THE CHALLENGE OF EVALUATING STUDENTS' SCIENTIFIC LITERACY IN A WRITING-TO-LEARN CONTEXT

Abstract

This paper reports on the challenge of evaluating students' scientific literacy in a writing-to-learn context, as illustrated by our experience with an online science-writing project. In this mixed-methods study, Year 9 students in a case study class (13-14 year olds, n = 26) authored a series of two 'hybridised' short stories that merged scientific and narratives genres about the socioscientific issue of biosecurity. In seeking to measure the efficacy of the intervention, we sought evidence of students' conceptual understanding communicated through their stories. Finding a suitable instrument presented our first challenge. This led to the development of scoring matrices to evaluate students' derived sense of scientific literacy. Student interviews were also conducted to explore their understanding of concepts related to the biosecurity context. While the results of these analyses showed significant improvements in students' understanding arising from their participation in the writing tasks, the interviews highlighted a second challenge in evaluating students' scientific literacy; a disparity between their written and vocalised understandings. The majority of students expressed a deeper level of conceptual understanding at interview than they did in their stories. The interviews also revealed alternative conceptions and instances of superficial understanding that weren't expressed in their writing. Aside from the methodological challenge of analysing stories quantitatively, these findings suggest that in a writing-to-learn context, evaluating students' scientific literacy can be difficult. An examination of these artefacts in combination with interviews about students' written work provided a more comprehensive evaluation of their developing scientific literacy. The implications of this study for our understanding of the derived sense of scientific literacy, as well as implications for classroom practice, are also discussed.

Introduction

The development of scientific literacy remains a key priority of science education in schools (Sadler, 2004; Tytler, 2007). At the same time, researchers continue to call for innovative curricula and pedagogical approaches that address concerns about students' negative attitudes toward school science, and declining participation in post-compulsory science studies (Hackling, Goodrum, & Rennie, 2001; Lyons & Quinn, 2010; Tytler, 2007). As one way of addressing these issues, we have been engaged in a program of research that has investigated the learning potential of a writing-to-learn science strategy with the intention of developing students' scientific literacy and engaging them positively in the learning of science. These research projects have provided students at schools in different cities in Queensland, Australia, with the opportunity to write and share 'hybridised' narratives (i.e., short stories that integrate scientific information, which we call '*BioStories*') about the socioscientific issue of biosecurity. While detailed analyses of the cognitive and affective outcomes arising from this research have been reported previously (see Ritchie, Tomas, & Tones, 2010; Tomas, Ritchie, & Tones, 2011; Tomas, 2012; Tomas & Ritchie, 2012), in this paper, we focus specifically on the challenges that we encountered in seeking to evaluate students' scientific literacy, as evidenced by the BioStories written by Year 9 students. In doing so, we present the findings of our evaluation as they pertain to the development of students' derived sense of scientific literacy through their participation in the study.

Writing for Scientific Literacy

There are many conceptions of scientific literacy presented within the literature (see Laugksch, 2000). As well as the mastery of science content, a number of themes may be identified as common to most definitions: nurturing and promoting students' orientation and disposition towards science; encouraging the ability to understand and apply scientific ideas; and educating for future citizens, as opposed to disciplinary experts (Millar & Osborne, 1998; Tytler, 2007).

In his extensive review of scientific literacy and its role in science education, Roberts (2007) highlights two potentially divergent visions of scientific literacy that have very different implications for curriculum planning and assessment. Vision I is focused on the importance of science subject matter; that is, scientific literacy as viewed from a scientists' perspective. Vision II acknowledges the ways in which science plays a role in human affairs – a socioscientific view of scientific literacy. Roberts argues that over-emphasising either Vision I or II in any science curriculum is problematic. Vision I would have students view the world through the eyes of a scientist, which risks narrowing 'the student's experience with the breadth of science as a human endeavour' (Roberts, 2007, p. 767). At the same time, while there may be an implicit assumption that teaching students scientific knowledge and methods of inquiry will result in the socially responsible use of science, or a citizenry that will involve themselves in scientific discussions and debates, Vision II programs may not focus sufficiently on scientific content (Eisenhart, Finkel, & Marion, 1996; Roberts, 2007).

