Core Skills for Effective Science Communication: A Teaching Resource for Undergraduate Science Education

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Science communication is a diverse and transdisciplinary field and is taught most effectively when the skills involved are tailored to specific educational contexts. Few academic resources exist to guide the teaching of communication with non-scientific audiences for an undergraduate science context. This mixed methods study aimed to explore what skills for the effective communication of science with non-scientific audiences should be taught within the Australian Bachelor of Science. This was done to provide a basis from which to establish a teaching resource for undergraduate curriculum development. First, an extensive critique of academic literature was completed to distil the communication ‘skills’ or ‘elements’ commonly cited as being central to the effective communication of science from across the fields of science, communication, education, and science communication. A list of ‘key elements’ or ‘core skills’ was hence produced and systematically critiqued, edited, and validated by experts in the above four fields using a version of the Delphi method. Each of the skills identified was considered by experts to be mostly, highly, or absolutely essential, and the resource as a whole was validated as ‘Extremely applicable’, within the context of teaching undergraduate science students to communicate with non-scientific audiences. The result of this study is an evidence-based teaching resource: ‘12 Core skills for effective science communication’, which is reflective of current theory and practice. This resource may be used in teaching or as a guide to the development of communication skills for undergraduate science students in Australia and elsewhere.

Keywords: Science Communication; Undergraduate Skills; Higher Education; Science Education; Curriculum

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Introduction

Science communication is a diverse and transdisciplinary field which has undergone rapid evolution in recent years. Simultaneously, the expectation of scientists to be proficient at communicating their science to a range of audiences is increasing (Brownell, Price, & Steinman, 2013a; Greenwood & Riordan, 2001; Leshner, 2003). Effective science communication draws on a wide range of disciplines including science, communication, education, psychology, philosophy, and sociology (Mulder, Longnecker, & Davis, 2008). In the past, the emphasis of science communication revolved around the transmission or deficit models of communication—a top-down transferal of facts from scientific to non-scientific audiences (van der Sanden & Meijman, 2008). This now outdated model assumed that by making the facts of science available we were fulfilling the role of public education and generating more interest in, and improving the understanding of, science and technology (Besley & Tanner, 2011). More recently, this focus has shifted to reflect a more egalitarian two-way discourse, or dialogue-based model of science communication (Bray, France, & Gilbert, 2012; Mulder et al., 2008). It is this engagement or interaction between scientific audiences (with technical training in science) and non-scientific audiences (with no technical training in science) that is pivotal in facilitating public engagement with science rather than just public understanding of science (Besley & Tanner, 2011).

‘Science communication’ will be defined for the purpose of this study as the process of translating complex science into language and concepts that are engaging and understandable to non-scientific audiences such as politicians, industry professionals, journalists, government, educators, business, and the lay public (adapted from Burns, O’Connor, & Stocklmayer, 2003). The need to provide a definition arises because of the broad and transdisciplinary nature of the field and the variation that exists in the literature, which often results in conflicting definitions and standards. These conflicts raise many questions about how best to teach science communication. The number of courses teaching science communication is growing worldwide (Mulder et al., 2008) but there is little evidence to support what content should constitute the core elements of science communication education (Bray et al., 2012; Mulder et al., 2008).

Tertiary science degrees internationally are placing increasing emphasis on the inclusion of generic skills to equip science graduates with broadly employable skills. Communication is one such skillset that is highlighted consistently by educators, employers, government, and professionals as being highly important for science graduates (Brownell, Price, & Steinman, 2013b; Gray, Emerson, & MacKay, 2005; McInnis, Hartley, & Anderson, 2000; West, 2012). Accordingly, communication has been introduced as a learning outcome for science degrees in many countries, including Australia, the UK, the US, and Canada (AAAS, 2009; AQF, 2013; Jones, Yates, & Kelder, 2011; OCGS, 2005; QAA, 2007). For example, in Australia communication has been recommended as one of five fundamental Threshold Learning Outcomes (TLOs) of a Bachelor of Science (BSc) degree. These five TLOs were developed by the Australian Learning and Teaching Academic Standards project to guide curriculum development and to facilitate the standardisation and integration
of broad learning outcomes into science degrees (ACDS, 2013; Jones et al., 2011). The communication TLO recommends that, upon completion of a BSc in Australia, science graduates should ‘be effective communicators of science by communicating scientific results, information, or arguments, to a range of audiences, for a range of purposes, and using a variety of modes’ (Jones et al., 2011).

