
Title	Title descriptive	Title partially descriptive	Title not descriptive	Title missing
Introduction (Area of Study)	Clear and concise description of the area of study including two references with at least one being peer reviewed.	Satisfactory description of the area of study. Peer reviewed reference may be included.	Limited description of the area of study. References may be included.	No description of the area of study. No references included.
Introduction (Link between aims and background information)	Clear and concise description of link between background information and research aims.	Satisfactory description of link between the background information and research aims.	Limited description of link between the background information and research aims.	No link between background information and research aims.
Introduction (Aims)	Aims of research clearly outlined. Brief explanation of how aims were achieved.	Most aims of research outlined. Explanation of how aims were achieved included.	Limited outline of aims of research. Explanation of how aims were achieved could be further developed or missing.	Aims not included. No explanation of how aims were achieved.
Introduction (Hypothesis)	Hypothesis clearly stated and relevant to aims of research.	Hypothesis relevant to aims of research but could be further developed.	Hypothesis statement unclear.	Hypothesis not stated.
Methods (Language)	Concisely written in continuous text.	Written in continuous text.	Numbered or written in dot points OR reads like a series of dot points combined into a paragraph format.	Methods not included.
Methods (Content)	Brief outline of all methods used with reference to topic manual. Any changes to methods indicated. Clear description of control and experimental treatments used.	Brief outline of most methods used. Most changes to methods indicated. Description of control and experimental treatments used. Reference may be included	Outline of some methods used. Some changes to methods may be indicated. May include description of control and experimental treatments used.Reference may be included.	Methods not included. No reference included.
Results (Text and Language)	Clear and concise statement of results written in past tense for all data. Clear and concise description of trends of relevant data. Clear comparison of experimental treatments to controls. Only summary data included.	Satisfactory statement of results written in past tense. Some description of trends of relevant data. Comparison of experimental treatments to controls.Only summary data included.	Limited statement of results. May be written in past tense. Includes description of data included in figures and tables with no description of trends of relevant data. Comparison of experimental treatments to controls may be included. Raw data may be included.	No statement of results included.
Results (Reference of data)	All figures/tables referenced where appropriate.	Most figures/tables referenced where appropriate.	Some figures/tables may be referenced.	Figures and tables not referenced
Results (Table)	Has a descriptive title in appropriate position. Table is numbered. Table has appropriate column/row headings. Units are correctly indicated. Only summary data included.	Has a title. May or may not be in correct position. Minor errors made in layout of table. Only summary data included.	May have a title in correct position. Major errors made in layout of table. Raw data may be included.	No table included.

