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Teaching Scientists to Communicate: Evidence-based assessment for undergraduate science education

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Communication skills are one of five nationally recognised learning outcomes for an Australian Bachelor of Science (BSc) degree. Previous evidence indicates that communication skills taught in Australian undergraduate science degrees are not developed sufficiently to meet the requirements of the modern-day workplace—a problem faced in the UK and USA also. Curriculum development in this area, however, hinges on first evaluating how communication skills are taught currently as a base from which to make effective changes. This study aimed to quantify the current standard of communication education within BSc degrees at Australian research-intensive universities. A detailed evidential baseline for not only *what* but also *how* communication skills are being taught was established. We quantified which communication skills were taught and assessed explicitly, implicitly, or were absent in a range of undergraduate science assessment tasks ($n = 35$) from four research-intensive Australian universities. Results indicate that 10 of the 12 core science communication skills used for evaluation were absent from more than 50% of assessment tasks and 77.14% of all assessment tasks taught less than 5 core communication skills explicitly. The design of assessment tasks significantly affected whether communication skills were taught explicitly. Prominent trends were that communication skills in tasks aimed at non-scientific audiences were taught more explicitly than in tasks aimed at scientific audiences, and the majority of group and multimedia tasks taught communication elements more explicitly than individual, or written and oral tasks. Implications for science communication in the BSc and further research are discussed.

Keywords: *Science Communication; Undergraduate Skills; Higher Education; Science Education; Employability*

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Introduction

Communication Skills as a Graduate Learning Outcome

There is an international push to improve the effectiveness with which scientists communicate. It is acknowledged that the role of communicating science research to a broad range of audiences is the responsibility of the trained science community (Brownell, Price, & Steinman, 2013a; Greenwood & Riordan, 2001; Leshner, 2003). One approach to facilitating this expectation is to ensure that science graduates are equipped with relevant and well-developed communication skills. There is global agreement that training undergraduate and postgraduate science students in science communication is beneficial at both societal and individual levels (e.g. Besley & Tanner, 2011; Bray, France, & Gilbert, 2011; Poronnik & Moni, 2006). The introduction of 'generic skills', or 'learning outcomes', such as communication skills, into science degrees is becoming more common in higher education across the UK, the USA, and in Australia (American Association for the Advancement of Science [AAAS], 2009; Jones, Yates, & Kelder, 2011; Yorke & Knight, 2006). One aim of such introductions is to bring a degree of accountability into science higher education and to create a stronger link between graduate education and graduate employability (Bath, Smith, Stein, & Swann, 2004; Cummings, 1998).

A set of Science Threshold Learning Outcomes (TLOs), for example, has been developed to guide curriculum development within Australian Bachelor of Science (BSc) degrees. These TLOs provide a framework for the development of learning objectives based on 'nationally agreed upon descriptions of what a science graduate should know and be able to do' (Academic Council of Deans of Science [ACDS], 2013). Integrating learning outcomes and graduate attributes into pre-existing curricula is notoriously complex, however, and an analysis of quality audits for Australian universities found widespread failure to integrate or assess learning outcomes for graduate attributes into Australian university curricula (Ewan, 2009; Hodgson, Varsavsky, & Matthews, 2013). Integration problems are also faced by higher education institutions elsewhere, with a lack of constructive alignment between assessment practices and learning outcomes being common in the USA, New Zealand, and the UK (Borrego & Cutler, 2010; Bray et al., 2011; Knight, 2001; Kuh & Ewell, 2010).

One result of this scarcity of education practices that support enhanced graduate learning outcomes is a lack of generically employable skills within the graduate cohort. Communication specifically is a learning outcome cited by graduates, professionals, employers, and educational institutions as being underdeveloped within the tertiary science curriculum. A report prepared for the Australian Council of Deans of Science found that analytical, technical, and problem-solving skills along with science content knowledge are being taught successfully but communication skills (oral, interpersonal, and written) consistently are falling short of requirements (McInnis, Hartley, & Anderson, 2000). Similarly, research shows that science graduates and employers from across Australia and New Zealand have found that training received by undergraduate science students does not reflect the reality of workplace requirements (Gray, Emerson, & MacKay, 2005; McInnis et al., 2000).

Evidence-based Curriculum Development

Champagne and Klopfer (1974)—40 years ago—argued the need for evidence-based approaches to evaluating educational practices as an important source of insight for developing new science curriculum. Candy, Crebert, and O'Leary (1994) argued that in Australia 'the concept of "curriculum" in the university setting is unfamiliar to many academics, who develop and teach units or courses to reflect their own interests with little attention to ensuring coherence or identifying the aims and objectives of teaching'. This approach results in fragmented tertiary curricula, the kind of which is also seen in the UK and the USA (Huber, 1992; Knight, 2001). This highlights the need to look outward towards the curriculum as a whole rather than inward at a course level. A predominant example of this strategy is the Carl Wieman Science Education Initiative which took a four-step, evidence-based approach to improving undergraduate science education in Canada and the USA; these steps involved establishing what students *should* learn, measuring what they *actually* learned, developing teaching and learning to promote learning goals, and disseminating and adopting effective practices (Wieman, Perkins, & Gilbert, 2010). The Scholarship of Teaching and Learning (SoTL) takes a similar approach to curriculum development. The term SoTL 'describes research that involves rigorous examination of teaching and learning by faculty who are actively involved in the educational process' (Rowland & Myatt, 2014) and is involved directly with the quantification and improvement of teaching and learning outcomes (Rowland & Myatt, 2014).

There is a need within science degree programs to apply this rigorous evaluation of teaching practices to communication skills at a macro-, rather than micro-, level in order to establish an evidential baseline for effective curriculum development. Previous research has focused primarily on teaching practices at an individual course or single assessment task level (e.g. Kuchel, Wilson, Stevens, & Cokley, 2014; Poronnik & Moni, 2006). One of the five Australian TLOs for science degrees is 'Communication' and it recommends that science graduates should be able to communicate scientific results effectively 'to a *range of audiences*, for a *range of purposes*, and using a *variety of modes*' (Jones et al., 2011). Few studies exist that examine how this diverse range of communication skills is taught across a degree program and how and where in the BSc they are being taught. Stevens (2013) completed an analysis of science undergraduate assessment tasks from five research-intensive Australian universities. This research found that 31% of tasks involved communication but 59% of those were for the purpose of presenting scientific results; 69% were in the mode of traditional written assessment (for example, laboratory reports); and 96% of communication assessment tasks were targeted at an audience of scientists of the same discipline. These findings highlight two major issues. The first is that the way communication is taught in the BSc encompasses only a narrow range of communication skills, despite the recommendations for diversity given by the communication TLO for science. The second issue is that very little empirical evidence exists as to *how* we are teaching this narrow range of communication skills.