Integrating such a broad learning outcome into existing curricula, however, is a difficult process and one quality audit for universities in Australia found a lack of teaching or assessment of learning outcomes for graduate attributes, such as communication (Ewan, 2009). An analysis of assessment practices at five Australian research-intensive universities found that while 31% of undergraduate science assessment tasks involved communication (Stevens, 2013), the diversity of these tasks did not align with the diversity of communication recommended by the TLO: 59% of tasks were for the purpose of presenting scientific results; 69% were in the mode of traditional scientific written assessment (e.g. laboratory reports); and 96% were targeted at an audience of scientists of the same discipline (Stevens, 2013). These data suggest that significant implementation barriers exist for the assessment (and development) of a diverse range of communication skills in undergraduate science curricula, particularly those skills that teach science communication with non-scientific audiences.

As a likely result of this underdevelopment of communication skills, research shows that the skills currently possessed by BSc graduates do not align with employer and workplace requirements (Herok, Chuck, & Millar, 2013; McInnis et al., 2000; Zou, 2014). Analytical, technical, and problem-solving skills along with subject-specific knowledge apparently are being taught successfully but communication skills are consistently falling short and do not reflect the needs of writing tasks outside academia (Gray et al., 2005; McInnis et al., 2000). These findings gain further significance in the light of the fact that only approximately 20% of science graduates progress to be employed as technical scientists (Graduate Careers Australia, 2011; University of Sydney, 2008).

One explanation for the shortfall of graduates’ more generic communication skills could be that the inclusion of communication content in science courses is left mostly to the discretion of the scientists in charge of lecturing and hence reflects the focus of their careers on traditional research and conventional communication to other scientists (Barrie, Hughes, Smith, & Thomson, 2009; Dietz, 2013). Science academics already carry a heavy workload under the current higher education system. One specific hurdle facing these lecturers in teaching communication skills is that they are specialised in one specific scientific area and cannot also be expected to be masters of educating undergraduates on communication, a topic they also may find challenging (Brownell et al., 2013b). Science academics rarely have the time, resources, or formal training to communicate their own research to non-scientific audiences (Metcalf & Gascoigne, 1995) let alone to develop the skills, resources, and courses components required to teach such communication thoroughly.

It is here that we need to acknowledge that a fundamental ‘recognisable framework’ is essential for development of science communication curricula (Mulder et al.,
Previous research has examined current education practices and produced resources for science communication in postgraduate science or professional communication courses (e.g. Baram-Tsabar & Lewenstein, 2013; Bray et al., 2012; Brownell et al., 2013a; Fischhoff, 2013; Miller, Fahy, & Team, 2009; Sevian & Gonsalves, 2008), but to date literature has rarely investigated undergraduate science education specifically and the skills that might comprise such a framework within this context.

Such a framework is certainly possible. For example, Mulder et al. (2008) demonstrated that common elements are likely to exist in the content of both undergraduate and postgraduate courses taught in a wide range of science communication programmes across various academic fields and countries. In an effort to more directly inform teaching practices, Bray et al. (2012) published a consensus among science communication experts as to what should be taught in a postgraduate science communication course at a university in New Zealand. The result of their study was a list of ‘essential elements’ for effective science communication within the postgraduate context. Such resources are useful in aiding curriculum development but may not always be directly transferrable to different educational contexts given differences in course content and complexity, program structure, or student demographics. The requirements for effective teaching of undergraduate science students, for example, might be expected to differ from those that would be suited best to postgraduate students of communication. Colthorpe, Rowland, and Leach (2013) have developed a Good Practice Guide for the Australian communication TLO to aid Australian academics in integrating communication skills into BSc courses. The guide provides practical, high-quality examples of activities and assessment items that target communication skills and have been successfully implemented in undergraduate science courses. These examples are, however, individual tasks. As such they provide limited insight into what specific skills should form the foundation of student activities and assessments to systematically develop core communication skills within and across courses in a science degree programme.

**Purpose of this Study**

The purpose of this study is to provide an evidence-based resource of core skills for effective communication of science with non-scientific audiences, which is appropriate to a general undergraduate science degree (e.g. BSc). We intend the resource to be used to inform the design of activities and assessment tasks which scaffold the development of communication abilities of science students. Thus our specific research questions are:

1. What elements or skills required for effective science communication are commonly cited across science, communication, education, and science communication literature?
Do expert practitioners across the fields of science, communication, education, and science communication agree that these commonly cited skills or elements reflect science communication practice? And how relevant and essential do experts deem these skills to be within undergraduate science education?

**Methods**

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

**Literature Critique**

A review was conducted of scholarly articles located using Web of Science, Scopus, and the Education Resources Reference Centre databases and various combinations of the search terms: ‘science’, ‘communication’, ‘science communication’, ‘education’, ‘core competencies’, ‘key concepts’, ‘essential elements’, ‘communication skills’, ‘tertiary education’, and ‘undergraduate’. A total of 99 articles from the fields of science, science communication, communication, and education were identified as potentially useful to this study, 19 of which contained information that was deemed specifically relevant given the context of (i) communication with non-scientific audiences and (ii) undergraduate science education. The 19 articles were then analysed to assess their reliability for inclusion in the literature critique according to the following factors: research method; sample size and type; type of analysis of results; and justification of interpretation. A comprehensive list of 17 key elements was compiled by recording any element (element being defined as a skill, consideration, principle, or competency) cited in one or more scholarly articles as being important to effective communication of science with non-scientific audiences.