BIOL1102 Scientific Writing Assignment Rubric page 2 of 2

Results (Figure)	Has a descriptive title in appropriate position. Figure is numbered. Axes are correctly labelled. Units are correctly indicated. Legend is complete. Only summary data included.	Has a title. May or may not be in correct position. Minor errors made in layout of figure. Only summary data included.	May have a title in correct position. Major errors made in layout of figure. Raw data may be included.	No figure included.
Discussion (Aims)	Clear and concise statement of aims included.	Satisfactory statement of aims included.	Limited statement of aims included.	Aims not stated.
Discussion (Hypothesis)	Hypothesis restated. Clear and concise statement included regarding whether experimental results support or reject hypothesis.	Hypothesis restated. Satisfactory statement included regarding whether experimental results support or reject hypothesis.	Hypothesis may be restated. Limited statement regarding whether experimental results support or reject hypothesis.	Hypothesis not restated. No statement regarding whether hypothesis was supported or rejected.
Discussion (Previous Research)	Clear and concise explanation of whether results were expected based on previous research. At least one peer reviewed reference is cited.	Satisfactory explanation of whether results were expected based on previous research. At least one reference is cited.	Limited explanation of whether results were expected based on previous research. References may be included.	No explanation of whether results were expected.
Discussion (Limitations)	Limitations of study concisely discussed.	Satisfactory discussion of limitations of study.	Discussion of limitations of study needs further development	No discussion of limitations of study.
Conclusion (Summary)	Concise summary of key results included.	Satisfactory summary of results included.	Limited summary of results included.	No summary of results.
Conclusion (Application of Research)	Brief statement of how the research could be used outside of the teaching laboratory including reference.	Satisfactory statement of how the research could be used outside of the teaching laboratory. Reference may be included.	Limited statement of how the research could be used outside of the teaching laboratory. Reference may be included.	No statement of how the research could be used outside of the teaching laboratory.
References (Harvard Style)	At least four references cited correctly. At least two references are peer reviewed. All listed references cited in text. All references correctly referenced.	At least four references cited. At least three references included in reference list cited in text. Minor errors made in in text citations and/or reference list.	At least two references cited. Cited references may be included in reference list. Major errors made in in-text citations and/or reference list.	One or no reference cited. Reference list may be missing.
Language	Formal scientific language is correctly used. Correct scientific terminology is used. Paragraphs flow easily from one sentence to another. Grammar, punctuation and spelling is correct. Assignment is written in student's own words.	Formal scientific language is mostly used. Correct scientific terminology is mostly used. Grammar, punctuation and spelling may be correct. Assignment is written in student's own words.	Formal scientific language is sometimes used. Correct scientific terminology is sometimes used. Errors in grammar, punctuation and/or spelling. Assignment is written in student's own words.	Formal scientific language is not used or is used inappropriately. Paragraphs consist of discrete sentences. Errors in grammar, punctuation and/or spelling. Assignment is not written in student's own words.
Layout	Logical format. Headings used. Adhered to word limit. 1.5 line spacing and size 12 font used.	Adhered to word limit. Minor errors in layout.	Adhered to word limit. Major errors in layout.	Not adhered to word limit. May include major errors in layout.

BIOL1112 Biology & Society
Discussion Paper Rubric

Feedback Statement	Adequate response to feedback included. Student has incorporated feedback to improve writing. Response to Turnitin report included. ***5points***	Limited response to feedback included. Student has not incorporated feedback to improve writing. Response to Turnitin report included. ***3points***	Limited response to feedback included. Student has not incorporated feedback to improve writing. No response to Turnitin report included. ***1points***	No response to feedback included. No Turnitin report included. ***0points***
Title	Title is informative and attention grabbing ***5points***	Title partially informative ***4points***	Title not very informative ***2points***	Title missing ***0points***
Introduction (Opening Statement)	Opening statement creative and attention grabbing ***10points***	Opening statement attention grabbing but not well constructed ***7points***	Opening statement included but not well constructed ***3points***	No opening statement ***0points***
Introduction (Question/Argument)	Question/Argument developed around lecture themes. Adequate background information included. ***10points***	Question/Argument could be further developed. Background information included is mostly relevant. ***7points***	Question/Argument is unclear. Limited background information included. ***3points***	No Question/Argument ***0points***
Introduction (Referencing)	Adequate referencing including material related to lectures ***5points***	Adequate referencing but not including material related to lectures ***4points***	Referencing needs further development ***2points***	Not referenced appropriately ***0points***
Body (Logical Progression)	Generally one main point per paragraph. Logical progression of points with linking sentences/questions. ***5points***	Generally one main point per paragraph. Logical progression of points but missing linking sentences/questions. ***4points***	Multiple points per paragraph. Mostly logical progression of points with or without linking sentences/questions. ***2points***	Paragraphs not clearly defined. Logical progression of points lacking. ***0points***
Body (Content)	Demonstrated understanding of lectures and other resources. Developed and extended upon ideas from lectures. ***5points***	Demonstrated understanding of lectures. Developed upon ideas from lectures. ***4points***	Demonstrated understanding of lectures. No further extension upon ideas from lectures. ***2points***	Understanding of lecture content is not clear. Lecture material is not further developed ***0points***
Body (Opinions)	Student opinions are clearly presented throughout the body. ***5points***	Student opinions are presented throughout the body. ***4points***	Student opinions are presented but are unclear or limited throughout the body. ***2points***	Student opinions are not included. ***0points***
Body (Argument)	Convincingly argued with a good use of evidence and logic. ***10points***	Argued with a good use of evidence and logic. May include very minor errors in logic. ***7points***	Argued with use of some evidence and logic. Main points may be lacking support. ***3points***	Lacking an argument using evidence and logic. ***0points***