The Need for Explicit Assessment

Colthorpe, Rowland, and Leach (2013) identify the need to *explicitly teach and assess* those concepts, such as communication, which are central to student learning within science higher education. The need for explicit teaching and assessment also is highlighted in other educational contexts. For example, Ritchhart and Perkins (2008) identify that whether educational expectations are made implicit or explicit shapes what and how learning occurs in a school classroom. How learning occurs is not only influenced by the pedagogical approach but also by how the skills are assessed, which is particularly relevant within the assessment-driven tertiary science setting. The concept that 'assessment drives learning' is well established and stresses that methods of assessment are central to optimal student learning and retention (Biggs & Tang 2011; Kuh, 2008; Morgan, Clarke, Weidmann, Laidlaw, & Law, 2007). Research has shown that assessment practices have a significant effect 'on whether students adopt a "deep" or "surface" approach to learning' (Healey, 2000; Prosser & Trigwell, 1999; Ramsden, 1992). This focus on assessment also is pivotal in evaluating the efficacy with which concepts are taught given that 'assessment literally defines the curriculum for most students' (James & McInnes, 2001, p. 4).

Strong links between learning outcomes and assessment practices therefore need to be made visible to students in higher education. Constructive alignment is one such process which involves articulating *explicit* learning outcomes and aligning the design of teaching activities and assessment tasks to facilitate students' abilities to achieve those outcomes (Biggs & Tang 2011). The key consideration in this process is the need to make those learning outcomes explicit to students. Contemporary students often have substantial commitments within and outside of university and do not have the time or cognitive capacity to wade through tacit or implicit teaching practices to reach valid learning outcomes, and nor should that be the expectation. Varsavsky, Matthews, and Hodgson (2013) outline the need for an examination of teaching and assessment practices in Australian higher education science programs to elucidate how graduate skills are integrated throughout the program, and to address the question: Are graduate skills included explicitly in teaching and assessment tasks? Colthorpe et al. (2013) state that 'despite the central nature of communication to student success, many undergraduate courses do not explicitly teach scientific communication skills; instead, the skills are implicit within assessment design'. The key question arising from this is: If communication skills are being taught implicitly within assessment tasks, are students actually learning them?

Theoretical Framework

'One of the best tools available to educators is explicit instruction, a structured, systematic, and effective methodology for teaching academic skills. It is called explicit because it is an unambiguous and direct approach to teaching' (Archer & Hughes, 2011, p. 1). Explicit instruction sits within the broader pedagogical context of *instructional design* which aims to design teaching and learning events in ways that 'makes the acquisition of knowledge and skill more efficient, effective, and appealing' (Merrill, Drake, Lacy, Pratt, & ID2_Research_Group, 1996). Explicit instruction leaves nothing to chance and makes no assumptions about the skills and knowledge being taught (Torgesen, 2004, p. 363). It was derived, in part, from the theory of *direct explanation* whereby new material is taught in a concrete and overt manner and entails 'a clear description of a skill, strategy, process, or concept using concise and consistent language' (Coyne et al., 2009; Duffy, 2009; Reutzel, Child, Jones, & Clark, 2014; Stevens, Van Meter, Garner, & Warcholak, 2008). This approach has been applied and integrated into other educational contexts, at both school and tertiary levels, for numerous complex skills such as in teacher education, medical clinical reasoning, and reading comprehension in science (Concannon-Gibney & McCarthy, 2012; Freeman, 1991; O'Neill, Geoghegan & Petersen, 2013). All these instances provide evidence to support the benefits of making the educators' tacit knowledge explicit and visible to students (Shulman, 1988, p. 33). The approach of explicit instruction is cited to be particularly effective for teaching complex 'multistep' skills whereby the purpose of learning and learning outcomes are made visible to students explicitly and supported by a series of 'step-by-step' scaffolding learning events (Archer & Hughes, 2011, p. 11; Rosenshine, 1997).

The teaching of communication—as a complex learning outcome—rarely has been viewed through the lens of explicit instruction within a tertiary science context. One Australian study found that explicit teaching of an opinion-editorial writing style in an undergraduate physiology and pharmacology course led to improvements in the students' abilities to communicate effectively in writing with the lay public (Moni, Hryciw, Poronnik, & Moni, 2007). Another study based in the UK found that making expectations explicit when teaching communication in a science graduate program was important for quality learning (Divan & Mason, 2015). This indicates that there has been some documented success in applying the lens of explicit instruction to teaching communication skills in undergraduate science. Rosenshine (1986) speaks to the broad applicability of such an instructional approach stating that it is pertinent to any well-structured discipline where the goal is to teach specific skills. We contend here that some of the most structured aspects of tertiary education are assessment practices, which have the goal of teaching and assessing specific skills, and thus analysing the assessment of communication in science degrees through an explicit instruction and direct explanation lens is appropriate.

Purpose and Context

Context of Study

This research focused on communication assessment practices through the lens of explicit instruction and direct explanation in undergraduate science courses at a subset of Australian universities belonging to the Group of Eight (Go8) coalition, all of which are research-intensive universities with similar teaching missions and cultures

(Rowland, 2012). Undergraduate demographics of these universities are relatively uniform with the majority of science students being Australian domestic students aged 17–25 years (Australian Government Department of Industry, 2013; Universities Australia, 2014). Science programs within the Go8 are comparable in breadth and depth (Varsavsky et al., 2013) and include three years of undergraduate study with an optional fourth year for Honours. The BSc within the Go8 and nationally has a set of aforementioned Science TLOs. The curricular intention of the communication-focused learning outcome is that all science graduates possess diverse science communication skills as a result of development within the BSc.

Purpose of Study

The purpose of this study is to address the scarcity of evidence evaluating *what* and *how* communication skills are taught and assessed currently in undergraduate science degrees in Australia. Findings are specific to the above context and not necessarily representative of the BSc at all Australian universities or universities outside Australia but are presented as a case study with broader application given reports of similar conditions internationally. The intention of this case study, rather than comprehensive program review, is to provide a snapshot into the current communication assessment practices in a diverse range of science courses to provide much needed baseline evidence.

The specific research questions addressed in the study are:

1) How explicitly are core communication skills taught and assessed in undergraduate science assessment tasks?
2) What assessment designs affect how explicitly communication skills are scaffolded, taught, and assessed?
3) What structural aspects of the BSc degree program (year level, discipline, major) affect how explicitly communication skills are taught and assessed?

Methods

Ethics approval for this study was granted by the University of Queensland Behavioural & Social Sciences Ethical Review Committee (Approval Number: 2014000655).