Notwithstanding the value of Roberts's (2007) categories of scientific literacy, the role of communication – specifically, reading, writing and, of course, language – remains fundamental to science and scientific literacy (Yore, Bisanz, & Hand, 2003). While traditional views of the role of writing in the classroom privilege the mastery of scientific discourse and the communication of science knowledge (e.g. Langer & Applebee, 1987; Wallace, 1996), Glynn and Muth (1994) assert that '… the importance of being able to understand and explain – *in clear language* – the meaning of fundamental science concepts is central to scientific literacy' (p. 1058, emphasis added). This view aligns with broader notions of scientific literacy that require students to practise writing about science for non-expert readerships; a view of scientific literacy that '… emphasises the centrality of communication skills and a commitment to informed and accessible contributions to public debate of the uses of science' (Hand, Prain, Lawrence, & Yore, 1999, p. 1023).

In their exploration of scientific literacy, Norris and Phillips (2003) make a distinction between a fundamental sense of scientific literacy (reading and writing science content), and a derived sense (being knowledgeable, learned and educated in science). A distinction also has been made between a simple sense of fundamental scientific literacy that refers to the ability to successfully decode texts, and an expanded sense that involves being able to infer meaning from texts (Norris & Phillips, 1994, 2003). They claim that while coming to know science requires competency in both the derived and fundamental senses of scientific literacy, notions of scientific literacy tend to privilege the former.

There is growing recognition amongst educators that there is value in writing to learn science, beyond the traditional scientific genres taught in schools (Prain, 2006; see also Tomas, 2012). In our program of research, we have explored the use of BioStories as a diversified writing-to-learn science strategy that centralises the role of communication through particular consideration of content, context, code and representation (Kulgemeyer & Schecker, 2013): students write hybridised scientific narratives (representation) that communicate their conceptual understandings (content) related to the socioscientific issue of biosecurity (context) using clear, everyday language and appropriate vocabulary (code). In a series of multi-method studies conducted with Year 6, Year 9 and Year 12 students, it was reported that writing a sequence of BioStories enhanced students' familiarity with biosecurity issues and helped them to develop a deeper understanding of related biological concepts (Ritchie, Tomas, & Tones, 2010); significantly improved their attitudes toward science and science learning (Tomas, Ritchie, & Tones, 2011), and elicited positive emotional responses in science classes (Tomas & Ritchie, 2012). In this paper, we report on the investigation into students' developing scientific literacy, and in doing so, explore the challenges that we encountered in this context.

The Challenges of Assessing Broader Notions of Scientific Literacy

Orpwood (2007) asserts that, for the past 35 years, notions of scientific literacy have grown richer and more profound; however, such notions are under threat due to a lack of creativity on the part of researchers to develop new approaches to assessing scientific literacy. He argues that 'politically high-profile assessments' such as TIMSS (Trends in International Mathematics and Science Study) and PISA (Programme for International Student Assessment) encourage 'teaching to the test' (p. 2). At the same time, the development of a scientifically literate citizenry that is able to make informed personal and social decisions about contemporary socioscientific issues that '… go well beyond the science that underpins TIMSS or PISA' (Fensham, 2013, p. 28) requires diverse, authentic and creative assessment techniques that meet the broadening intentions of science education (Fensham & Rennie, 2013).

Roberts (2007) claims that it is difficult to assess fairly notions of scientific literacy according to Vision II, as students' own experiences and personal contexts are unique. This, and the fact that Vision II does not emphasise formal knowledge structures, is problematic for international, national and school-based assessment alike that seeks to capture a broader notion of scientific literacy. The need for accountability by governments and schools often means that assessment is driven and constrained by specific indicators and numeric scoring at the expense of high-order learning outcomes (Tytler, 2007; Fensham & Bellocchi, 2013).

A misalignment also exists between the goals of scientific literacy and the way in which success in science learning has been traditionally defined and assessed at school. Rather than examining how students use and produce science knowledge to respond to a need or concern pertinent to their individual or community's future, 'success [in school science] takes the form of a predetermined response to a cooked-up problem, an abstract set of ideals, predicated upon an imposed ideology' (Roth & Barton, 2004, p. 8).

Unlike many pencil and paper tests, the PISA Science project overcame this problem by adopting real world contexts involving science and technology in their assessment of scientific literacy (Fensham, 2009, 2013). PISA Science emphasises process- rather than content-focused competencies by assessing 'student practices in situations offered in the lived experiences of everyday people' (Sadler & Zeidler, 2009, p. 911). In doing so, it clearly privileges a Vision II orientation. Although real world contexts are rarely 'purely scientific … their inclusion of non-scientific aspects—social, aesthetic, economic, and ethical' (Fensham, 2009, p. 893) can offer a more balanced approach to the teaching of science while engaging students' interest. While PISA Science is not a curriculum, it highlights the value of real world science and technology contexts in assessing broader notions of scientific literacy.

