Learning to write Writing to learn : Anchoring student writing cultures with disciplinary literacies

تعلم الكتابة والكتابة من أجل التعلم: ربط ثقافة الكتابة لدى الطالب بالمعرفة المتخصصة

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Abstract

Academic writing is challenging to learn and challenging to teach. With the proliferation of graduate attributes and employability metrics throughout higher education, how is academic writing to be defined, valued, assessed and disseminated? This article situates academic writing into disciplinary literacies, aligned via information literacy, to enable, support and enhance a student writing culture. Noting the failures and challenges of online learning faced during and post- COVID-19, there is an opportunity to revise and reimagine student writing for new times. This article explores how teaching practices can evolve to provide a more meaningful, predictable and assessable undergraduate pathway for learners. Our goal is to anchor student writing with disciplinary literacies. Only when carefully connected can interdisciplinarity become possible.

Keywords: Disciplinary literacy, information literacy, academic writing, multimodality, STEM education, student success

الملخص:

تطرح الكتابة الأكاديمية صعوبات كبيرة في عمليتي التعليم و التعلم. فكيف يمكن تعريف الكتابة الأكاديمية ، تقييمها و تقويمها ونشرها في ظل تزايد عدد المتخرجين وصرامة معايير التوظيف عبر مؤسسات التعليم العالي. يضع هذا المقال المعرفة المتخصصة جنبا إلى جنب مع المعرفة المعلوماتية لتشجيع ثقافة الكتابة لدى الطالب و تعزيزها. بناء على الإخفاقات و الصعوبات المسجلة في التعليم عن بعد خلال فترة كوفيد 19 و بعدها. فهناك فرصة لمراجعة كتابة الطلبة و إعادة تصورها خلال المرحلة الجديدة. يسلط هذا المقال الضوء على كيفية تطوير الممارسات التعليمية لمنح مسار أفضل للطالب. حيث تهدف إلى ربط كتابة الطالب مع المعرفة المتخصصة. ففي ظل ذلك الربط فقط يصبح تعدد التخصصات أمرا ممكنا.

الكلمات الدالة: المعرفة المتخصصة- المعرفة المعلوماتية- الكتابة الأكاديمية-

Biographies

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1. Introduction

Ironically – or perhaps not - writing about student writing often necessitates a trigger warning. Whenever academics gather and the conversation turns to student writing, the resultant conversation is punctuated by the wringing of hands, the shaking of heads, and frequently – unproductive – nostalgia about 'the good old days.' This rose-coloured lament details the falling standards of the contemporary university. Such commentaries are not simply chardonnay-fuelled disquiet and displeasure at our disappointing and frequently dark academic present (Fleming, 2021). They celebrate a utopic university of elitism and strong public funding for that elitism. These conversations – shadowboxing an imagined past while bemoaning a brutalizing present - block the development of enabling strategies to create transformational writing experiences for students. This is challenging work. It is tough to sit in the current context and construct effective solutions, rather than to be drawn to and sit in a rose-coloured history of 'traditional' universities, or the strategic plan-fixated future.

Certainly, student writing requires attention, and it is needed in all disciplines. It is timely – post the pandemic – to activate this topic. Our article also revisits a book from over a decade ago that diagnosed and predicted our current wrangle with standards, quality, scope and scale. Richard Arum and Josipa Roksa conducted a longitudinal study of the United States university system, tracking and testing a group of students over a four- year degree. Their results were predictable, although depressing: "given that students are spending very little time studying or attending classes, in both absolute and relative terms, we should not be surprised that on average they are not learning very much" (2011, 98).They confirmed that, when students completed standardized testing at the start and end of their degrees to measure their development, there was little change in the results. Learning did not take place. Are we – as educators – prepared for generation after generation (after generation) of students to 'pass' courses that are 'backwardly mapped' for their 'graduate attributes' and 'flexibility,' rather than evaluated for their difficulty, challenge and rigour? How can teachers in our universities provide alternative pathways for our students to learn more, learn with greater precision, and learn through (and for) transformation? COVID-19 has concentrated and intensified our awareness of these problems. How many online lectures – prepared with such care and such panic (Brabazon, Quinton, Hunter, 2020) – were unwatched? An under-

viewed, high-quality lecture, seminar or 'flipped' presentation is still unseen. Significantly, Neuwirth, Jović and Mukherji argued that students lacked the skills, abilities and literacies to manage and understand these new modes of learning (2021). They showed the value of "reimagining higher education" (2021, 141).With no 'normal' to return to, this is the moment to rethink and revise student writing within disciplinary literacies (Shanahan and Shanahan, 2008; Shanahan and Shanahan, 2012), rather than evaluate competence against vaguely configured 'graduate outcomes.'