Collecting Teaching Resources and Assessment Instructions

Written assessment instructions for communication-style assessment tasks in undergraduate science courses in the BSc were collected for analysis. Science courses included in this process were only core scientific courses (units) rather than communication electives taught into BSc programs or science communication courses or degrees offered outside of the BSc. This was the result of aiming to capture the pedagogical approaches taken to teaching communication in a discipline-specific context within the BSc, rather than as an external course. Two main categories of assessment tasks were included: tasks targeting communication with (1) scientific or (2) non-scientific audiences, where a scientific audience was defined as scientists from the same or similar discipline (e.g. tasks such as laboratory reports) and a non-scientific audience referred to as non-scientists. Suitable assessment tasks were identified using a database of existing Australian undergraduate science assessment tasks (Stevens, 2013) and teaching documents were obtained by contacting course coordinators, asking them to provide details of existing non-scientific communication tasks ($n = 23$) and technical assessment tasks ($n = 84$). Positive response rates from course coordinators were 79% ($n = 18$) for non-technical communication tasks and 20% ($n = 17$) for technical tasks. Written assessment documents containing instructions were collected for 35 assessment tasks in total, across 28 undergraduate science courses ('courses' are referred to, and in this case are synonymous with, 'units' at other universities) from four of the leading Go8 universities. These instructions included a range of teaching documents, including written instructions, online course profiles, assessment outlines, criteria rubrics, lecture notes, and tutorial notes made available to students prior to completing assessments. In total, 106 assessment documents were analysed. The most common document type was 'Assessment Task Outline' and the least common was 'Learning Outcomes'. For detailed information including descriptions and numbers of each document type that was analysed, see Table 1. Verbal instructions and supplementary documents (such as 'suggested readings') were excluded from analyses, as it could not be assumed that the majority of students had read these documents or been present for the verbal delivery of content or instructions. Each assessment task was categorised by university, audience, year level, participation structure, major, discipline, and format. Table 2 summarises these categories, including sample sizes for each category level. It should be noted that for 'participation structure', the category 'group' indicates that the format of the assessment task was designed to be completed by more than one student in collaboration.

Quantification of Communication Skills

The core communication skills used for analysis are listed in Table 3 and are derived from the evidence-based teaching resource from Mercer-Mapstone and Kuchel (in press), which established 12 core skills necessary for the effective communication of science to non-scientific audiences. Each of the 12 core communication skills was classified, per assessment task, as being:

- *Explicitly present*—having an explicit or overt description of the skill within the written assessment instructions which make the expectations, requirements, or outcomes of that skill visible, leaving no room for ambiguity;
- *Implicitly present*—the skill was indirectly alluded to without an overt description and the expectations, requirements, or outcomes of that skill were not explicitly visible, leaving room for ambiguity; or
- *Not present*—the skill was not mentioned.

Table 1. Descriptions of documentation included in our analysis. A breakdown of document type by audience and by those that included step-by-step instructions for how to carry out specific communication skill(s) is also provided

Assessment document with description	Number of document type analysed as part of sets of assessment instructions		Total number of this type of document analysed	Percentage (and number) of documents of this type that included step-by-step instructions for how to carry out specific communication skill(s)	
	Tasks with scientific audience	Tasks with non-scientific audience		Tasks with scientific audience	Tasks with non-scientific audience
Assessment task outline—documents outlining the assessment task specifically, often including the format, the weighting, and requirements of the task	11	15	26	18% (2)	6% (1)
Marking criteria—a set of criteria or a marking rubric used for grading the completed task	6	10	16	0	0
Lecture—PowerPoint slides used in lectures containing information on the task, for example: discussing the concepts involved. Often including teacher delivery notes	7	8	15	57% (4)	50% (4)
Tutorial—PowerPoint slides or student worksheets/information handouts used in a tutorial class containing information on the task, often including teacher delivery notes. For example: having previous exemplars of the assessment	5	8	13	20% (1)	38% (3)
Practical/Laboratory—student worksheets/information, handouts, or laboratory manuals used in a practical class containing information on the task, often including teacher delivery notes	8	1	9	0	100% (1)
Course (unit) profile—usually an online profile explaining all the details of the course, often addressing assessment instructions such as weighting	8	11	19	0	0

(*Continued*)

Table 1. Continued

Assessment document with description	Number of document type analysed as part of sets of assessment instructions: Tasks with scientific audience	Number of document type analysed as part of sets of assessment instructions: Tasks with non-scientific audience	Total number of this type of document analysed	Percentage (and number) of documents of this type that included step-by-step instructions for how to carry out specific communication skill(s): Tasks with scientific audience	Percentage (and number) of documents of this type that included step-by-step instructions for how to carry out specific communication skill(s): Tasks with non-scientific audience
Learning outcomes/objectives—a list of outcomes that can be expected as a result of either the course (unit) or the assessment task	1	7	8	0	0

These definitions were based on the requirements for explicit instruction and direct explanation as outlined above in the theoretical framework (Section 2). The classification of skills was done using an iterative process using the decision-making questions outlined in Table 4. Classification of skills in the above categories was refined until >95% agreement was achieved in the independent analysis of a 10% subset of data by two researchers to guarantee their validity and repeatability in application to remaining tasks. Some communication skills existed only in marking criteria provided, as feedback post-assessment in some tasks and in those cases these skills were recorded as implicit, even if explicitly stated, since the provision of post-assessment feedback was not formative for the task being assessed. This decision was based on the idea of 'transparent grading' as a part of explicit instruction whereby assessment criteria are, at minimum, provided to students prior to assessment, or at best, actively discussed with students to make the grading process transparent (Moni et al., 2007). Where a communication skill was present in an assessment document, it was also recorded whether that skill was simply a statement of the skill (for example 'the target audience of this assessment task is your scientific peers') or whether the teaching material included incremental scaffolding used to teach the students how to do the skill. This scaffolding was defined as 'step-by-step instructions' guiding students on the process of specifically *how* to carry out, do, or apply the communication skill, either in the context of the assessment task or more broadly (adapted from Archer & Hughes, 2011).