Research Problem

Implementing a diversified writing-to-learn strategy like BioStories with a view to develop students' scientific literacy raises the question as to whether this goal has been met, and calls for the employment of appropriate evaluative techniques. In the context of this study, the following questions arose: to what extent is students' scientific literacy developed through the writing of BioStories, and how can students' scientific literacy be evaluated effectively in this writing-to-learn science context?

This study explored students' conceptual science understandings (a derived sense of scientific literacy), framed within a view of scientific literacy as citizenship preparation that draws upon Visions I and II (Roberts, 2007). Through their participation in the BioStories project, students' learning was contextualised within a socioscientific issue (cf. Vision II); however, the development of conceptual science understandings (cf. Vision I) was also prioritised. In-keeping with this view of scientific literacy as citizen preparation, students engaged with conceptual science understandings at a level that was appropriate in the context of everyday conversations about science. That is, they were required to communicate their understandings about biosecurity in clear language, as suggested by Glenn and Muth (1994), through their hybridised narratives.

Setting and Procedures for Inquiry

The students in this case study, a single, coeducational Year 9 class (13-14 year-olds), wrote a series of two BioStories over a 5-week period. A highly regarded and experienced science teacher at the school, who was their regular classroom teacher, taught the class.

The writing tasks presented students with two unfinished stories that they were required to complete (Appendix A). The genre was 'hybridised' as students integrated information about a socioscientific issue within narrative storylines. The following excerpt from a student's story illustrates this merging of genres:

> *"Well," Steve continued energetically, "fire ants, also known as* Solenopsis invicta*, are native to South America. This nasty ant is an invasive pest in many parts of the world, including Australia. It can affect our environment and lifestyle, and even our agricultural production," he explained.*

"How on earth did fire ants enter Australia in the first place?" Jennifer asked.

"Good question, mate. They were discovered in Brisbane in 2001. It's believed they arrived here in contaminated soil carried by shipping containers. It reminds us why quarantine is so important".

Jennifer was very interested to learn this. "Wow! I didn't realise quarantine had to watch for something so small like foreign ants as well! How can they be identified?"

"It's important to keep an eye out for these little fellas. They range from 2-6mm in length. They are brown in colour, with their abdomen being slightly darker. They are very aggressive and inflict a nasty, burning sting, which can cause an allergic reaction – hence their name, fire ants".

Part A introduced students to two key characters, the late Australian environmentalist, Steve Irwin, and a young girl by the name of Jennifer, who meet at airport customs. The story called for students to write about one of five biological incursions (chytrid fungus, citrus canker, silverleaf whitefly, tilapia and fire ants) that had affected Australian natural and/or agricultural ecosystems. In doing so, they were required to write about the environmental, social and economic impacts of their chosen incursion.

The Part B scenario was about an incursion that had not been found in Australia for almost 20 years, avian influenza (or 'bird flu'). In this case, students wrote about the potential implications for Australia's agricultural industry and the wider community if it were to break through quarantine barriers.

Students wrote their stories with the support of a dedicated website, and uploaded them there so they could be read by their peers online. The website contained all necessary resources, including links to online resources about biosecurity, story templates and task instructions that guided students' composition of stories.

The BioStories tasks were embedded in an existing 7-week ecology unit within the Year 9 science curriculum that examined concepts of food chains, food webs, adaptations and evolution. The writing tasks supplemented the work in the unit; that is, no explicit teaching of related science concepts was afforded, with the exception of the term 'biosecurity' when the tasks were introduced. The teacher's role was limited to introducing the writing tasks and explaining the requirements, assisting students with their research, and reviewing and editing their written drafts. In this way, learning was largely student-centred and driven. The teacher engaged in discussions about particular science concepts with individuals or small groups of students when the need arose; for example, when students asked a question about new information they had researched.

This study adopted a mixed methods design (Erzberger & Kelle, 2003) in which both qualitative and quantitative data were generated to develop a deeper understanding of the students' developing scientific literacy. Given that this study extended our previous qualitative treatment of students' conceptual understanding of a writing-to-learn science project (see Ritchie, Tomas & Tones, 2010), we were interested in developing a data source that facilitated quantitative analysis of students' BioStories as a way of measuring the efficacy of the intervention. We sought to triangulate these data through qualitative analysis of semi-structured interviews that probed students' understanding. In the following subsections, we describe these data sources in more detail.