Arum and Roksa used the evocative title of *Academically Adrift* for their research and scholarly monograph. The word 'adrift' is a gift. It offers the capacity to intervene, reorient, recalibrate and re-anchor direction and purpose. Arum and Roksa, confirmed the barriers to learning for students, including drinking and socializing and other "non-academic" activities. They also showed that,

> many students come to college not only poorly prepared by prior schooling for highly demanding academic tasks that ideally lie in front of them, but – more troubling still – they enter college with attitudes, norms, values, and behaviors that are often at odds with academic commitment. (2011, 3).

Their argument did not conclude by allotting blame to students or the schooling system that underprepared them. Instead, their critical eye and critique were placed on academic teachers, including our expectations, our (lack of) preparation, and our inability to lift students to the required scholarly standards. They confirmed that completing a PhD – while demonstrating subject-based knowledge – does not instruct a researcher how to teach (2011, 5). It is easy to blame schools (Cass, 2011), or students. It is tougher to ask overscheduled and overworked academics to interrogate -deeply – their andragogies, curricula design, preparation, and scaffolding to enable students to read and write with great effectiveness.

Academically Adrift was written in 2011. The precariat workforce (Standing, 2011; Vatansever, 2022), the Trump Presidency (Brabazon, Redhead, Chivaura, 2018; McRae, 2020),Brexit (Brändle, Galpin and Trenz, 2022) and COVID-19 (Oliveira, Grenha Teixeira, Torres and Morais, 2021) have all intensified public concerns about the ability of citizens to read, write, interpret and think beyond fear, shame, blame and paranoia. Our universities have never

been more important. Our universities – through a bleeding of public funding, credibility and disinterest in expertise – have never been less able to intervene, transform and challenge these problems of public policy and public good (Nichols, 2017). This article therefore stands – resolutely – in our complex, difficult present. We recognize the challenges confirmed by Arum and Roksa, and note how these tendencies were intensified through the pandemic. We offer positive interventions to improve student writing, focussing specifically on disciplinary literacies and disciplinary contexts, before exploring how to enable the trans-disciplinary and interdisciplinary movement of 'skills.' Our goal is to stop academic drift by anchoring studentwriting cultures with disciplinary literacies. Our foundational definition is that literacy is the capacity to encode and decode signs in a way that other members of the culture can understand, interpret and use. This definition will be deployed through the paper, demonstrating the importance of intwining information and disciplinary literacy to frame student writing.

Disciplinary texts and their audiences

Since first pondering how to assist students improve their writing, our research has uncovered a much deeper pattern and trajectory in the way that students learn to write disciplinary texts. An intervention requires building – through predictable and assessable curricula design - the relationship between writing, disciplinary literacy and information literacy. In an academic environment driven by knowledge, where expertise provides learners with enhanced opportunities, educators are well positioned to prepare students. However, current practices reveal learning cultures that provide a blinkered and narrowed version of the scientific landscape. Our article explores how these practices should evolve to provide a more meaningful undergraduate environment for learners. We share this knowledge so that the process of disciplinary literacy development is widely accessible.

Disciplinary literacy for science students offers an opportunity for reflection and communication with a diversity of audiences. The capacity to communicate with rigour, clarity and effectiveness is crucial, noting that the recent health emergencies and environmental transformations require the dissemination of high quality and accurate science in a way that is meaningful for citizens making decisions and choices. The gift that education researchers