Body (References)	Evidence is critically evaluated and accurately presented. References are used to substantiate statements. *10points*	Evidence is evaluated and presented. Some references used to substantiate statements. *7points*	Little use of references to substantiate statements. *3points*	No use of references to substantiate statements. *0points*
Conclusion (Summary)	Main points of evidence concisely summarised. No new evidence is introduced. *5points*	Main points of evidence summarized. *4points*	Main points of evidence partially summarized. *2points*	Main points of evidence not summarized. *0points*
Conclusion (Further Questions)	Creative and appropriate further questions included. *5points*	Appropriate further questions included *4points*	Further questions included but could be further developed. *2points*	No further questions included. *0points*
Appropriate Argument	Appropriate use of arguments based on literature. The information provided is clear and concise and discussed scientifically. *10points*	Some use of argument based on literature. The information provided is somewhat clear and uses some scientific basis. *7points*	Little use of argument based on literature. The information provided is unclear and uses little scientific basis. *3points*	No use of argument based on literature. The information provided is unclear and uses no scientific basis. *0points*
Grammar and Spelling	Grammar and written expression to a high level. Spelling and editing to a high level. Adhered to word limit. *4points*	Grammar and written expression to adequate level. Spelling and editing adequate. Adhered to word limit. *3points*	Grammar and written expression to a basic level. Spelling and editing to a basic level. *2points*	Grammar and written expression poor. Multiple spelling and editing mistakes. May not adhere to word limit. *0points*
Referencing Sources	At least one lecture and two additional peer reviewed sources. May include few reliable web site sources but not relied upon heavily. *3points*	At least one lecture and one additional peer reviewed source. May include reliable web site sources. *2points*	Only lecture or website sources used. Peer reviewed sources not included. *1points*	No references used or only unreliable sources included. *0points*
References in Harvard Style	In text citations included and formatted correctly. Reference list included and formatted correctly. *3points*	In text citations included. Reference list included. Minor mistakes in one or both. *2points*	In text citations included. Reference list included. Major mistakes in one or both. *1points*	In text citations not included. Reference list not included. *0points*

BIOL1101 IMPACT STATEMENT RUBRIC.

Please note that this rubric is designed in conjunction with the assignment instructions on FLO and should be read together before completing the assignment.