Exploring the Development of a Quantitative Data Source

Inferences about the development of the students' scientific literacy were drawn from the extent to which their written artefacts demonstrated their understanding of concepts related to the biosecurity context. We wondered how students' BioStories could be assessed for evidence of their developing scientific literacy. We were interested in quantifying students' conceptual understandings so they could be analysed for any statistically significant changes. We focussed on concepts related to biosecurity that were clearly communicated in the context of everyday conversations about science through the characters in the stories. Therein lay our first key challenge: finding an instrument that quantified students' written understandings expressed in their stories.

With the exception of standardised paper and pencil tests, a review of the literature revealed few working examples of quantifying and making judgments about students' developing scientific literacy (see Laugksch, 2000). In particular, there was a paucity of frameworks or instruments specifically designed to scrutinise students' written artefacts in writing-to-learn science contexts. Initially, Bybee's (1997) five dimensions of scientific literacy (i.e. scientific illiteracy, nominal scientific literacy, functional scientific literacy, conceptual scientific literacy, and multidimensional scientific literacy) were explored and trialled as a framework for making judgements about the students' demonstrated scientific literacy.

The framework was applied to a sample of BioStories written by Year 6 students in an earlier case study (Ritchie, Rigano, & Duane, 2008). The stories were scrutinised qualitatively for instances where scientific ideas or related concepts were communicated. Preliminary results found that all 77 stories analysed generally presented correct scientific descriptions of ideas or concepts, demonstrating an overall functional level of scientific literacy (Bybee, 1997). This indicated that the framework was not nuanced enough to identify variations in students' developing scientific literacy. Importantly, the framework did not enable us to assess how well the students wrote about issues relating to biosecurity in the context of their stories. With this in mind, matrices were developed that specifically assess how well students addressed the BioStories task requirements. As the requirements for Parts A and B differed, a separate matrix was developed for each task (Appendix B, C).

The preliminary trial analysis using Bybee's (1997) framework revealed three general trends in the ways in which the stories incorporated information about biosecurity. Firstly, some stories did not include any of the required information specified in the task. Secondly, the majority of the stories attempted to include most of the information required, with some inaccuracies or alternative conceptions evident. Thirdly, some stories met the task requirements fully, completely and accurately. For example, Part A called for an explanation of how the chosen biological incursion entered Australia. The students' BioStories would either: (a) not explain how the incursion entered Australia at all; (b) incorrectly explain how the incursion entered the country; or (c) correctly explain how the incursion entered Australia. For this reason, the criteria within the matrices were assigned a score of 0, 1 or 2, depending on whether the student addressed them, and how well they did so (i.e. 0 for no attempt; 1 for an incomplete or incorrect attempt; and 2 if the criteria were addressed completely and accurately). It was not deemed necessary to differentiate between incomplete and incorrect responses as we adopted the position that a student's demonstrated understanding of a particular concept was no better or worse if they wrote an incomplete explanation, compared to one that was not fully correct.

The matrices for Parts A and B produce a *derived scientific literacy score* that reflects the scope and accuracy of the conceptual information presented in the students' stories. In order to facilitate comparisons of students' derived scientific literacy scores across the two tasks, they were converted to a percentage of the highest possible score attainable for each part (i.e. a maximum of two marks per criterion). An interpretation of the derived scientific literacy score is presented in Table 1.

Table 1
An interpretation of the derived scientific literacy score as applied to Parts A and B of students' BioStories

Derived scientific literacy score	Interpretation
0-3	Story includes little of the required information stipulated in the task, and/or the information that has been included is incorrect and/or incomplete.
4-6	Story includes most or all of the required information stipulated in the task, some of which is incorrect and/or incomplete.
7-8	Story includes all of the required information stipulated in the task, which is largely correct and complete.

Note. The highest possible derived scientific literacy score for Parts A and B was 8 – a maximum of 2 marks per criterion in the scoring matrices).

The reliability of the scoring matrices was established by moderating judgements between two scorers: the first author and a secondary science teacher with 10 years of teaching experience. Discussions between the scorers resolved slightly different interpretations of the criteria, and what constituted accurate responses to more open-ended criteria. These discussions led to a refinement of the interpretations until the results from each scorer were in agreement. These final scores were analysed using dependent-samples t tests in order to identify any significant changes in students' performance across Parts A and B.