can grant the science context is a productive, overt and explicit learning framework that recognizes the diverse audiences for information. Effective dissemination of knowledge requires a carefully configured relationship between content, interface and audience (Figure 1).   Being overt in the construction of this alignment allows focused attention on the most appropriate interface to bring together particular audiences and content. To engage varied audiences, researchers must first recognise that each audience member – each decoder - has his/her own literacies and ways to engage with content.
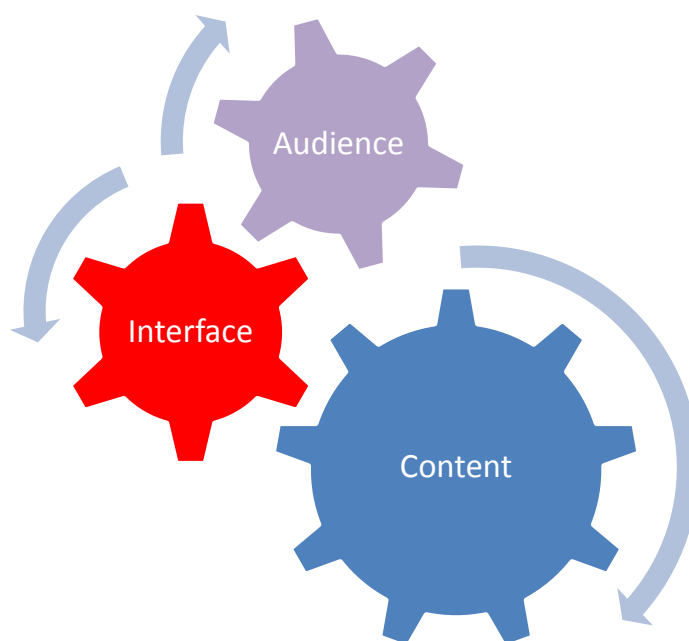
Figure 1 Dissemination Model 1: Content – Audience – Interface (Brabazon, 2021)

All literacy development is derived from the extension of prior literacies operating at the edges of our comfort zones. Yet without interventions by teachers or skilled professionals such as librarians, we all remain in environments where we feel safe, comforted and in control. This 'stability' however forms a natural barrier to learning, for we do not know what we do not know. Knowing what we know gives us confidence and identity-affirming feedback.   However whilst in this comfort zone of literacy, we are not challenged to transcend our current literacy states. Instead, our current capacity to encode and decode information in particular interfaces and with particular

vocabularies becomes our 'real' and our 'truth', which we then apply to new contexts, regardless of its efficacy. This conceptualization is also accurate for academics in any particular discipline. The parameters of a discipline become limitations that delineate 'the real' and 'the true' for engaging with – or disengaging with – different semiotic and knowledge systems and thereby challenging the boundaries of comfort and expertise.

The question is how any of us recognize that our current mode of literacy is not the world, but only a slice of competencies and content. This question is answered by Mary Macken-Horarik, who offered an explicit teaching and learning strategy to intervene in literacy states and create movement and momentum. Macken-Horarik (1998) configured a model of literacy that can move through educational processes, and life more generally. She constructed a four tier model of literacy, sweeping from the everyday to the applied, from the theoretical to the reflexive.(Figure 2)

Mary Macken-Horarik's model of literacy

Everyday	Applied	Theoretical	Reflexive
Diverse and open ended	Attaining a particular expertise	Gain disciplinary knowledge	Negotiation of social diversity
Confluent with spoken language	Use of spoken and written words to enable activity	Production and interpretation of epistemic texts	Probing assumed and specialized knowledge systems
Moving through roles and relationships in the family and community	Skill-based literacy	Situated in educational learning environments	Finding alternatives
Personal growth literacy		Specialized literacies	Challenging commonsense

		Assimilating and reproducing knowledge	Meaning determined through diverse media
			Critical literacy

Figure 2 - Table based on Mary Macken-Horarik (1998, 78)

Everyday literacies emerge in the family home, with attention to spoken language, personal growth, and primary socialization. Applied literacies confirm the attainment of a particular skill. This is literacy with a measurable outcome, such as writing a sentence or speaking words to enable an activity or behaviour. Theoretical literacy is – as we describe it in this article – disciplinary literacy. It confirms socialization of competency and success within a particular academic community. Epistemic texts are interpreted and produced – read and written – in formal learning environments such as schools and universities. Most formal learning takes place in this theoretical tier, ensuring the ongoing development of specialized literacies. The final slice of this model is reflexive literacy. Also termed critical literacy, negotiating social difference and diversity is located in this particular mode of expertise. The limits of a particular knowledge system and discipline are recognized. Commonsense is challenged. Multimodality – the ability to understand the best use of particular platforms and interfaces to perform particular tasks – becomes clear.