Data Analysis

Descriptive statistics were examined for the quantified assessment tasks using Microsoft Excel 2007. All other statistics were calculated using R statistical package (R Core

Table 2. Categories with relevant levels used to summarise the assessment tasks ($n = 35$). These categories also form the predictor variable used for the statistical analyses of communication skill presence

Category (predictor variable)	Sub-category	Number of assessment tasks represented in each category
Audience	Non-scientific	18
	Scientific	17
University (not included in statistical analyses)	University 1	20
	University 2	2
	University 3	2
	University 4	11
Major	Biology	9
	Ecology	5
	Marine Biology	1
	Mathematics and Statistics	1
	Chemistry	4
	Physics	2
	Biochemistry	1
	Genetics	2
	Geography	10
Discipline (compared graphically—not included in permutation tests)	Biology	17
	Chemistry	6
	Physics & Mathematics	3
	Geography	10
Format	Multimedia	8
	Oral	4
	Written	23
Participant Structure	Group	11
	Individual	24
Undergraduate Year Level	First year	4
	Second Year	11
	Third Year	20

Team, 2014). Data for the classification of the presence of each communication skill (implicit, explicit, or absent) were analysed to highlight any statistical effects among variables. A multinomial model (Venables & Ripley, 2002) was built to include the response variable (presence of communication skill as explicit, implicit, or absent within each of the 35 individual assessment tasks) and the following predictor variables: audience, year level, major, assessment format, participation structure, and skill (levels for each variable given in Table 2). Only main effects were considered. Interactions among variables were not analysed because they do not address the research questions of this study. A permutation test (Good, 2005) for association between predictors and the response variable was done as follows. The deviance chi-square statistic (Seminar for Statistics [SfS], 2012) was calculated for the model and observed data. The data were then permuted under the null hypothesis of 'no

Table 3. Core communication skills for effective science communication derived from Mercer-Mapstone (in press) with reference words used throughout study for brevity

Reference word	Core communication skills for effective science communication
Audience	Identify and understand a suitable target audience
Language	Use language that is appropriate for your target audience
Content	Separate essential from non-essential factual content in a context that is relevant to the target audience
Context	Consider the social, political, and cultural context of the scientific information
Engagement	Promote audience engagement with the science
Style	Use/consider style elements appropriate for the mode of communication (such as humour, anecdotes, analogy, metaphors, rhetoric, images, body language, eye contact, and diagrams)
Prior knowledge	Consider the levels of prior knowledge in the target audience
Narrative	Use the tools of storytelling and narrative
Purpose	Identify the purpose and intended outcome of the communication
Mode	Use a suitable mode and platform to communicate with the target audience
Dialogue	Encourage a two-way dialogue with the audience
Theory	Understand the underlying theories leading to the development of science communication and why it is important

Table 4. Questions used to drive the iterative decision-making process for the classification of communication skills within assessment tasks

Question		Answer	Result
1	Was the skill explicitly described in the written assessment instructions, leaving no ambiguity about expectations?	Yes	EXPLICITLY PRESENT
		No	Continue to Question 2
2	Was the skill indirectly alluded to with no overt description in the written assessment instructions, leaving room for ambiguity about expectations?	Yes	IMPLICITLY PRESENT
		No	Continue to Question 3
3	Was the skill described explicitly, or indirectly alluded to, in the marking criteria that were given only in post-assessment feedback?	Yes	IMPLICITLY PRESENT
		No	Continue to Question 4
4	Was the skill absent from the written assessment instructions?	Yes	ABSENT
		No	Re-evaluate from Question 1

association between predictor variables and the response' 10,000 times and a corresponding null distribution of associated chi-square statistics derived. The value of the observed deviance chi-square statistic was then compared to this null distribution to test for a significant association between the predictors and response variable. The test was declared significant if the observed chi-squared value was greater than the 95th percentile of the null distribution. A permutation test was used because many of the categories of observed data contained fewer than five counts, which violated assumptions for the standard large-sample chi-square test. Deviance chi-square tests were subsequently run for the data relating to each of the 12 skills, separately, to elucidate the element-specific effects in the model. Statistical values reported for effects of the predictor variables on individual elements are those from the observed data. The 'Theory' skill (Table 3) was excluded because the response variable had only one level.

Results

Quantifying the Communication Skills that are Explicit, Implicit, or Absent in Australian Science Assessment Tasks

There was a significant difference in how explicitly each of the 12 communication skills was taught across the 35 assessment tasks (Figure 1, Permutation Test $\chi^2 = 214.24$, $p = <.01$). The majority of skills (83.33% or 10 of 12) were absent from more than 50% of assessment tasks, with the exception of 'audience' and 'mode' skills (reference words in Table 3) which were taught explicitly in 51.43% and 94.29% of assessment tasks, respectively. The percentage of tasks that taught an element explicitly ranged between 0% ('theory' skill) and 94.3% ('mode' skill). One

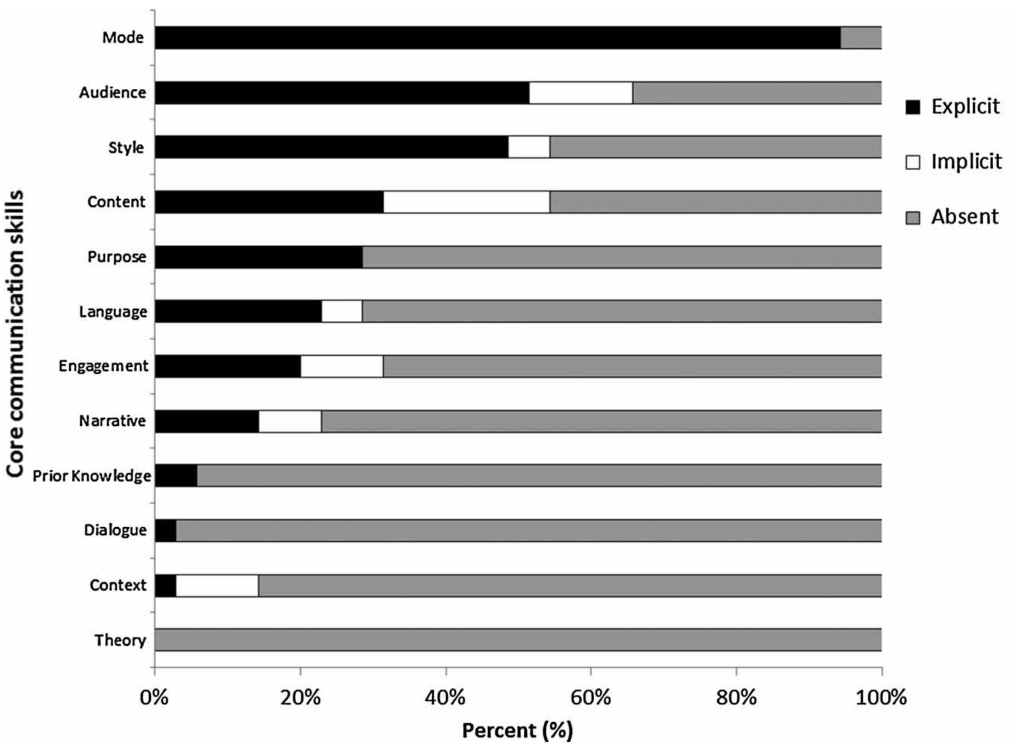

Figure 1. The proportion of each core communication skill that was explicit, implicit, or absent in written assessment instructions for all science undergraduate assessment tasks ($n = 35$)

task had all elements absent, 77.14% of all assessment tasks taught fewer than five skills explicitly, and 22.86% taught five or more skills explicitly. No task taught more than seven skills explicitly and only two of 35 tasks included this maximum number of explicit skills. Only 2 tasks (5.71%) had fewer than five skills absent from their documentation and 65.71% of tasks had eight or more skills absent from teaching materials. The percentages of tasks that taught each skill explicitly, implicitly, or not at all are shown in Figure 1.