Turnitin Statement	Satisfactory statement of how Turnitin reports was used to improve the assignment.	Limited statement of how Turnitin was used to improve the assignment.		Turnitin statement missing.
Title	Title descriptive	Title partially descriptive	Title not descriptive	Title missing
Description of the Issue	Clear and concise description of the issue or problem being addressed.	Satisfactory description of the issue or problem being addressed.	Limited description of the issue or problem being addressed.	No description of the issue or problem being addressed.
Description of the Issue (Background)	Clear and concise description of the area of study including two references with at least one being peer reviewed.	Satisfactory description of the area of study. Peer reviewed reference may be included.	Limited description of the area of study. References may be included.	No description of the area of study. No references included.
Statement of Action	Clear and concise description of the research project.	Satisfactory description of the research project.	Limited description of the research project	No description of the research project.
Impact	Clear and concise description of who benefits from the research and how. At least 3 benefits have been described.	Satisfactory description of who benefits from the research and how. At least 2 benefits have been described.	Limited description of who benefits from the research and how. At least 1 benefit has been described.	Benefits of the research are not described.
People Involved	Collaborators all listed and clear and concise explanation of contribution included.	Collaborators all listed and satisfactory explanation of contribution included.	Collaborators listed and limited explanation of contribution included.	Explanation of collaborators contribution not included.
Author's Involvement	Clear and concise description of author's background and contribution.	Satisfactory description of author's background and contribution.	Limited description of author's background and contribution	Description of author's background and contribution not included.
References (Harvard Style)	At least four references cited correctly. At least two references are peer reviewed. All listed references cited in text. All references correctly referenced.	At least four references cited. At least three references included in reference list cited in text. Minor errors made in in-text citations and/or reference list.	At least two references cited. Cited references may be included in reference list. Major errors made in in-text citations and/or reference list.	One or no reference cited. Reference list may be missing.
Language	Appropriate scientific language is correctly used. Correct scientific terminology is used. Accurate spelling and grammar. Paragraphs flow easily from one sentence to another. Assignment is written in student's own words.	Appropriate scientific language is mostly used. Correct scientific terminology is mostly used. May include minor errors in spelling and/or grammar. Assignment is written in student's own words.	Appropriate scientific language is sometimes used. Correct scientific terminology is sometimes used. May include minor errors in spelling and/or grammar. Assignment is written in student's own words.	Appropriate scientific language is not used or is used inappropriately. May include major errors in spelling and/or grammar. Assignment is not written in student's own words.
Layout	Logical Format. Appropriate structure. Adhered to word limit. 1.5 line spacing and size 12 font used.	Adhered to word limit. Minor errors in layout.	Adhered to word limit. Major errors in layout.	Not adhered to word limit. May include major errors in layout.

APPENDIX D : UNDERGRADUATE STUDENT SURVEY

Explanatory Statement

Chief Investigator:
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Flinders University
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Prof Martin Westwell
College of Science and Engineering
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You are invited to take part in this study. Please read this Explanatory Statement in full before deciding whether or not to participate in this research.

What does this research involve?
This study will investigate educational strategies used to teach science communication to undergraduate students and assess student self-efficacy of writing skills.

Why were you chosen for this research?
You have been identified to participate in this research because you have been enrolled in first year Biology topics at Flinders University.

What will you be asked to do?
You are invited to respond to a survey about your experience of being taught how to communicate scientifically and how well you think you can perform this task in a variety of written genres. Participation is entirely voluntary. The survey will take about 5 minutes. Participants will be asked if they consent to the researchers including their scientific writing assignment submission in the analysis. Any analysis of assignments will be done once topic grades are finalised, there will be no impact on student grades.

What benefit will you gain from being involved in this study?
The sharing of your experiences will enable the researcher to determine how students learn to write scientifically. This will help to guide the development of teaching resources for science communication for students.

Will you be identifiable by being involved in this study?
Any identifying information will be removed, and your comments will not be linked directly to you. All information and results obtained in this study will be stored in a secure way, with access restricted to relevant researchers.

Are there any risks or discomforts if you are involved?
The researcher anticipates no risks from your involvement in this study. If you have any concerns regarding anticipated or actual risks or discomforts, please raise them with the researcher.

How do you agree to participate?

Participation is voluntary. You may skip any questions, and you are free to withdraw from the survey at any time without effect or consequences.

How will you receive feedback?
Outcomes of the project will be summarised given to participants on request.

Thank you for taking the time to read this information sheet, and we hope that you will accept our invitation to be involved.

This research project has been approved by the Flinders University Social and Behavioural Research Ethics Committee (Project number: 2.19).

For more information regarding ethical approval of the project only, the Executive Officer of the Committee can be contacted by telephone on (08) 8201 3116, by fax on (08) 8201 2035, or by email to human.researchethics@flinders.edu.au

* 1. By ticking this box you are giving consent to participate in this research.

☐ I have read and understood the Explanatory Statement and I hereby consent to participate in this project.

2. This research aims to find out how students learn to write scientifically. We would like to analyse examples of student writing. If you consent to past assignments being included in this research please provide your student ID. All student work will be de-identified prior to analysis.