Exploring Students' Understanding Qualitatively

Twenty-four students consented to participate in interviews conducted two to six weeks after completion of the project (note that any students' names referred to in the findings are pseudonyms). Classroom observations and reviews of the students' BioStories were used to identify questions and issues for further exploration in the interviews.

The first author conducted the interviews with individual students in a computer lab. Each student was asked to log-on to the BioStories site, upon which time they were asked to tell the researcher about the biological incursion that featured in their particular stories. These responses were probed for understanding of related concepts, and further clarification was sought, where appropriate. For example, when students referred to some of the impacts of the incursion in their Part A stories, they were asked 'So, does it matter if some native lizards die-off as a result of the introduction of fire ants?'. For the Part B stories, students were asked about the impacts of a bird flu outbreak and what should happen if the disease was discovered by a poultry farmer, in order to identify their understanding of the social and economic impacts, and how the community should respond to an outbreak of the disease. Audio recordings of student interviews were transcribed and analysed inductively for evidence of conceptual understanding of biosecurity and related socioscientific concepts.

Evaluating Students' Scientific Literacy Based on their Writing

In this section, we discuss the second important challenge that we encountered in the assessment of students' scientific literacy, situated within our experiences of the BioStories project — evaluating students' learning based on their writing. In discussing this challenge, we present the results of the quantitative analysis of the students' BioStories and report on the major findings of the student interviews.

While the students' BioStories were analysed for instances in which they communicated conceptual understandings related to the biosecurity context, the interviews provided an opportunity to explore these understandings further. We initially sought to triangulate the quantitative analysis of students' stories with the interview findings, however, a comparison of these analyses revealed two key observations, one of which presented a second key challenge in seeking to evaluate their scientific literacy. Our first observation, as we expected, was that many students recalled and explained the same concepts about which they wrote with comparable detail and accuracy. In most cases, their explanations were accurate; however, a small number of students recalled the same alternative conceptions from their stories. Secondly, and unexpectedly, the interviews revealed a significant disparity between students' writing and the understandings that they articulated vocally. Specifically, most demonstrated a deeper level of conceptual understanding at interview than was expressed in their BioStories. These students elaborated on the concepts that they wrote about, or, alternatively, introduced and explained new concepts that they had not previously written about. Conversely, some could only offer superficial explanations of what they wrote, or expressed alternative conceptions not evident in their writing.

In-keeping with the tenets of mixed methodology, we present the results of the analysis of students' derived scientific literacy scores alongside the interview findings to illustrate each of these observations, in turn. In doing so, we aim to develop a deeper understanding of students' developing scientific literacy. A discussion of the challenges that we encountered, and their implications, is presented in the final section.

Evidence of Comparable Understanding

Descriptive statistics for the students' mean BioStories scores (i.e. a percentage of the highest possible score attainable for each task) are presented in Table 2. The highest mean scores were obtained for Part B.

Table 2
A summary of the descriptive statistics for each of the variables explored via dependent samples t tests

Variable	Mean	*n*	SD
Part A derived scientific literacy	58.65%	26	21.44
Part B derived scientific literacy	74.04%	26	9.30

Table 3 presents a summary of the number of BioStories that fell within the various ranges of scores identified earlier in Table 1. For Parts A and B, the majority of derived scientific literacy scores fell in the middle range, which indicates that students attempted to include most or all of the desired scientific information in their BioStories, with some inaccuracies (Table 3). There was also a considerable increase in the number of BioStories that fell in the middle range, from Part A to Part B. A small number of BioStories fell in the high score range, which indicates that all of the required information was presented and it was largely accurate.

Table 3
A summary of the number of BioStories that fell within each range of derived scientific literacy scores presented in Table 1

Derived scientific literacy score	**Number of BioStories in this range**
0-3	Part A: 9 Part B: 0
4-6	Part A: 13 Part B: 23
7-8	Part A: 4 Part B: 3

Irrespective of the extent to which the students included the desired information in their writing, 22 of the 24 students interviewed could accurately recall and explain the concepts in their stories. This suggests that the students did learn science through their participation in the BioStories project, and this learning had more than a short-term effect as they could recall concepts two to six weeks after completing the final writing task.