The comprehensive list of 17 elements was distilled into a list of 10 key elements by relevance against the following criteria:

1. The number of scholarly citations—elements with five or more citations were included automatically, elements cited only once were excluded as not representing common themes in the literature, and elements with two to four citations were included or excluded using criteria 2 and 3;
2. Relevance to an undergraduate science education context—based on the Teaching and Learning Outcomes and standards for undergraduate science outlined by the Australian Learning and Teaching Council (Jones et al., 2011); and
3. Complexity—judged by what might be expected of undergraduate students within the modal Australian undergraduate science student demographic (described below).

Undergraduate demographics of Australian universities are relatively uniform with the majority of science students being Australian domestic students aged 17–25 years
Some elements were considered on an individual basis for inclusion or exclusion in the final list. The elements addressing mode and purpose of communication had only two and three citations, respectively but were included (despite having low citation rates) because both elements have been identified previously by the Australian Learning and Teaching Council (Jones et al., 2011) as integral to the communication skills taught in Australian science degrees. Likewise, ‘Use the tools of storytelling and narrative’ had only three citations but was included because it is acknowledged widely in more generic communication textbooks and guides as being an important part of effective communication (e.g. Fog, Budtz, Munch, & Blanchette, 2010; Ryan, 2004).

The complexity of the skills required to understand or deliver each element also was considered on an individual basis in refining the list of 17 key elements. For example, the element ‘Evaluate the adequacy of the communication’ was excluded because this is a process which requires a highly developed self-evaluative skill set that is largely specific to people specializing in communication. Specificity to science communication also was considered and elements such as ‘Use correct grammar, punctuation, and spelling’ and ‘Communicate organised ideas and concepts using clarity, accuracy, and logic’ were excluded because they are not specific to science communication, though they clearly are important to communication in general. ‘Consider aesthetic components to promote the visual appeal of the communication’ was excluded because it is a skill specific to particular modes of communication (e.g. web design) and is not applicable generically.

Survey of Expert Practitioners

A modified version of the Delphi method was used to consult expert practitioners about the applicability and essentiality of the key elements selected from the literature critique, within the context of teaching undergraduate science students how to communicate with non-scientific audiences. The Delphi method allows researchers to pose carefully designed questionnaires to a group of (ideally) 10–15 experts in a series of rounds, interspersed with summarised feedback, that allow a consensus to be generated (Bray et al., 2012; Murry & Hammons, 1995). The method was used here in a way that kept participants anonymous from each other so that answers were not influenced by the status and answers of co-participants (as per Bray et al., 2012). Two rounds of surveys were used in this study. The first allowed experts to rate and provide feedback on the initial list of key elements which was then applied to refine the list. The second was used to ensure a consensus was reached and to allow experts to rate the revised list of key elements.

The first round of survey involved presenting the list of 10 key elements resulting from the literature review online to 20 experts across Australia and New Zealand—five practitioners each from the fields of science, education, communication, and science communication. Experts were identified based on their practical and theoretical expertise in one of the above fields, being in the established stage of their career,
Table 1. Details of experts who participated in the survey round one and/or two as part of the Delphi method used to generate a consensus on the key elements of effective communication. The indicated fields of expertise are self-reported.

<table>
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<th>Education</th>
<th>Science communication</th>
<th>Communication</th>
<th>Other</th>
<th>Survey Participation</th>
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<th>Round two</th>
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</table>

Table 1. Details of experts who participated in the survey round one and/or two as part of the Delphi method used to generate a consensus on the key elements of effective communication. The indicated fields of expertise are self-reported.
and their familiarity with tertiary education. Fifteen out of the 20 invited experts responded to the survey (Table 1). The survey contained a mix of open answer, multiple choice, and Likert-scale questions (Appendix 1.1). Experts were asked to provide their view first (prior to presentation of the list of key elements) on what concepts are central to effective science communication in answer to the question: ‘In your opinion, what key elements are integral to educating undergraduate science students to communicate to non-scientific audiences?’. Experts thereafter were invited to:

- rate the applicability of the list as a whole (5-point Likert scale: 1—Not at all applicable to 5—Extremely applicable) within the context of teaching undergraduate science students to communicate with non-scientific audiences; and
- rate the essentiality of each element individually (7-point Likert scale: 1—Not at all essential to 7—Absolutely essential) within the same context.