3. What degree program are you enrolled in?

4. What language do you write in most frequently?

- ○ Arabic
- ○ Cantonese
- ○ English
- ○ Greek
- ○ Hindi
- ○ Italian
- ○ Mandarin
- ○ Punjabi
- ○ Spanish
- ○ Tagalog
- ○ Vietnamese

Other (please specify)

5. Please indicate your level of agreement with the following statement.
I feel confident in my ability to use English written language in day to day activities.

Strongly disagree	Disagree	Neutral	Agree	Strongly agree
○	○	○	○	○

6. Which of the following topics have you been enrolled in at Flinders University? Select all that apply.

- ☐ SPOC1701 - The Nature of Science
- ☐ BIOL1112 - Biology & Society
- ☐ BIOL1102 - Molecular Basis of Life
- ☐ BIOL1101 - Evolution of Biological Diversity
- ☐ None of these topics

7. What is your experience of learning to write to persuade your audience in scientific writing? Select all that apply.

- ☐ I don't recall ever learning how to write to persuade an audience with scientific writing
- ☐ Some experience at high school learning to persuade an audience with scientific writing
- ☐ Some experience at university learning to persuade an audience with scientific writing
- ☐ Some experience outside of formal education learning to persuade an audience with scientific writing

8. Please indicate which of the following scientific writing assessments you have undertaken during your undergraduate studies. Select all that apply.

- [ ] Scientific Writing Assignment
- [ ] Impact Statement
- [ ] Scientific Poster
- [ ] Literature Review
- [ ] Laboratory Notebook
- [ ] Newspaper Article
- [ ] Laboratory Report
- [ ] Science Blog
- [ ] Scientific Journal Article/Manuscript
- [ ] Public Health Announcement
- [ ] Persuasive Exposition
- [ ] Professional Email to an Industry Partner
- [ ] Argumentative Essay
- [ ] Grant Application
- [ ] Other, please describe

9. During your undergraduate degree program, which of the following resources have you found the most useful in learning to write scientifically? Select all that apply.

- [ ] Written instructions from teaching staff
- [ ] Group Q & A sessions with teaching staff
- [ ] Rubric
- [ ] Assignment examples
- [ ] Face to face consulting with teaching staff
- [ ] Online tutorial provided via FLO
- [ ] Student Learning Centre resources
- [ ] Online resources from other sources (e.g. Khan Academy etc)
- [ ] Other (please specify)

Please indicate your level of agreement with the following statements:

10. I feel confident in my ability to write an assignment in the format of **persuasive scientific writing** in my specific field.

Strongly disagree	Disagree	Neutral	Agree	Strongly agree
○	○	○	○	○

11. I feel confident in my ability to write an assignment in the format of a **scientific writing assignment** in my specific field.

Strongly disagree	Disagree	Neutral	Agree	Strongly agree
○	○	○	○	○

12. I feel confident in my ability to write an assignment in the format of a **scientific poster presentation** in my specific field.

Strongly disagree	Disagree	Neutral	Agree	Strongly agree
○	○	○	○	○

13. I feel confident in my ability to write an assignment in the format of a **peer reviewed scientific journal article** in my specific field.

Strongly disagree	Disagree	Neutral	Agree	Strongly agree
◯	◯	◯	◯	◯

14. I feel confident in my ability to write an assignment in the format of an **impact statement** in my specific field.

Strongly disagree	Disagree	Neutral	Agree	Strongly agree
◯	◯	◯	◯	◯

15. I feel confident in my ability to write an assignment in the format of a **grant application** in my specific field.

Strongly disagree	Disagree	Neutral	Agree	Strongly agree
◯	◯	◯	◯	◯

16. I feel confident in my ability to write an assignment in the format of a **literature review** in my specific field.

Strongly disagree	Disagree	Neutral	Agree	Strongly agree
◯	◯	◯	◯	◯

17. I feel confident in my ability to write an assignment in the format of a **newspaper article for the general public** in my specific field.