The goal of an undergraduate degree is to confirm the passage through theoretical – or disciplinary – literacy. Hopefully, there can also be momentum into reflexive or critical literacy. Indeed, through socio-political awareness and the ability to disseminate and apply disciplinary literacies through diverse interfaces and audiences, it is a highly desired graduate outcome for students. Therefore, by the conclusion of an undergraduate degree, (at least an) awareness of reflexive / critical literacy is required. This consciousness will enable the next stage of literacy development outside of a foundational degree.

There is another key intervention in Macken-Horarik's model. Without an intervention from more experienced learners, teachers and citizens, all of us remain in one slice of literacy. One definition of education is momentum through literacy. Macken-Horarik recommends educational strategies that facilitate "explicitness" (1998, 82).   Through this explicitness, students and citizens can move texts between contexts, and recognize how meanings change. Textual systems are transformed by contextual systems. Explicitness enables what Claire Wyatt-Smith, Joy Cumming, Jill Ryan and Shani Doig describe as the "enacted curriculum" (1999, 29-35). The important corrective offered by Macken-Horarik is that critical literacy is not an 'add on' to literacy discussions, but it necessitates a movement from other modes of literacy. Stages of literacy cannot be jumped. Simply because a student can use a search engine, an example of applied literacy, does not mean that they have the names and key terms derived from the most important researchers in a discipline (theoretical / disciplinary literacy) to insert into that blinking cursor. Macken-Horarik configures literacy as linear and progressive. We all require competence in easier and earlier modes of encoding and decoding before an educational intervention enables new insights, reflections, fears and confusions in a different slice of literacy. Clearly, most formal education environments – and most citizens – are locked into applied literacy. Therefore the capacity to shape the relationship between information and interface is lacking. Disciplinary expertise is not present. That is why foreign policy has been conducted by Tweet, or relationship problems are performed on Facebook. These are inappropriate configurations of information, audience and platform. Further, the discomfort and disrespect of expertise (theoretical / disciplinary literacy) on popular cultural platforms can be explained. Disciplinary literacy threatens personal opinions and feelings. This specialist knowledge questions and probes the comfort zones of citizens remaining in Everyday and Applied literacies.

What this model of literacy confirms is that specialised vocabulary and literacies are necessary in public debates, but that it is important to scaffold textual systems (information) into contextual systems (society). There must be a considered, careful building of the relationship between the content to be disseminated, the audience to engage with this information, and the interface that links the two. Multiple relationships are built through the translation and adaptation of this model. Only by reconfiguring the way educators approach

dissemination of content, while being more open to a wider range of interfaces, can we hope to build relationships more widely and connect across disciplines.
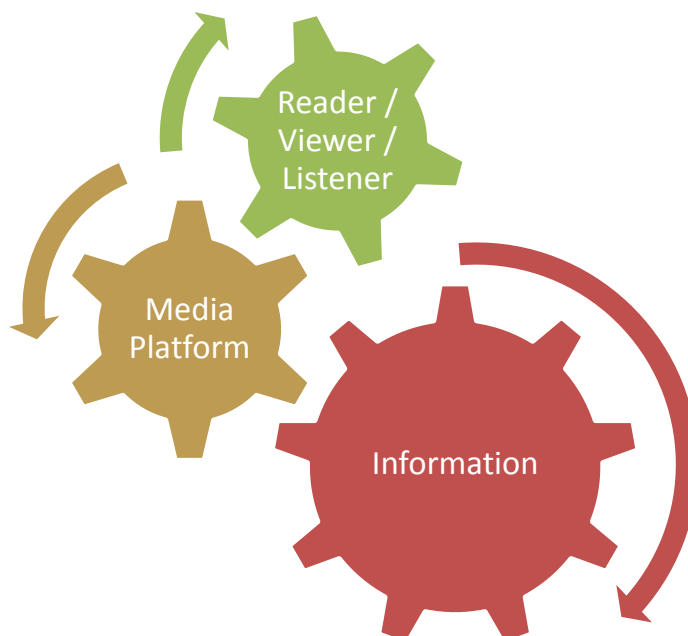
Figure 3 Dissemination Model2: Information - Media Platform - Readers / Viewers / Listeners