All experts answered all Likert-scale questions. Further feedback from experts was invited with an open comment response question for both of the above ratings. All experts wrote responses in open comments in regard to the ‘applicability’ question, and 11 of the experts commented on the ‘essentiality’ question. Results from this survey were used to revise the list of key elements by reviewing summary statistics of the quantitative data and by highlighting the common themes that emerged in open responses using a simplified version of thematic analysis (Braun & Clarke, 2006).

The second round of the survey (Appendix 1.2) was issued 10 months after the first survey and resembled a simplified version of the first survey. Ten experts participated in this round (Table 1). All experts answered all Likert-scale questions and five experts provided comments. Results from this survey were used to ensure that a consensus had been reached and to rank the list of key elements from most to least essential within the context of teaching science undergraduates to communicate with non-scientific audiences. Final rankings discussed below result from the second round of survey as these are reflective of the final list of elements. Descriptive statistics for quantitative data were calculated using Microsoft Excel 2007.

Results

Developing a List of ‘Key Elements of Effective Science Communication’

The majority of the 99 articles in the literature review discussed the theoretical basis of science communication. There were no scholarly articles discussing the practicalities of implementing science communication education in undergraduate science degrees or other levels of Australian science training. Some did address various educational contexts in America and Europe, such as for undergraduate or postgraduate or professional training courses in science communication in America, Europe, and New
Zealand (e.g. Bray et al., 2012; Brownell et al., 2013a; Mayhew & Hall, 2012; Miller et al., 2009; Tuten & Temesvari, 2013; Whittington, Pellock, Cunningham, & Cox, 2014). One noteworthy article has also been published following the completion of our study which describes assessment in an Australian undergraduate science communication programme (McKinnon, Orthia, Grant, & Lmberts, 2014). Most methods used in the reviewed articles were qualitative rather than quantitative, relying primarily on the Delphi method, surveys, or interviews to gauge expert opinion, or literature reviews and critiques. Seventeen key elements of effective science communication were identified from the 19 relevant scholarly articles derived from the literature review. This comprehensive list of 17 elements (Table 2)

Table 2. The comprehensive list of 17 key elements derived from the literature critique in order from most to least scholarly articles in which each element was cited, with an indication of whether the element was included in the distilled list of 10 elements presented to experts in the Delphi method survey

<table>
<thead>
<tr>
<th>Element of effective science communication</th>
<th>Number of articles cited</th>
<th>Included in the list of 10 elements</th>
</tr>
</thead>
<tbody>
<tr>
<td>Identify/consider a suitable target audience</td>
<td>13</td>
<td>Yes</td>
</tr>
<tr>
<td>Use language that is appropriate for the target audience—for example, consider what jargon to use or explain</td>
<td>8</td>
<td>Yes</td>
</tr>
<tr>
<td>Consider the social, political, and cultural context of the communication</td>
<td>7</td>
<td>Yes</td>
</tr>
<tr>
<td>Use style elements such as humour, anecdotes, metaphors, imagery, etc.</td>
<td>7</td>
<td>Yes</td>
</tr>
<tr>
<td>Use (factual) content that is appropriate, interesting, and relevant to the target audience</td>
<td>6</td>
<td>Yes</td>
</tr>
<tr>
<td>Promote audience engagement with the scientific content</td>
<td>5</td>
<td>Yes</td>
</tr>
<tr>
<td>Consider the levels of prior knowledge in your target audience</td>
<td>5</td>
<td>Yes</td>
</tr>
<tr>
<td>Communicate organised ideas and concepts using clarity, accuracy, and logic</td>
<td>4</td>
<td>No</td>
</tr>
<tr>
<td>Use the tools of storytelling to create a coherent narrative</td>
<td>3</td>
<td>Yes</td>
</tr>
<tr>
<td>Identify the purpose/goal/objective of the communication</td>
<td>3</td>
<td>Yes</td>
</tr>
<tr>
<td>Consider aesthetic components to promote the visual appeal of the communication</td>
<td>3</td>
<td>No</td>
</tr>
<tr>
<td>Use a suitable mode of communication</td>
<td>2</td>
<td>Yes</td>
</tr>
<tr>
<td>Present the information within a relatable context</td>
<td>2</td>
<td>Yes</td>
</tr>
<tr>
<td>Use correct grammar, punctuation, and spelling</td>
<td>1</td>
<td>No</td>
</tr>
<tr>
<td>Use a suitable platform for dissemination</td>
<td>1</td>
<td>No</td>
</tr>
<tr>
<td>Consideration of potential misconceptions as a result of the communication</td>
<td>1</td>
<td>No</td>
</tr>
<tr>
<td>Evaluate the adequacy of the communication</td>
<td>1</td>
<td>No</td>
</tr>
</tbody>
</table>
was distilled to a draft list of 10 elements (Table 2) against the stated assessment criteria.