Strongly disagree	Disagree	Neutral	Agree	Strongly agree
◯	◯	◯	◯	◯

18. I feel confident in my ability to write an assignment in the format of a **science blog for the general public** in my specific field.

Strongly disagree	Disagree	Neutral	Agree	Strongly agree
◯	◯	◯	◯	◯

19. I feel confident in my ability to write an assignment in the format of a **public health announcement** in my specific field.

Strongly disagree	Disagree	Neutral	Agree	Strongly agree
◯	◯	◯	◯	◯

20. I feel confident in my ability to write an assignment in the format of a **laboratory report** in my specific field.

Strongly disagree	Disagree	Neutral	Agree	Strongly agree
◯	◯	◯	◯	◯

21. I feel confident in my ability to write an assignment in the format of a **professional email to an industry partner** in my specific field.

Strongly disagree	Disagree	Neutral	Agree	Strongly agree
○	○	○	○	○

APPENDIX E : POSTGRADUATE STUDENT SURVEY

Explanatory Statement

Chief Investigator:
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Flinders University
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You are invited to take part in this study. Please read this Explanatory Statement in full before deciding whether or not to participate in this research.

What does this research involve?
This study will investigate educational strategies used to teach science communication to undergraduate and postgraduate students and assess student self-efficacy of writing skills.

Why were you chosen for this research?
You have been identified to participate in this research because you are enrolled in a higher degree research program.

What will you be asked to do?
You are invited to respond to a survey about your experience of being taught how to communicate scientifically and how well you think you can perform this task in a variety of written genres. Participation is entirely voluntary. The survey will take about 5 minutes.

What benefit will you gain from being involved in this study?
The sharing of your experiences will enable the researcher to determine how students learn to write scientifically. This will help to guide the development of teaching resources for science communication for students.

Will you be identifiable by being involved in this study?
The survey is anonymous. All information and results obtained in this study will be stored in a secure way, with access restricted to relevant researchers.

Are there any risks or discomforts if you are involved?
The researcher anticipates no risks from your involvement in this study. If you have any concerns regarding anticipated or actual risks or discomforts, please raise them with the researcher.

How do you agree to participate?
Participation is voluntary. You may skip any questions, and you are free to withdraw from the survey at any time without effect or consequences.

How will you receive feedback?
Outcomes of the project will be summarised given to participants on request.

Thank you for taking the time to read this information sheet, and we hope that you will accept our invitation to be involved.

This research project has been approved by the Flinders University Social and Behavioural Research Ethics Committee (Project number: 2.19).

For more information regarding ethical approval of the project only, the Executive Officer of the Committee can be contacted by telephone on (08) 8201 3116, by fax on (08) 8201 2035, or by email to human.researchethics@flinders.edu.au

* 1. By ticking this box you are giving consent to participate in this research.

☐ I have read and understood the Explanatory Statement and I hereby consent to participate in this project.

2. Which college do you belong to within Flinders University?

3. Where did you complete your most recent undergraduate qualification?

4. Which one of the following fields does your research project align most closely with?

- ☐ Medicine and/or Health
- ☐ Physics
- ☐ Biology
- ☐ Earth Sciences
- ☐ Chemistry
- ☐ Education
- ☐ Other (please specify)

5. What language do you write in most frequently?

- ◯ Arabic
- ◯ Mandarin
- ◯ Cantonese
- ◯ Punjabi
- ◯ English
- ◯ Spanish
- ◯ Greek
- ◯ Tagalog
- ◯ Hindi
- ◯ Vietnamese
- ◯ Italian

Other (please specify)

6. Please indicate your level of agreement with the following statement.
I feel confident in my ability to use English written language in day to day activities.

Strongly disagree	Disagree	Neutral	Agree	Strongly agree
◯	◯	◯	◯	◯

7. Throughout your **postgraduate** studies have your supervisors discussed writing with you?

◯ No ◯ Yes

If yes, briefly explain what was discussed.