Effects of Assessment Design on Explicitness

Assessment tasks aimed at a non-scientific audience ($n = 18$) were significantly more explicit in the teaching of communication skills than assessment tasks aimed at scientific audiences ($n = 17$; Permutation Test $\chi^2 = 11.80$, $p < .01$). Detailed comparisons between these two types of assessment task are shown for each skill in Figure 2. Various predictor variables significantly affected whether certain elements were taught explicitly (Table 5). Prominent trends were that (a) communication skills in tasks aimed at non-scientific audiences were taught more explicitly than in tasks aimed at scientific audiences and (b) the majority of group and multimedia tasks taught communication elements more explicitly than individual, or written or oral tasks.

Effect of Degree Structure on Explicitness

There was a significant difference in how explicitly the communication skills were taught between science *majors* (Permutation Test $\chi^2 = 29.81$, $p = .04$) with marine science having the highest proportion and geography having the lowest proportion of explicitly taught communication skills (Figure 3). Physics assessment tasks were slightly more explicit overall in teaching communication elements than biology, chemistry, or geography when majors were pooled into the four *disciplines* (Figure 4), while proportions of implicit or absent skills were similar across disciplines. There was no significant difference in explicit teaching of communication skills between year levels but some skills were taught more explicitly for skill-specific interactions in some year levels than others (Table 5). The directions of these effects varied among skills, however, and no consistent year-level trends were obvious.

Scaffolding of Communication Skills

It was rare to see step-by-step scaffolding teaching students a process by which they could learn to carry out the communication skills in each assessment. Of the 106 documents analysed, 15% ($n = 16$) of all documents included some level of step-by-step instructions. The percentage of documents with scaffolding of communication skills for tasks with scientific ($n = 7$) versus non-scientific audiences ($n = 9$) was the same for both audiences—15%. For detailed information on the numerical breakdown of document types, see Table 1.

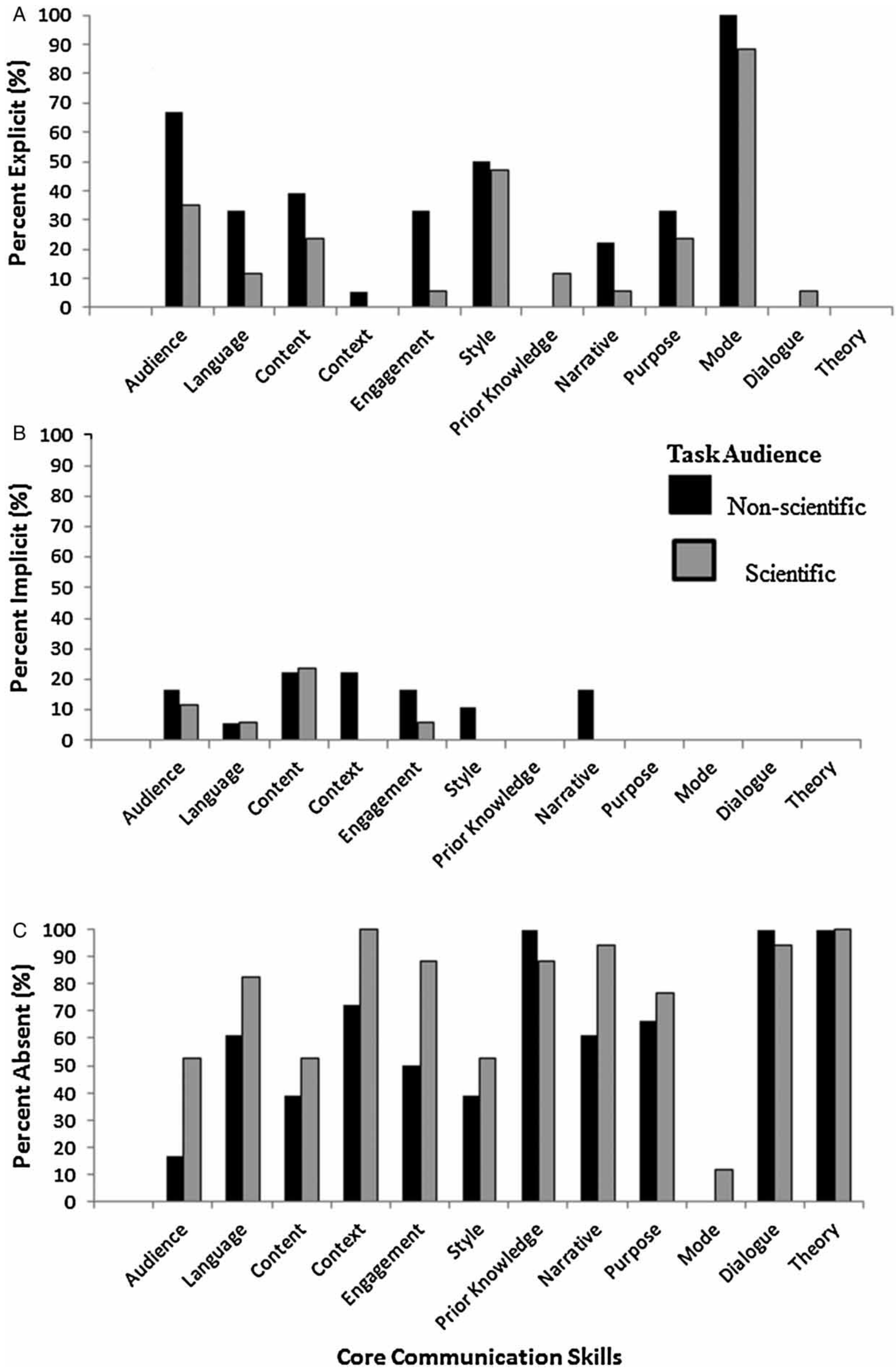

Figure 2. A comparison of the presence of each core communication skill in assessment tasks ($n = 35$) that targeted scientific versus non-scientific audiences, for whether each skill was taught: (a) explicitly, (b) implicitly, or (c) was absent

Table 5. Significant effects of predictor variables on how explicitly certain communication skills were taught across the 35 assessment tasks as determined by deviance chi-square tests. The symbols > & < are used to indicate more or less explicit teaching of a task, respectively