Content can be a vague description, varying from paid Instagram promotions to an archived document in a database. As content becomes more specialized, it is clear that more specialized literacies must be enacted, while also recognizing the linear progression required by the Macken-Horarik model. In summoning theoretical literacy, or disciplinary literacy, attention to the vocabulary and assumptions in the information must be rendered explicit. The interface can – similarly – be narrowed to a specific media platform, such as scholarly monographs or podcasts. When moving students and citizens to reflexive literacy, audiences are activated and tasked with specific actions, such as reading, viewing, or listening in ways that meet their literacy needs alongside the needs of others, and allow valuable engagement with specialist knowledge. The major intervention in reflexive literacy is the capacity to recognize cultural differences, respect those differences, and confirm a range of multimodal options and alternatives to enable meaning, while validating a diversity of possible interpretations. This is (post) disciplinary literacy. This is interdisciplinarity.
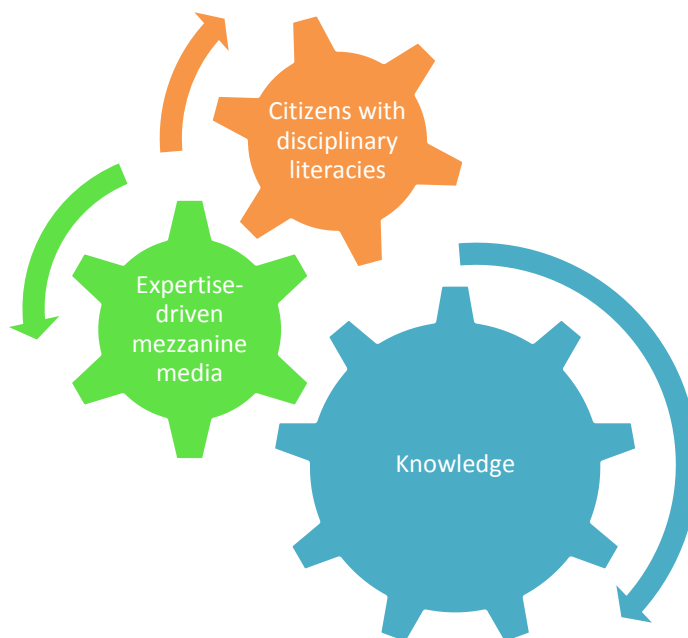
Figure 4 Dissemination Model 3: Knowledge - Expertise Scaffolded Mezzanine – Citizens with disciplinary literacies

The movement from content to information and on to knowledge necessitates distinctive choices with regard to where the textual material is to be located, stored or archived, and who is able to access it. Knowledge – frequently confirmed through peer review – appears in expertise-driven mezzanine media, such as a refereed journal, scholarly monograph or conference paper or post. The metaphor of a scholarly mezzanine has been deployed as the information is heighted with specialist vocabulary, and the audience must lift their disciplinary literacies to decode this textual system encoded by experts. It is also verified and confirmed via academic processes, such as peer review. The step up to – and through - a specific disciplinary space may be vast, requiring choices of vocabulary.   These choices may exclude those outside of the discipline. Therefore, one final stage of literacy is available to transcend and transform these limitations. It is reflexive literacy.

To build this content-interface-audience relationship in teaching and learning requires the crossing of the disciplinary boundaries. Educators want our learners to broaden their literacies and develop translatable skills. Similarly, educators must connect with other experts and expertise to improve teaching

practices. 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 high quality scholarship into accessible forms so that can be used to inform disciplinary practice. At the very least, students will gain an awareness of what they do not know.

Such research is important for all disciplines, but it has profound implications for how science education is enacted and how disciplinary literacy is developed within the sequence of undergraduate subjects in a science degree. By thinking critically about the way disciplinary literacy develops in the sciences, educators can move beyond the discipline and describe a way of understanding that transcends this single context. The only way to locate and understand a disciplinary frame, border or boundary is to transcend it. By examining writing through the lens of disciplinary literacy and applying a combination of approaches from educational and scientific disciplines, our research moves far beyond the flippant allocation or description of 'interdisciplinarity.' As our literacy models demonstrate, interdisciplinary is not a tick a box exercise. Instead, interdisciplinary is inserted in reflexive or critical literacy, the highest and most intricate mode of literacy. Most importantly however, disciplinary literacy must be mastered before the student, research or teacher can transcend it. The use of empirical data in combination with educational theory enables the ability to evaluate classroom practices and understand how they contribute to disciplinary literacy development. Disciplinary literacy can be developed by providing authentic experiences that push the boundaries of student learning, and create consciousness and reflection on the meaning of those boundaries. Disciplinary literacy is not the end of an intellectual journey. But it is a necessity to enable a respect for difference, diversity and multimodal futures.