An excerpt drawn from a Part A story written by Year 9 student Lizzy is presented in Figure 2. Her story is about the invasive fish, tilapia, and includes information about how the animal was introduced into Queensland's waterways, its reproductive habits, and how it competes with native fish for food. At interview, Lizzy accurately recalled some of the concepts in her story. Through drawing a comparison between tilapia and another invasive species in Australia ("Tilapia are like the rabbit of Queensland's waterways"), she explained that tilapia breed very quickly and present as competition for native fish:

Researcher	So, you wrote tilapia in your Part A story. Can you tell me a little more about tilapia?
Lizzy	Tilapia are like the rabbit of Queensland's waterways. They breed really quickly and they're not really fussy eaters, so they basically take over the other fish's habitat and outnumber them.
Researcher	Okay. How do they do that?
Lizzy	Because the breed so quickly, and faster than all the normal fish … and they eat weed and plants like that.
Researcher	You said they breed really quickly. How does that affect native fish?
Lizzy	Because it takes over their habitat and the tilapia eat the resources the other fish use and the other fish end up dying off because there aren't enough resources for them.

"Tilapia invade and take over local waterways. They have a very effective reproductive strategy which allows them to lay 1200 eggs at a time!" Steve replied enthusiastically.

"Wow, 1200 is a really big number!" Jennifer replied in amazement.

"Yeah, tilapia were brought into the country for the aquarium trade, but some were accidentally let out in dams and rivers throughout Queensland," Steve said.

"Oh no, that is terrible!" Jennifer said, sounding upset. "But how did they spread so quickly?"

"Well Jennifer, tilapia aren't very fussy with their food and will eat insects and weed, but they mostly eat plants. They also take over the other fish's habitat and eat the food the other fish need to survive. They also breed very quickly," Steve said.

Figure 2. An excerpt from a Part A story about tilapia written by Lizzy.

In the context of avian influenza (Part B), students could recall information about the disease itself, and, to different extents, explain how to respond to an outbreak and what the potential impacts were. For example, in the following excerpt from a student's Part B story, Tara writes that bird flu is a "highly contagious infection" originating in wild birds that can affect a variety of domestic poultry. She also writes that the disease can be spread via contaminated cages, clothing and animal feed, and that humans can contract the disease (Figure 3).

"Avian influenza or more commonly known as bird flu is a highly contagious infection with is mostly found affecting domestic fowls like chickens, turkey, quail, pheasants, guinea fowl, and other animals like our pigs!"

"But, that's terrible, what problems does it cause on a farm like ours and to the wider community?" Jennifer's Dad replied anxiously.

"Well Dad, when domesticated birds catch the disease from wild birds the avian influenza virus becomes extremely severe and kills the domestic fowl but usually not before it has time to pass the disease on. So Dad potentially if an outbreak occurred on our farm if we were unaware of didn't act fast enough we could lose all of our animals! Now it gets worse. Not only can bird flue affect domestic fowls but humans can be affected also and the disease can be carried between humans," Jennifer stated using her professor's exact words.

"How are farmers controlling this disease?"

"The disease is very hard to control as it is past [sic] *on from wild birds to domestic birds, the case is then highly severe and is passed to animals through farm contaminated objects such as cages, clothing and the animals feed and sometimes humans can also contract the disease …"*

Figure 3. An excerpt from a Tara's Part B story that outlines the origin of avian influenza, the organisms it can infect, and how it is spread.

At interview, this student recalled the same information, albeit in lesser detail; however, the origin of the disease, the organisms it can infect, and the ways in which it can be spread are all mentioned. She also explained that humans could contract the disease by consuming infected poultry, a concept that didn't appear in her story:

Researcher	Now you wrote about bird flu in your story as well. What can you tell me about that?
Tara	That bird flu starts off in animals that aren't domesticated and then it spreads through, and once it gets to the domesticated animals it gets worse and if one bird has it, it can, like, if it goes through cages and another bird comes in contact with that cage, then it can get it and they all die off … It would affect people as well because if people eat the bird that has bird flu then they could get it and pass onto other humans.

Of the students who recalled the same information as was written in their stories, three recalled, or confirmed, the same alternative conceptions or errors at interview. For example, in Lizzy's Part B story, the key characters discover a chicken exhibiting the symptoms of avian influenza on their farm. The sick bird was dealt with by removing it from the coop so as to avoid spreading the disease any further. It ultimately passed away and was buried in a paddock. At interview, Lizzy was asked how a farm should respond to bird flu. She incorrectly described the response to an outbreak by recalling the approach outlined in her story: "They would have to … well, in my Part B story, I just said that they took the affected bird out of the enclosure … Yeah, and check the other birds to make sure they don't have any symptoms". Her response demonstrates that she underestimated the seriousness of a bird flu outbreak. Lizzy did not explain the importance of notifying appropriate authorities that would enact quarantine measures.