**Survey of Expert Practitioners**

*Round One.* Experts rated the draft list of 10 key elements (as a whole) in the first survey as ‘Extremely applicable’ (average of 4.8 out of 5 on a 5-point Likert scale: 1—Not at all applicable to 5—Extremely applicable) within the context of teaching undergraduate science students to communicate with non-scientific audiences. All individual elements were rated as either highly or absolutely essential within the same context (averages 5.87–6.80 out of 7 on a 7-point Likert scale: 1—Not at all essential to 7—Absolutely essential; Table 3). Open responses to the question ‘... what key elements are integral to educating undergraduate science students to communicate to non-scientific audiences?’ (Q4, Appendix 1), asked prior to being presented with the list of key elements, generally aligned with or reflected the list of 10 key elements. Incorporating feedback from the open responses resulted in the draft list of elements being edited and expanded from 10 to 12 elements (Table 3). The addition of two new elements arose because common themes (dialogue and science communication theory) in open response answers highlighted that these skills or elements also were essential in effective science communication but were missing from the draft list. Typical comments included:

The above list, as rightly pointed out, covers all the areas essential to science communication training.

The elements above are certainly important as part of teaching science students how to present on science to non-expert audiences. However, the list is not complete as there is no reference to engaging with the audience, hearing their understandings, responding to their questions, etc.

It depends for what purpose, but I personally don’t like to teach practical skills without a deeper exploration of the theory and history of science communication, so that students know why they’re doing what they’re doing.

Communication includes listening—so it is not ‘communicating to’, when you mean ‘presenting to’. It is ‘communicating with’.

*Round two.* Ten of the original 15 experts participated in round two. All experts responding to the second survey rated the list of 12 key elements (as a whole) as ‘Extremely applicable’ (average of 5.0 out of 5 on a 5-point Likert scale: 1—Not at all applicable to 5—Extremely applicable) within the context of teaching undergraduate students to communicate with non-scientific audiences. All individual elements were rated as either mostly, highly, or absolutely essential within the same context (averages 4.60—6.90 out of 7 on a 7-point Likert scale: 1—Not at all essential to 7—Absolutely essential; Table 3). The ranking of elements from most to least essential changed considerably for some elements between rounds one and two of the surveys. Some changes in rank might be expected because of the
increased number of elements being ranked from 10 elements in round one to 12 in round two, but changes in rank of more than two would signal some change beyond that simply attributable to insertion of an extra two ranks. ‘Audience’ (reference

Table 3. The final list of 12 core skills for effective science communication with rankings and average ratings of essentiality given by experts (based on a seven-point Likert scale ranging from 1 as ‘Not at all essential’ to 7 as ‘Absolutely essential’). Skills are referenced by the listed ‘reference words’ for brevity in other sections of this paper. Skills without a ranking or rating (NA) were added following round one of the surveys as a result of expert feedback

<table>
<thead>
<tr>
<th>Core skills for effective science communication</th>
<th>Reference words</th>
<th>Survey results: round one</th>
<th>Survey results: round two</th>
</tr>
</thead>
<tbody>
<tr>
<td>Identify and understand a suitable target audience</td>
<td>Audience</td>
<td>5/6 6.27</td>
<td>1 6.90</td>
</tr>
<tr>
<td>Use language that is appropriate for your target audience</td>
<td>Language</td>
<td>1 6.80</td>
<td>2 6.80</td>
</tr>
<tr>
<td>Identify the purpose and intended outcome of the communication</td>
<td>Purpose</td>
<td>2 6.53</td>
<td>3 6.70</td>
</tr>
<tr>
<td>Consider the levels of prior knowledge in the target audience</td>
<td>Prior knowledge</td>
<td>4 6.33</td>
<td>4 6.60</td>
</tr>
<tr>
<td>Separate essential from non-essential factual content in a context that is relevant to the target audience</td>
<td>Content</td>
<td>10 5.87</td>
<td>5/6 6.50</td>
</tr>
<tr>
<td>Use a suitable mode and platform to communicate with the target audience</td>
<td>Mode</td>
<td>5/6 6.27</td>
<td>5/6 6.50</td>
</tr>
<tr>
<td>Consider the social, political, and cultural context of the scientific information</td>
<td>Context</td>
<td>8 6.07</td>
<td>7/8 6.30</td>
</tr>
<tr>
<td>Use/consider style elements appropriate for the mode of communication (such as humour, anecdotes, analogy, metaphors, rhetoric, images, body language, eye contact, and diagrams)</td>
<td>Style</td>
<td>9 6.00</td>
<td>7/8 6.30</td>
</tr>
<tr>
<td>Understand the underlying theories leading to the development of science communication and why it is important</td>
<td>Theory</td>
<td>NA NA</td>
<td>9 5.70</td>
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<tr>
<td>Promote audience engagement with the science</td>
<td>Engagement</td>
<td>3 6.47</td>
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<td>Use the tools of storytelling and narrative</td>
<td>Narrative</td>
<td>7 6.13</td>
<td>11 5.30</td>
</tr>
<tr>
<td>Encourage a two-way dialogue with the audience</td>
<td>Dialogue</td>
<td>NA NA</td>
<td>12 4.60</td>
</tr>
</tbody>
</table>
words in Table 3), for example, was ranked fifth in round one but first (most essential) in round two. Elements addressing ‘Language’ and ‘Purpose’ remained in the top three most essential elements. Other changes included ‘Content’ moving from 10th in round one to 5th in round two, ‘Engagement’ dropping from 3rd to 10th, and ‘Narrative’ dropping from 7th to 11th. All rankings (with mean ratings) are shown in Table 3.