Student learning is complex and intricate. It is simplified and reified when university educators summon homology and experience, restating how writing was taught to them in the past. A data point of one – personal experience – is not a valid foundation from which to create an interpretation. By performing the process of learning-led literacy, researchers can recognise the transcendent nature of literacy development, enabling this research – and education researchers - to cross the boundaries of their discipline. Students are changed

through this process. So are educators. By implementing a disciplinary literacy framework to examine the development of communication skills in undergraduate students improves the accessibility of science education to historically under-represented groups. Explicitness is key. By employing a transdisciplinary approach – noting that 'trans' requires a movement across disciplines – educators can track and evaluate the development of disciplinary literacy and reveal the stages – or slices – of literacy. While our model and research are focused on science, this research is not bounded by a single discipline. History, nursing, architecture and philosophy can be similarly taught and evaluated. Such research actions a broader question of how educators are preparing university graduates for the world that is and will be. Well-developed transferrable and engaging communication skills in future scientists are key to an informed and productive citizenry. As COVID-19 has demonstrated, meaningful and informed discussions are required between scientists, politicians, policy makers, a diversity of industry stakeholders, and citizens. Such conversations, as shown by our cascading dissemination models, require an awareness of information, interface, and audience.

Writing as a situated activity

In uncovering the importance of disciplinary literacies in an undergraduate science degree program, it is necessary to probe how disciplinary literacies are built. 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 apprenticeships with and 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 like scientists. 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 enfolded into and defined by the discipline. Hoping that writing will improve will not enable improvement. Modelling behavior assumes that the social background of the teacher and learner is shared. This notion blocks learning from disempowered groups and communities. Instead, explicitness (McLuhan, 1994, 57) in curricula design teaches the assumptions of a discipline. Until students can see and understand the frame around their

discipline, they cannot gain awareness of the specialist language, referencing, sentence construction and argument development.

Our research aligns two fields that in many ways are opposed in their approaches to research. Scientific research is necessarily refracted by scientific methods and bounded by the physical environment in which it is conducted. Conversely, educational researchers must recognize, respect and manage the enormous variations found in people. The interactions produced from this diversity are important and powerful, but can rarely be predicted or restricted. As shown in the first sections of this article, interdisciplinarity is located in the final slice of literacy – reflexive or critical literacy. Therefore, without interventions, it is easier for academics to remain in their disciplines, rather than be challenged by alternative epistemologies, ontologies and methodologies. Education research rarely reveals the certainty of empirically driven methodologies. This diversity of methodologies and results often limits the ability of educational researchers to develop robust theories that encompass the diversity of human experiences (Berliner, 2002). Therefore, researchers cannot expect that the empirical results from an educational study are able to be replicated. While repeatability is a trope of scientific research, it is much more difficult to configure in education research. For our research, both approaches are required. It is necessary to reflect – with transparency and accountability – how our values as educators transform the way we design and carry out educational research. One strategy to mitigate and manage these variables is to focus research on assessment practices, as they provide a point of comparison and a measurable impact of an intervention.

Much learning – most learning - occurs outside of assessment protocols. Therefore, it is important to recognise that restricting educational research to assessment excludes other equally valuable learning outcomes. Educational researchers must carefully consider how to measure learning, ensuring that it is not simply returning a confirmation bias, a measure of what we as teachers value, but is more inclusive of wider educational outcomes. There is no one-size-fits-all approach to teaching and learning. Each educational context will create new variations and possibilities. The conclusion of this article offers a set of guidelines to 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 lack of attention to the development of disciplinary literacy in the sciences has widespread consequences for both educators and learners. With an international shift towards valuing the needs of industry over the traditional purposes of education, scholars are witnessing 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, it is timely 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, disciplinary literacy is the pathway – the singular lens – to activate interdisciplinarity. Only when attaining mastery of disciplinary literacy can communication strategies and systems between disciplines become more effective. Thus, by understanding and reflecting on disciplinary literacy development, a learner can understand the needs of others and recognising links between other disciplines.

How do learners develop specialist knowledge?