Core communication skills	Predictor variables that had a significant effect	Statistical values	Direction of the effect (Percentage of tasks in which skill was explicit)
Identify and understand a suitable target audience	Audience	LRT $\chi^2_2 = 6.24$, $p = 0.044$	Non-scientific (67%) > scientific (35%)
	Year level	LRT $\chi^2_4 = 19.94$, $p = 0.001$	Third (60%) > first (50%) > second (36%)
Use language that is appropriate for your target audience	Participation structure	LRT $\chi^2_2 = 8.12$, $p = 0.017$	Individual (33%) > group (0%)
Separate essential from non-essential factual content in a context that is relevant to the target audience	Audience	LRT $\chi^2_2 = 7.53$, $p = 0.023$	Non-scientific (39%) > scientific (24%)
	Format	LRT $\chi^2_4 = 13.66$, $p = 0.008$	Multimedia (50%) > written (30%) > oral (0%)
	Participation structure	LRT $\chi^2_2 = 9.77$, $p = 0.007$	Group (55%) > individual (21%)
Promote audience engagement with the science	Year level	LRT $\chi^2_4 = 18.67$, $p < 0.001$	First (50%) > second (45%) > third (0%)
	Participation structure	LRT $\chi^2_2 = 6.59$, $p = 0.037$	Group (27%) > individual (17%)
Use/consider style elements appropriate for the mode of communication	Format	LRT $\chi^2_4 = 9.97$, $p = 0.040$	Multimedia (75%) > written (43%) > oral (25%)
Identify the purpose and intended outcome of the communication	Audience	LRT $\chi^2_1 = 7.84$, $p = 0.005$	Non-scientific (33%) > scientific (24%)
	Year level	LRT $\chi^2_2 = 7.84$, $p < 0.001$	Second (45%) > first (25%) > third (20%)
	Format	LRT $\chi^2_2 = 10.72$, $p = 0.004$	Oral (50%) > written (30%) > multimedia (13%)
Use a suitable mode and platform to communicate with the target audience	Audience	LRT $\chi^2_1 = 7.74$, $p = 0.005$	Non-scientific (100%) > scientific (88%)

Discussion

The results and implications of this study are not maintained to be representative of all Australian universities but to rather provide a case study with detailed insight into a sample of current pedagogical approaches towards communication. The discussed implications should be interpreted as such. It is appropriate to infer that the results are likely to be representative of the Go8 research-intensive Australian universities given that the student demographics, assessment practices, teaching missions, and breadth and depth of the BSc at this group of tertiary institutions are comparable

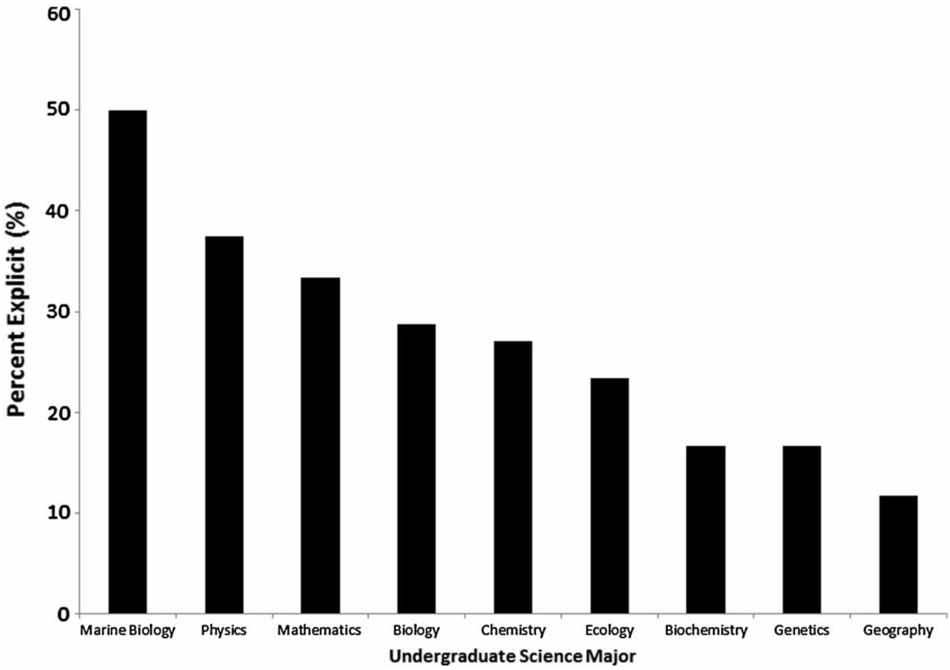

Figure 3. The proportion (%) of communication skills that were taught explicitly within assessment tasks ($n = 35$) for each undergraduate science major examined

(Australian Government Department of Industry, 2013; Rowland, 2012; Stevens, 2013; Universities Australia, 2014; Varsavsky et al., 2013). It is also fair to expect that the following implications may resonate with science teaching academics on a broader national and international scale given other reports from the literature on the subject.

Are Communication Skills Explicit in BSc Programs?

The results of this study indicate that there is a significant lack of explicitness and diversity in the way communication skills are currently being taught to undergraduate science students. Through the lens of explicit instruction and direct explanation, there seems to be little translation of the fundamental expectations of either pedagogical approach into teaching communication in higher education science curricula. Both instructional approaches recommend that the description of, expectations, and requirements for a new complex skill be made visible to students overtly (Coyne et al., 2009). The idea that the explicit instruction of skills or content should leave nothing to chance and make no assumptions about the skills and knowledge being taught (Torgesen, 2004, p. 363) seems to be applied rarely in current teaching of communication in science degrees. The analysis of the written assessment instructions for the assessment tasks included in this study found that the majority of communication