Evidence of Deeper Conceptual Understanding

As shown in Table 4, dependent-samples *t* tests revealed a significant improvement in students' derived scientific literacy scores from Part A (M = 58.65%, SD = 21.44) to Part B (M = 74.04%, SD = 9.30), $t(26) = -4.33$, $p < .01$. Effect size, as measured by Cohen's d, was 0.85, which is indicative of a large standardised difference between the means (i.e. $d \geq 0.8$) (Cohen, 1988).

Table 4
Significant results of the dependent-samples t test that examined changes in students' derived scientific literacy scores across the two BioStories tasks

Variable 1	Variable 2	*t*	*df*	*p*	*d*
Part A derived scientific literacy	Part B derived scientific literacy	-4.326	26	.000*	0.85

* Significant at the 0.01 level (2-tailed).

As well as a significant improvement in students' derived scientific literacy scores from Part A and to Part B, students' responses at interview revealed instances in which they expressed a deeper level of conceptual understanding than was evidenced in their writing, by elaborating on the concepts in their stories or explaining new concepts altogether.

Fourteen students elaborated on the ecological, social and/or economic impacts of the biological incursions in their Part A BioStories. The following excerpt illustrates an instance in which Lizzy explains some of the ecological impacts of tilapia, by referring to ecological relationships and food webs. Her Part A story, however, did not make reference to such concepts. Instead, her writing was dominated by descriptive information about tilapia (including its habitat, food and reproductive habits), which she also recalled at interview (see Figure 2).

Researcher	If native fish die-off because of the tilapia, should we be worried about that, is that a problem?
Lizzy	Well, because eventually it would kill off some species of our native fish … because we eat fish and it would just throw the whole cycle off because if one thing dies then other species would be affected by it.
Researcher	Oh yeah, tell me about that. Give me an example of how other species might be affected.

Lizzy	Well, if the tilapia overtake all the native fish, they would die out, which will in the long-run would affect us because we eat fish. But it won't affect us that much because we have other resources like meat and chicken.
Researcher	So if the native fish did die out and we didn't need them because we don't need to eat them, does it really matter then?
Lizzy	Probably it still would, because it would affect the food web, for animals lower than the fish.

Lizzy's articulation of ecological relationships in food chains was not surprising as the science unit in which the BioStories project was embedded had an ecology focus. However, this topic was taught prior to the commencement of the writing tasks, and the students' science teacher made no explicit links between the concept of a food web and the environmental impacts of the biological incursions in their stories. This connection was one that Lizzy made herself, and demonstrates a deeper understanding of the impact of tilapia in Australian waterways than the descriptive information that dominates her story.

Eight students could explain some of the social and economic impacts of an avian influenza outbreak, while five students correctly explained how an outbreak should be responded to, despite not writing about these concepts in their Part B BioStories. Like the previous example, most students' stories included accurate descriptions of avian influenza, including the organisms it affects and how it is spread (cf. Figure 3), however, the wider implications of the disease were not addressed, even though the task asked students to write about *"the problems that an outbreak of avian influenza would cause on a farm and in the wider community (social and economic impacts)*". Despite this, when Jackson was explicitly asked at interview whether there were would be any impacts of an avian influenza outbreak, he explained:

> It really impacts on the production of chickens and eggs, and it sends farmers out of their jobs. They lose money and they go bankrupt, like a lot of companies due to epidemics of bird flu and the outbreaks that occur. It's good that it hasn't happened in Australia yet.

Evidence of Superficial or Erroneous Understanding

Just as the interviews provided students with an opportunity to demonstrate a deeper level of understanding than was evidenced by their stories, so too did they provide an opportunity to identify alternative conceptions or superficial understandings omitted from their writing. It is important to note, however, that no student demonstrated a superficial or erroneous level of understanding overall, given that a significant improvement was found in students' derived scientific literacy scores from Part A to Part B. Instead, this pertained to their understanding of specific concepts. The majority of cases related to avian influenza, most likely due to the complexities surrounding its biology, the strict quarantine measures imposed when an outbreak is detected, and the far-reaching implications of an outbreak.