Recognizing and naming a disciplinary text requires literacy. Reading a disciplinary text with understanding is a literacy. Writing a literacy text with expertise is a literacy. Too often these literacies are reified to 'skills' and conflated. Indeed skills – through considered curricula design – should emerge organically and predictably through disciplinary literacy development. Reading is crucial to the development of writing, but it is not a linear progression.   Assumptions about the relationship between 'reading and writing' undermine the differences between them. 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. Content area literacy focuses on being able to read disciplinary texts. However reading is complex and diverse, and activates an array of cognitive skills. Reading an Instagram post, saturated

with visual literacy, is distinct from reading a scholarly monograph. Reading a peer reviewed article in Biology or an Elizabethan play requires highly differentiated cognitive approaches. Of greater interest is how reading – as an intellectual practice – shifts to interpret each text. Instead of researching this more complex task, much current teaching practices that have carried through into higher education in the sciences, dedicate little time to discipline-specific literacy development. Do educators consider that being literate (enough) to read and write is sufficient for students to understand and interpret highly complex scientific text? Whilst 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 scholarly 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. 'The Google Effect' flattens information sources, creating false equivalences (Brabazon, 2006). The ability to interpret multimodal information is crucial to developing disciplinary literacy. Before the proliferation of Google, 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. However, the simplification of information literacy into digital literacy has reduced these skills to a simple CTRL + F function. Increased accessibility has proliferated low quality information that rarely demands more specialized information literacy. As shown in our three dissemination models, knowledge cannot be reduced to information or content. Each term – knowledge, information and content - requires a different selection of both interface and audience. Disciplinary literacy necessitates knowledge development and is an expert-driven model for learning. The challenge is that informational content is available at speed and does not require specialist education to access. Understanding knowledge through disciplinary literacies is difficult. Accessing content is much easier, but scaffolding it to knowledge without context, technique or expertise is risky at best, and dangerous at worst.

As scientific knowledge progresses and new techniques are developed, educators are under pressure to include even more disciplinary content, ensuring students have a strong foundation to understand the evolution of their discipline, whilst also incorporating generic skills. However, because of a lack of professional development in delivering transferrable skills, educators are unprepared for this challenge. This is relevant, not only 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 three reasons. Firstly, they are ill prepared to scaffold learning due to a lack of education-specific training. Secondly, the content they learn, teach, and disseminate is often highly technical and specialised, justifying the need to stay within the confines of discipline specific language. Thirdly and perhaps most importantly, it takes time to learn with accuracy and depth. Reductionism and rationalisation is the fuel of neoliberal higher education. Less knowledge can be justified for more efficiency.

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 assume that disciplinary literacy will develop gradually through time via chance exposure, in many cases only emerging in the postgraduate space where learning experiences are highly individualised. This is accidental learning that reinforces the asymmetrical power differences in science disciplines. Those who experienced effective school-based learning cultures, who come from a home with books and tertiary educated parents, can spend time in the lab and library, rather than caring for children or in paid employment, are more present and more likely to collect this accidental learning through a chance exposure. Chance favours the empowered. These affordances increase through postgraduate degrees, where the chances for accidental learning intensify. Yet very few students continue to postgraduate studies, meaning that most graduates will not be situated in an environment in which to develop adequate

disciplinary literacy to establish transferrable skills, and open out the opportunities for critical or reflexive literacy.

created through a multimodal learning and assessment culture. They must evaluate how much work is required to create different educational pathways

Our research confirms the importance of creating a rich multimodal environment that supports the development of disciplinary literacy. This is not a difficult step, but it requires intentionality. As Gunther Kress confirmed (2003; 2009; 2014), the greater the cultural difference, the more likely miscommunication will result.   Therefore, a multi-sensory, multimodal learning culture increases the opportunities for a diversity of students to access and comprehend the signs, codes, ideologies, and discourse that forms the semiotic system of disciplinary literacy. To enact change, educators must see value in the outcomes created through a multimodal learning and assessment culture. They must evaluate how much work is required to create different educational pathways, they must tip the balance in favour of how much work is required, and they must be relatively easy to put in place. The use of e-learning modules –introducing the artefacts of science and the literacies required to decode them –are crucial. Such artefacts for disciplinary literacy development demonstrate to educators that such a shift does not require an extraordinary amount of investment in curricula redesign. Instead, the artefacts highlight how to embed workplace practices into teaching, without squeezing out valuable disciplinary content (Brabazon, Quinton, Hunter, 2022). The artefacts demonstrate how the daily patterns of academics, configured through research and professional relationships, can mesh into the educational practices of students. 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. The learning embedded in the artefacts of science are not bound by any particular platform, but are an example how these everyday practices can be incorporated into any classroom or learning experience simply by shifting our thinking about what literacies are valuable to any discipline.