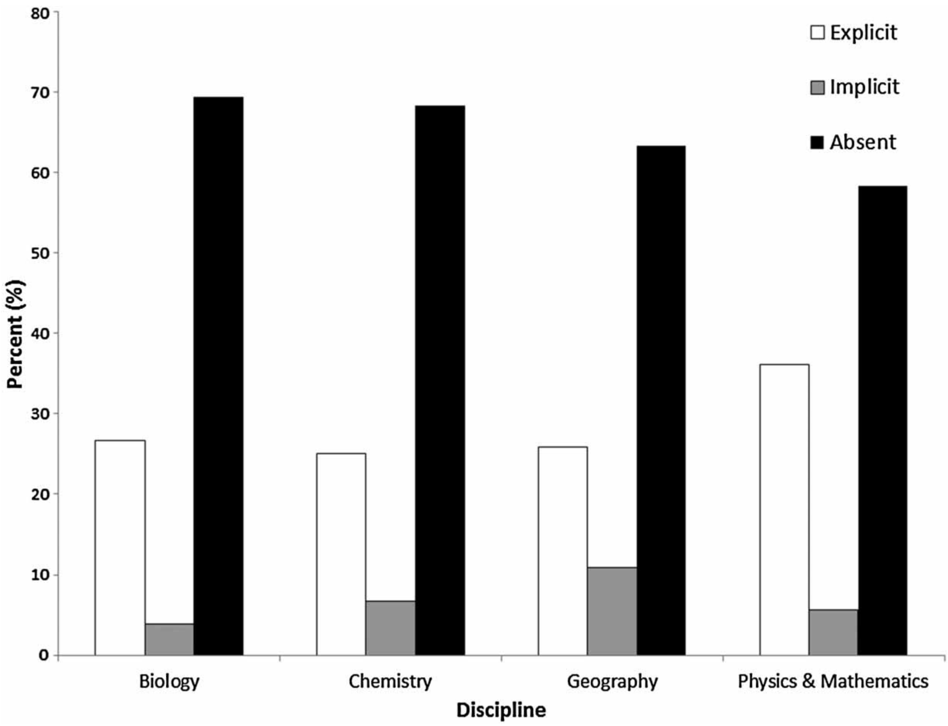

Figure 4. The proportion (%) of communication skills that were taught explicitly, implicitly, or were absent within assessment tasks ($n = 35$) for each undergraduate science discipline examined

skills (83.33% or 10 of 12, Figure 1) were absent from more than 50% of assessment tasks. No task taught more than seven skills explicitly and only two of 35 tasks included this maximum number of explicit skills. This trend towards the majority of communication skills being absent or implicit in assessment tasks could be a facet of the institutional structure where course content is left mostly to the discretion of the scientists in charge of lecturing and hence reflects their focus on traditional research and conventional communication to other scientists (Barrie, Hughes, Smith, & Thomson, 2009; Dietz, 2013). Other implementation barriers preventing lecturers from teaching communication more explicitly could reside in a lack of familiarity, confidence, or professional training in the subject—which are all major factors limiting scientists' willingness to engage with broader communities (Ecklund, James, & Lincoln, 2012).

The outliers when it came to explicitness of communication skills are important in identifying those areas in the curriculum that are done well and those which are in need of focus most—especially within a resource-limited environment such as higher education. Overall, the ability to *Use a suitable mode and platform to communicate with the target audience* was taught explicitly in the highest proportion of tasks because assessment tasks specify format clearly (e.g. essay, laboratory report, web page) which aligns closely with the 'mode' of communication. It must be considered, however, that the statement of assessment format may overlook the 'how' aspect of communicating effectively within that format. The fact that teaching of science communication 'Theory' was absent from all assessment tasks is not surprising given that this requires large amounts of background knowledge and research for it to be taught with comprehension. This is an important finding, however, as this element (theory) highlights the importance of *why* science communication is necessary for scientists and is an integral part of overcoming many perception-based implementation barriers within the student cohort, and perhaps for some teaching academics.

Closer consideration of the assessment materials through the lens of explicit instruction highlighted the issue that even when a description of the skill was stated explicitly (and hence classified as such) it was rare to see the step-by-step scaffolding of learning (present in only 15% of all teaching documents analysed) which is recommended by these theories in regard to teaching complex skills (Archer & Hughes, 2011, p. 11; Rosenshine, 1997). This is an important issue to recognise because the cumulative development of skills has been found to be an approach that enables more effective communication (Brownell, Price, & Steinman, 2013b; Knapp & Watkins, 2005; Poronnik & Moni, 2006). The implication of this is that while we may be making the 'what' clear in some assessment tasks, we seem to be overlooking the 'how' process of actually *doing* the skill which is required for adequate development and transferal of such integral skills. The few similar studies that examine communication in science degrees support this finding, also indicating that these skills are poorly represented and underdeveloped in other BSc programs in Australia as well as the USA (Brownell et al., 2013a; Herok, Chuck, & Millar, 2013; Stevens, 2013). For example, Herok et al. (2013) found that although graduate attributes, including communication, have been articulated and disseminated, there has been a lack of translation into the alignment of these graduate outcomes with educational practices in Australia. This has resulted in a mismatch between what universities say graduates should be able to do at the end of a science degree and the quality of the skills they actually possess (Herok et al., 2013). This finding is reflected by widespread complaints from journalists, industry, government, and the public that scientists are rarely equipped with the communication skills required to convey information effectively to non-scientists (e.g. Besley & Tanner 2011; Zou, 2014).

Significant change in current teaching practices is required if BSc education is to equip graduates with proficiency in a diverse range of communication skills. We recommend that such changes focus on making the tacit explicit when it comes to communication education. This might include, but is not limited to, developing assessment tasks that are constructively aligned with learning activities that incrementally scaffold the teaching and learning of communication skills.

Is there a 'Best Practice' Method for Assessing Science Communication?

Tasks that specified non-scientific audiences, used multimedia formats and were carried out in a group structure, were found to be more explicit than their alternatives (in the majority of cases, Table 5). These results, in combination with other 'best practice' studies, give initial evidence for what assessment designs might promote the explicit teaching of communication. For example, our findings that multimedia assessment formats are linked to more explicit teaching (in the majority of cases) aligns with the idea that using a multimedia approach is beneficial for student learning. This notion is gaining support with research showing that new media in the classroom facilitates learning goals rather than distracting from them (Wilcox, 2012). This also is important because science communication increasingly occurs online (Bubela et al., 2009) and familiarity with the creation and use of multimedia will better prepare graduates for the requirements of a modern workplace.

Our findings also indicated that assessment tasks completed by students in a group format (in the majority of cases) had the effect of improving the explicitness with which communication skills were articulated in the assessment instructions. These data suggest that asking students to carry out assessment tasks as a group may result in encouraging explicit teaching of communication skills in the process of designing of such assessment tasks. Functioning successfully as part of team also requires the practice and application of effective interpersonal communication which, although not evaluated within this study, may prove beneficial for students' communication skills also. These initial findings provide supporting evidence for other research that finds group assessment to be beneficial for a range of outcomes, such as engaging students, enhancing critical thinking, and improving communication skills (Ofstad & Brunner, 2013).

Our findings that tasks involving communication with non-scientific audiences were more explicitly taught aligns with a body of literature outlining the wide-reaching benefits of asking science students to communicate science to non-scientific audiences. Moni et al. (2007) found that in an Australian bioscience course using an explicit teaching approach to a task teaching communication with lay audiences resulted in improvements in students' ability to communicate science. The alignment of our results with this practitioner-based example provides evidence that the lens of explicit instruction is appropriate within this context, and also gives further evidence in support of the benefits of asking science students to communicate with non-scientific audiences. A study in the USA (Brownell et al., 2013b) also found that the teaching of communication to non-scientific audiences in an undergraduate neuroscience course significantly improved communication skills as well as facilitating students' understanding of original scientific literature and critical analyses. Similar results from Australian studies say that communication assessment tasks in science degrees lead to improvements in quantitative reasoning, interpretation of scientific results, and learning of core science competencies as well as improving communication skills (Kuchel et al., 2014; Moni et al., 2007; Stevens, 2013).