Discussion

The literature critique revealed that there are communication skills or elements cited commonly that align across the fields of science, communication, education, and science communication. There has been thorough discussion and research across the literature on the theoretical basis for ‘best practice’ in modern science communication. A predominant theme among this discussion focussed on the redefinition of science communication as an ‘exchange (negotiation) of knowledge between scientists and the lay public in order to achieve a reciprocal understanding’ (van der Sanden & Meijman, 2008, p. 90). There are few studies, however, that articulate clear recommendations for, or examples of, how to apply this theory to train people in best practice science communication, especially during undergraduate science education. Miller et al. (2009) outlined and tested a curriculum for training professional scientists in reflexive public engagement (which comprised many generic communication skills) and Bray et al. (2012) conducted a study which negotiated a consensus among experts as to which essential elements should be taught in a postgraduate science communication course in New Zealand. There also are many optional science communication courses which provide useful examples of training targeted at professional scientists, such as the American Association for the Advancement of Science (AAAS, 2014) online module on communicating with the public or the European Commission’s survival kit for science communication (Carrada, 2006). These optional courses tend to be self-selecting in attracting scientists who actively seek out communication opportunities (Brownell et al., 2013a), rather than providing fundamental education to the broad range of scientists in the context of their tertiary studies.

The decision to present the final list as ‘Core Skills for Effective Science Communication’ rather than as ‘Key Elements’ (as they were presented to experts) was made in an effort to increase the practicality and accessibility of the list as a teaching resource for higher education. Framing the list as ‘skills’ rather than ‘elements’ aligns more closely with the movement in higher education towards teaching generic skills, and may be more relatable to science teaching academics than the previous (more abstract) framing as elements. It is important to note that ‘Elements’ and ‘Skills’ are terms used interchangeably within the literature reviewed and so the change in title does not misrepresent the contents of the final list. It is worthwhile noting here that many of these skills reflect or underpin the skills required for communication of science with scientific audiences as well as non-scientific audiences. As such, the list of core skills may resonate with science academics teaching scientific communication skills also.
There is strong alignment of the core skills presented in this study with comparable resources for international, postgraduate, and professional science communicators. This alignment suggests that this resource is likely to be applicable outside of an Australian undergraduate context, though further research would be required to explore the relevance and transferability of an Australian resource for application in other contexts. The emphasis on audience highlighted in the study by Bray et al. (2012) found that ‘the audience comes first in any interaction and this focus is non-negotiable’ which aligns with the findings of this study: the ability to identify and understand a target audience was ranked as the most essential science communication skill by experts (in round two) and was cited as important most commonly in the academic literature. Other similarities include acknowledgement of audience engagement; awareness of the social, political, and cultural context; the tools of storytelling; purpose of communication; and knowledge of science communication theories. What distinguished the two lists was the level of sophistication in the skills taught. Bray et al. (2012) took into account respect of the audience, fostering of trust between audience and communicator, and highly specific outcomes of communication, all of which are important in professional application but require a much more developed communicative skillset than can be expected within an undergraduate context. The high degree of agreement between our results and those of Bray et al. (2012), however, does suggest that adopting common recommendations across multiple levels of tertiary science education and certain international contexts may be possible.

The difference in the rankings of skills by experts between survey rounds is a point worthy of discussion. The jump of ‘Audience’ from fifth in round one to first in round two may be a result of the change in wording of that skill. The skill was presented in the first survey as ‘Identify a suitable target audience’ (Table 2) but was changed in the second survey, as a result of expert feedback, to ‘Identify and understand a suitable target audience’ (Table 3). The change in essentiality rating here may indicate that experts see the understanding of audience (rather than simply the identification) as key to the science communication process. The ranking of this skill as most essential aligns more closely with the results from the literature review as audience was cited most frequently in scholarly articles as important for effective science communication (Table 2). These findings also lend support to the idea that the ability to identify and understand an audience is a threshold concept in science communication (Pope-Ruark, 2011).