There are many ways to develop literacies within a discipline. Constructing – overtly and clearly – artefacts of and from a discipline allow educators and learners to embark on a collaborative journey, 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. 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 (Brabazon, Knight, Hills, 2020). Thus, the key principles to developing disciplinary literacy can be applied across other 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. The reason or this generalizability is that these principles activate explicitness. They demand that teachers stop, take an inventory of content, audience, and interface, assess the current literacy moment, and the boundaries around it. These principles provide the gateway to move between Mary Macken-Horarik's four slices of literacy.

There are four principles that reveal explicitness in literacy, a capacity to measure and evaluate the current status and mode of literacy, and the gateway between everyday, applied, theoretical and reflexive literacies.   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 student 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 emerge, 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. All literacies are based on prior literacies that have been mastered. Educators 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. To move students 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, we summon the following three questions. These are scaffolding questions.

1. How can disciplinary literacy be deployed 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 article provides 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. Artefact creation – from blogs to photographs, from soundscapes to posters – are a model for how educators can model disciplinary examples. Authentic reading

and writing can be situated in explicit assessment. Learners have increased opportunities to access and develop disciplinary literacy. Academics consider the prior experience of our students, ensuring adequate opportunities to build on current understanding rather than stifle it or make assessment too prescriptive.

Currently, opportunities for students to broaden communication skills are sparse in an undergraduate teaching program. The focus remains on 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 develop stronger connections to the discipline and the content by exploring and testing their understanding through writing. A crucial design element for students in assessment is the design of artefacts – from a blog to a poster to a podcast. Such learning objects and dissemination strategies provide writing tasks that are also present in the workplace and used by experts in the field. This is a critical element in providing learners with an experience that aligns the learning environment and expectations, and provides opportunities for engagement through and with authenticity. This process promotes change, not just in learners but in educators, and makes connections beyond the classroom. The learning culture creates and disseminates disciplinary practices and links them together.

These connections are further strengthened by enhancing accessibility using multimodal design. The concerns surrounding the inclusion of minority groups and communities, who were historically disempowered and disconnected from particular disciplines, can be addressed. Communication in various forms is crucial to academic success in higher education. These disciplinary literacies also transcend the institution. 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 the visibility of science to the broader community, existing barriers to women and other minorities in science disciplines are reduced (Fogg-Rogers & Hobbs, 2019). Developing multimodal artefacts as part of assessments provide clear examples of how this scaffolding project can be enacted 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, researchers 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.

The model of assessment is important to science education. The artefact and exegesis format in assessment design is not only uncommon in the sciences, but a challenging form due to the nature of empirical methods. By undertaking this mode of assessment, disciplinary literacy is visible and overt. Scientific research requires creativity to tackle challenging problems in novel ways. The development of the artefacts provides an opportunity to explore the way learners learn, investigating why they develop particular skills in the way they do. Instead of focussing on reading, writing and thinking as generic competencies or graduate outcomes , disciplinary literacy creates a new lens for learning 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.

Graduates who are provided with many opportunities to develop literacies in a variety of modes within a discipline are able to move more easily between disciplines, thereby summoning reflexive literacy. 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 the opposite of this stated outcome. 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). Developing artefacts – for example, blogs, films, photographs, and videos –as part of the assessment outputs throughout a science degree provides 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 it. 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. This alignment results in better-prepared graduates, but also productive industrial collaborations, and socially responsible universities.

Research Interrupted: Developing and Deploying Expertise in Challenging Times

Understanding how disciplinary literacy develops is essential in constructing an improvement arc for an individual learner. However, it is even more important in understanding the audience for science writing, teaching and research. COVID-19 summoned a fearful future for online teaching and learning. By recognising how and why disciplinary literacy develops, education researchers can reflect on the experiences of our students and provide meaningful modes of learning, no matter what the platform. In times of crisis

, citizens cling to comfort, to the familiar, to 'a normal.' Learning requires a transcendence of comfort. 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 and beyond the COVID-19 pandemic, there is a need to be more flexible and agile in tertiary teaching practices. 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 pertinent. These are unprecedented times in higher education where stress levels are at an all-time high for both students and staff. 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, academic educators 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.

Conflict of Interest
The authors declare that they have no conflict of interest

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