The growing body of evidence supporting the idea that teaching communication skills in science also benefits development of scientific skills (Brownell et al., 2013b; Kuchel et al., 2014; Moni et al., 2007; Stevens, 2013) has important implications for curriculum development. If communication also aids the teaching and learning of science, the introduction of communication content into existing science courses may mean that small changes can be made across the existing curriculum to facilitate the development of these skills without distracting from more discipline-specific content. Re-inventing a curriculum at the whole of degree program level is very uncommon and unlikely at most universities. Altering the methods used to teach and assess communication skills within existing courses, however, is more practical and likely at most institutions and could integrate the explicit teaching of these skills across the degree while being less resource-intensive than extensive curriculum reform.

Our results provide initial evidence that some assessment designs, often the more innovative, facilitate more explicit teaching of communication skills in science degrees than their conventional alternatives. Other resources which may be useful in developing activities that scaffold the teaching of communication in science undergraduate degrees in Australia include the list of 12 core skills for effective science communication (Table 3) sourced from Mercer-Mapstone and Kuchel (in press) and used in this study, and the Good Practice Guide for TLO4: Communication developed by Colthorpe et al. (2013).

It is worthwhile noting here that the use of multimedia assessment design, and tasks that target non-scientific audiences, remain relatively uncommon practices in science higher education. It is likely that that those academics who choose to implement such novel tasks are already innovative educators, driving them to reflect more deeply on how to scaffold or articulate their instructional information explicitly. Further research is required to establish whether it is the influence of the innovative educator or the design of such assessment tasks alone that leads to more explicit teaching of skills.

Is there Coherence in BSc Programs?

The academic curriculum is a conduit for the delivery of attributes that should remain constant regardless of disciplinary content (Fallows & Steven, 2000). This is particularly relevant in the current climate of placing increasing emphasis on the development of generic skills and graduate attributes in higher education, and more specifically, within BSc programs. The significant differences among majors and, for specific skills, year levels found in this study provide initial evidence that there may be little consistency across the BSc degree programs in the way that communication skills are taught and assessed. This raises questions about whether all graduates from such science degree programs have attained the minimum TLOs for communication, as recommended by the Science TLO guidelines (Jones et al., 2011). It is important to interpret these results within the limitations of the small sample size for some majors, in which case it may be more prudent to look at the majors as pooled by discipline (Figure 4). Discipline-level comparisons indicated that the way that communication skills were taught and assessed was fairly consistent, in contrast to the differences among majors within disciplines. The standard was consistently poor, however, and thus the same concern persists: that graduates have not attained the TLOs required.

The differences in how some particular communication skills were taught between year levels showed no distinct trends. This indicates that there is no one undergraduate year level that either under—or over—emphasises communication skills (also indicated by the lack of significant differences between year levels overall) and when viewed in light of other results of this study, suggests that there is likely to be a lack of explicit teaching of communication skills across year levels. This is particularly concerning given that the achievement of complex learning outcomes, such as communication skills, necessitates a coherent whole of degree program focus (Yorke & Knight, 2006) with iterative opportunities to practice and develop such skills. This conclusion offers support, and a potential curriculum-based explanation for, the complaints from many sectors that science graduates are not prepared for the communicative requirements of the modern-day workplace (Gray et al., 2005; Herok et al., 2013; McInnis et al., 2000; Zou, 2014).

One approach to integrating communication skills into the structure of BSc programs could be to introduce a compulsory science communication unit of study, which is being done at a small number of Australian higher education institutions. However, this approach may present resource issues in an already-crowded curriculum with a huge variety of courses already on offer. As an alternative to full curriculum review, findings from this study support the notion that small changes to assessment practices in courses in BSc programs may improve the explicitness with which communication skills are taught. It cannot be reasonably expected, however, that a single module or assessment task in an individual course should teach all 12 of the science communication skills used in this study with the appropriate depth required for mastery. Thus, it will be important that changes in assessment practices within individual courses are made in collaboration with other courses to allow students the opportunity to develop a diverse range of communication skills across the program. Coherent and collaborative curriculum development may be a successful approach to achieving this goal by implementing small changes within courses vertically and horizontally across degree programs.

Conclusion and Future Research

There are three limitations to the interpretation provided for the analysis of assessment instructions. The first is that judging whether a concept is implicit in instruction is difficult because by nature an implicit concept is hard to discern. This might explain why the number of skills classified as 'implicit' in assessment tasks was much lower than for either of the other categories. Second, the sample size of 35 tasks is relatively low and we should be cautious in extrapolating our results to assessment practices in BSc programs at all universities nationally or beyond. It is reasonable to infer, however, that these results may indicate a broader problem in teaching of science communication, given that our case study is based on four nationally leading and internationally highly ranked universities. Very little research exists in this context and further research, particularly at a whole of degree program level, would be valuable in establishing whether these findings are truly representative across Australian BSc programs generally. Finally, verbal assessment instructions and supplementary documents, such as recommended readings, were excluded from the analysis, which may mean that some nuances and emphases of the assessment tasks were overlooked. The decision not to include these was made because it cannot be assumed reliably that students will access them or, in the case of verbal instructions, be able to refer back to them during completion of assessment tasks. Second, this decision was made because researchers could not realistically be present to evaluate every type of these instructions in every course at each university due to time and resource limitations.

The analysis of communication-style assessment tasks in the sampled BSc programs revealed a distinct lack of diversity in the range of science communication skills we are teaching and a lack of explicitness in how those skills are being taught. There also appeared to be very little scaffolding for the incremental and cumulative development of complex and transferrable communication skills both within individual courses and across the sampled majors and year levels. There was an alignment between our results and the literature indicating that there are certain assessment designs that promote the explicit and effective teaching of communication skills. Unfortunately, the use of such innovative methods is relatively rare in assessments of communication skills in BSc programs, which currently reflect more traditional assessment formats.

The communication TLO for science degrees recommends that all science graduates be competent in a *diverse* communication skillset (Jones et al., 2011). The results from this study provide a detailed evidence-based case study showing that BSc assessment tasks in this sample from highly ranked universities are not supporting adequately student development of this TLO. The findings and recommendations we provide here are a useful starting point for providing insight into this area of the BSc curriculum and suggesting a way forward in curriculum development, but must be supplemented with further research. Questions worth exploring include: Are these results representative of undergraduate science degree programs more broadly nationally or internationally? If 'best practice' teaching and assessment designs do exist, how do we disseminate and implement them effectively? And finally, is there a practical approach that can be taken to develop curricula vertically and horizontally at a program level to integrate the explicit teaching of communication in BSc programs? Research addressing these questions would benefit greatly further development of science higher education.

Disclosure statement

No potential conflict of interest was reported by the authors.

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