The ability to ‘Use language that is appropriate for your target audience’ was ranked consistently in the top two most essential skills in both surveys which is consistent with the literature in that it was the second most frequently cited skill in scholarly articles. The fact that these two core skills have stood out as being the most central to effective science communication as well as being most relevant to teaching science students how to communicate with non-scientific audiences holds important implications for curriculum development. It will be likely that lecturers of undergraduate science will not have the time or resources to teach all 12 skills in the context of a course with primary focus on science per se and so a prioritisation of skills must occur. Academics therefore can be confident that by teaching the two skills addressing audience and language, at a minimum, they are introducing the
most essential aspects of science communication skills to students. Examples of science tasks which focus on these skills can be found among (but are not restricted to) the following scholarly teaching articles: McKinnon et al. (2014); Sharpe and Blanchfield (2014); Kuchel, Stevens, Wilson, and Cockley (2014); and Mercer-Mapstone and Kuchel (accepted). The essentiality rankings (Table 3) also may be used more generally to guide prioritisation of skills during curriculum development.

It was perhaps surprising that the skill addressing audience ‘Engagement’ dropped from 3rd to 10th and the skill addressing ‘Dialogue’ was last in essentiality ratings in round two. These skills both directly contribute to the modern aspirational notion of science communication as a two-way interaction in the process of sharing information and perspectives, and represent the recent shift in science communication theory from focussing on public understanding of science to public engagement with science (Besley & Tanner, 2011). The most likely explanation for this change of rank is the ambiguity around the word ‘engagement’ and an unintentionally implied deficit model of communication in the initial phrasing of this skill; ‘Present scientific information in an engaging context’ (Table 2). In a deficit model of science communication the term ‘engagement’ tends to imply transfer of information in a way that encourages people to like science, whereas a more modern approach encourages promotion of the ‘act of communication’ and involves the sharing of information and the possibility to question science. The modern approach is better reflected in the revised wording of the skill ‘promote audience engagement with the science’ (Table 3). The literature on audience engagement is complex and the change in wording also might have resulted in the drop in rankings because it was then seen as too complex for the context of undergraduate science education. The lower ratings for ‘Dialogue’ also could be a reflection of some experts’ comments questioning the difficulties of teaching such a skill in a science course at an undergraduate level. It is most likely that upon graduation, science undergraduates would be involved in one-way or asymmetrical two-way communication rather than true dialogue about science, and that during their undergraduate education they are still developing their own views of science. As such it may be that dialogue is more appropriately embedded in a postgraduate science education, advanced undergraduate courses or activities, or in programmes aimed at educating professional communicators—the graduates of which are more likely to engage in true dialogue approaches and need to consider differing values and views of science. Engaging audiences in a dialogue about the nature or process of science is a specialist skill to teach and learn which may be better placed beyond the undergraduate curriculum.

Some experts also raised questions around the efficacy of teaching these skills in science courses over ‘arts-type subjects for science students’, as well as questions about the ability of science academics to teach such skills. Much debate exists over where to teach communication skills in sciences degrees: whether it should be with the addition of a dedicated course, or integrated into existing courses. There are advantages and disadvantages for both approaches. A whole course (or unit) approach has been taken in some Australian universities with great success (e.g. Monash University and the Australian National University). Concerns are raised often, however,
that such ‘non-science’ courses detract from the time available to teach core discipline-specific science courses in already over-crowded science degree programmes. In contrast, integrating communication skills into existing courses can mean communication is taught in a discipline-specific context that is relevant to the student. Integration into multiple courses across a programme can also allow for multiple opportunities to practice and develop skills over time which has been shown to be key in developing complex learning outcomes such as communication (Divan & Mason, 2015; Knight, 2001; Lauer & Hendrix, 2009). This ‘integration’ approach, however, can lead to the under-emphasis of communication skills given the amount of other content already existing in the course. This does appear to be the case currently, given research that shows inclusion of these core communication skills in undergraduate science courses is rare at best, and in general, the skills are not taught explicitly or in a scaffolded manner (Mercer-Mapstone & Kuchel, 2015). Further research to explore which approach might best facilitate the development of communication skills in the BSc would benefit this discussion.

Educators interested in examples of good practice for implementing tasks and assessments that scaffold the development of skills identified in this study may find the following resources useful: the special edition of the *International Journal for Innovation in Science Education* focussed on communication (Volume 22, issues 4 and 5) including scholarly examples of learning activities and teaching design implemented predominantly by science practitioners; the good practice guide for the Australian TLOs of communication (TLO4) by Colthorpe et al. (2013); and exemplars associated with the Writing Across the Curriculum (WAC, e.g. http://wac.colostate.edu/intro/) and Writing In the Disciplines (WID, e.g. http://writingcenter.utk.edu/for-students/writinginthedisciplines/) movements which are popular in the USA and UK. A particularly practical resource for instructors is the book ‘Learning Together: Keeping Teachers and students actively involved in learning by writing across the discipline. A sourcebook of ideas and writing exercises’ by Theodore Panitz (2001).