8. During your **postgraduate** studies have you undertaken any training that focused on learning to write scientifically?

◯ No ◯ Yes

If yes, describe the training

9. Which of the following activities during your **postgraduate** studies do you feel has contributed significantly towards your preparation to write scientific publications? Select all that apply.

- ☐ Peer review
- ☐ Imitation of publications in the field
- ☐ Feedback from supervisors
- ☐ Co-authorship with supervisors
- ☐ Other (please specify)

10. During your **postgraduate** studies have you completed the Flinders University topic COMS9001: Communicating Research?

◯ Yes

◯ No

11. Please indicate which of the following scientific writing assessments you have undertaken during your **undergraduate** studies. Select all that apply.

- ☐ Scientific Writing Assignment
- ☐ Literature Review
- ☐ Scientific Poster
- ☐ Newspaper Article
- ☐ Laboratory Notebook
- ☐ Science Blog
- ☐ Laboratory Report
- ☐ Public Health Announcement
- ☐ Scientific Journal Article/Manuscript
- ☐ Professional Email to an Industry Partner
- ☐ Persuasive Exposition
- ☐ Grant Application
- ☐ Impact Statement
- ☐ Other, please describe

12. During your **undergraduate degree program,** which of the following resources did you find the most useful in learning to write scientifically? Select all that apply.

- ☐ Written instructions from teaching staff
- ☐ Group Q & A sessions with teaching staff
- ☐ Rubric
- ☐ Assignment examples
- ☐ Face to face consulting with teaching staff
- ☐ Online resources from other sources (e.g. Khan Academy etc)
- ☐ Student Learning Centre resources
- ☐ Other (please specify)

Please indicate your level of agreement with the following statements:

13. I feel confident in my ability to write in the format of a **scientific writing assignment** in my specific field.

Strongly disagree	Disagree	Neutral	Agree	Strongly agree
○	○	○	○	○

14. I feel confident in my ability to write in the format of a **persuasive scientific piece** in my specific field.

Strongly disagree	Disagree	Neutral	Agree	Strongly agree
○	○	○	○	○

15. I feel confident in my ability to write in the format of a **scientific poster presentation** in my specific field.

Strongly disagree	Disagree	Neutral	Agree	Strongly agree
○	○	○	○	○

16. I feel confident in my ability to write in the format of a **peer reviewed scientific journal article** in my specific field.

Strongly disagree	Disagree	Neutral	Agree	Strongly agree
○	○	○	○	○

17. I feel confident in my ability to write in the format of an **impact statement** in my specific field.

Strongly disagree	Disagree	Neutral	Agree	Strongly agree
○	○	○	○	○

18. I feel confident in my ability to write in the format of a **grant application** in my specific field.

Strongly disagree	Disagree	Neutral	Agree	Strongly agree
○	○	○	○	○

19. I feel confident in my ability to write in the format of a **literature review** in my specific field.

Strongly disagree	Disagree	Neutral	Agree	Strongly agree
○	○	○	○	○

20. I feel confident in my ability to write in the format of a **newspaper article for the general public** in my specific field.

Strongly disagree	Disagree	Neutral	Agree	Strongly agree
○	○	○	○	○

21. I feel confident in my ability to write in the format of a **science blog for the general public** in my specific field.

Strongly disagree	Disagree	Neutral	Agree	Strongly agree
○	○	○	○	○

22. I feel confident in my ability to write in the format of a **public health announcement** in my specific field.

Strongly disagree	Disagree	Neutral	Agree	Strongly agree
○	○	○	○	○

23. I feel confident in my ability to write in the format of a **laboratory report** in my specific field.

Strongly disagree	Disagree	Neutral	Agree	Strongly agree
○	○	○	○	○

24. I feel confident in my ability to write in the format of a **professional email to an industry partner** in my specific field.

Strongly disagree	Disagree	Neutral	Agree	Strongly agree
○	○	○	○	○

25. Please describe how your experience of learning to write scientifically could be improved.