**Conclusion and Future Research**

One limitation of this study that warrants further research was that the literature critique was comprehensive across science communication, communication, and science but could have been improved by including more articles from education research in order to access some of the pedagogical nuances relevant to undergraduate education more broadly. Similarly, future inclusion of non-scholarly resources would be beneficial because science communication teaching practices often are established better in professional training courses outside of scholarly institutions and may offer more practical examples of effective education techniques.

This research found that there are common theoretically derived elements for effective science communication across the fields of science, communication, education, and science communication. These elements aligned closely with the skills highlighted by expert practitioners from each of those fields as important for successful science
communication. The list of skills we have presented here was validated by experts as extremely applicable and essential within the practical context of teaching communication with non-scientific audiences within undergraduate science degrees. This evidence-based resource, reflecting theory and practice, provides a useful teaching resource for curriculum development. The alignment of the skills in this resource with other science communication education resources designed for international postgraduate and professional contexts further supports its relevance and indicates that such resources do have a degree of transferability. It might be inferred, therefore, that this resource may be applicable to other international and educational contexts. It would be worthwhile for future research to expand this list into a framework that considered scientific audiences as well. Focus might also be given to developing teaching and learning activities and assessment tasks that specifically scaffold the integration of these skills into existing science curricula. Effective dissemination of such resources is key to adoption and emphasis should be given to research that addresses this to facilitate uptake of such evidence-based resources in science higher education.

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References


Appendix 1

1.1 Survey for experts: Delphi method round 1

Questions for survey of experts, distributed using the online survey tool ‘Survey Monkey’ (https://www.surveymonkey.com)

(1) Please state your name.

(2) Please indicate if you give consent to your name being included in a list of people/experts consulted in any publications arising from this study. (Multiple Choice Question)
   - I am happy to be acknowledged.
   - Please keep my identity anonymous.

(3) Which of the following do you consider your primary field of expertise? (You can select more than one) (Multiple Choice Question)
   - Science
   - Communication
   - Science communication
   - Education
   - Other (please comment)

(4) In your opinion, what key elements are integral to educating undergraduate science students to communicate to non-scientific audiences?

(5) Please consider the following list of key elements of effective science communication. This suggested list was designed as a possible guide in teaching undergraduate science students to communicate to non-scientific audiences:

Core skills for effective science communication
Key elements of effective science communication

- Identify a suitable target audience
- Use language that is appropriate for your target audience
- Include factual content that is relevant to the target audience’s understanding of the science
- Consider the social, political, and cultural context of the science being communicated
- Present the scientific information in an engaging context
- Use style elements such as humour, anecdotes, metaphors, and imagery
- Consider the levels of prior knowledge in the target audience
- Use the tools of storytelling and narrative
- Identify the purpose and intended outcome of the communication
- Use a suitable mode and platform to communicate

How applicable do you think this list is for teaching undergraduate science students to communicate to non-scientific audiences? (Likert Scale)

1—Not at all applicable
2—Rarely applicable
3—Neutral
4—Somewhat applicable
5—Extremely applicable

(6) Please provide reasons for your above answer if you wish.
(7) Please rate how essential each element from the above list is within the context of educating undergraduate science students to communicate to non-scientific audiences. (Likert scale)

Each element rated on the following Likert scale:
1—Not at all essential
2—Rarely essential
3—Sometimes essential
4—Neutral
5—Mostly essential
6—Highly essential
7—Absolutely essential

(8) Please provide reasons for your above answer if you wish.
(9) To help inform the teaching of undergraduate science students, what changes would you recommend to be made to the list of key elements?

1.2 Survey for experts: Delphi method round 2
Questions for survey of experts, distributed using the online survey tool ‘Survey Monkey’ (https://www.surveymonkey.com)

(1) Please state your name.
(2) Please indicate if you give consent to your name being included in a list of people/experts consulted in any publications arising from this study. (Multiple Choice Question)
I am happy to be acknowledged.
Please keep my identity anonymous.

(3) Please consider the following list of key elements of effective science communication. This suggested list was designed as a possible guide in teaching undergraduate science students to communicate to non-scientific audiences:

Key Elements of Effective Science Communication

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

How applicable do you think this list is for teaching undergraduate science students to communicate to non-scientific audiences? (Likert scale)

1—Not at all applicable
2—Rarely applicable
3—Neutral
4—Somewhat applicable
5—Extremely applicable

(4) Please rate how essential each element from the above list is within the context of educating undergraduate science students to communicate to non-scientific audiences.

Each element rated on the following Likert scale:

1—Not at all essential
2—Rarely essential
3—Sometimes essential
4—Neutral
5—Mostly essential
6—Highly essential
7—Absolutely essential