Four students introduced alternative conceptions about avian influenza at interview. For example, one student explained that her friend contracted bird flu when an infected bird touched one of the school's water bubblers and she drank from it (at the time that this study was conducted, the last reported case of the disease in Australia was in 1997).

When questioned about how an avian influenza outbreak should be responded to or managed, nine students (who didn't address this aspect in their stories) could not offer an explanation that referred to the role of quarantine measures. For example, one student explained, "they [*the farmer*] would just have to kill all the birds".

Six students offered superficial explanations of the social and economic impacts of an avian influenza outbreak. For example, when questioned about this at interview (a concept that was not addressed in his Part B story), one student explained that an outbreak would not matter if it didn't occur where he lived, as he wouldn't be able to contract it. His response did not demonstrate an understanding of the wider social and economic implications of the disease.

When explaining the impact of the biological incursions that featured in their Part A stories, four students intuitively identified the loss of native species as being unfavourable but could not offer a scientific explanation. For example, when asked whether it was a problem that tilapia were causing native fish to die off, one student explained that "it's important to have fish that are native to Australia … it's nice to have Australian fish in Australian waters".

Negotiating the Challenges: Discussion & Conclusions

We encountered two key challenges in seeking to evaluate the scientific literacy of Year 9 students in a writing-to-learn science project. Firstly, after unsuccessfully trialling Bybee's (1997) five dimensions of scientific literacy as a framework for assessing students' demonstrated scientific literacy, a number of scoring matrices were designed to quantify written conceptual understandings across the BioStories writing tasks. Unlike the other assessment instruments, the matrices assessed conceptual understandings related to biosecurity at a level that was appropriate in everyday conversations about science. In doing so, it aligned with the notion of scientific literacy adopted in the BioStories project; one of citizen preparation that draws upon both Visions I and II (Roberts, 1997).

Secondly, evaluating students' scientific literacy presented another important challenge. Quantitative analysis of the BioStories revealed a significant improvement in students' derived scientific literacy scores from Part A to Part B. This indicates that they demonstrated greater conceptual understanding in their Part B BioStories, compared to Part A, which suggests that students' participation in the writing tasks had a significant positive impact on their learning. At interview, however, students articulated some very different understandings that weren't evidenced in their stories. While every student was able to recall or explain some of the concepts about which they wrote, some offered superficial or erroneous explanations of particular concepts, or, conversely, demonstrated a deeper understanding by elaborating on the concepts that they wrote about or by introducing and explaining entirely new ones. Most significantly, 19 of the 24 students within the case study class demonstrated deeper levels of conceptual understanding at interview by correctly explaining some of the environmental, social and economic impacts of the biological incursions that featured in their BioStories; concepts that weren't present in their stories, or only superficially addressed. These rich insights into the students' developing scientific literacy could not have been gleaned from the analysis of their written artefacts alone.

These findings have important implications for the evaluation of scientific literacy in writing-to-learn contexts. The difference between students' written and vocalised understandings might raise questions about the validity of analysing hybridised scientific narratives for evidence of their scientific literacy. As shown by our findings, instances where students either accurately explained new concepts or expressed superficial or erroneous understandings all pertained to concepts that were called for in the task requirements, but, for one reason or another, weren't addressed in their stories. For example, while the Part A and B writing tasks called for an explanation of the environmental, social and/or economic impacts of the relevant biological incursions, students like Lizzy and Jackson were able to explain some of these impacts when directly asked, even though such explanations were absent from their stories. It could be the case that the somewhat open nature of the writing tasks, where students composed their own story, did not encourage them to be systematic about ensuring that all of the required information was included. This issue could be addressed by engaging students in a reflective review of their work through formative peer or self-assessment. Such approaches can encourage students '… to apply criteria to help them understand how their work might be improved and to help deepen their understanding of the criteria by relating them to their own specific examples' (Black, 2013, p. 214). This will help students to consider more carefully whether they have addressed all aspects of the task through explicit engagement with the criteria, so that their writing more accurately reflects their level of understanding.

The disparity between students' written and vocalised understandings also reminds us of the importance of employing multiple assessment strategies in order to gain a fuller picture of students' developing scientific literacy. Any single style of assessment, including those that produce numerical scores, cannot offer a satisfactory representation of a student's learning and achievement (Champagne & Newell, 1992; Fensham & Rennie, 2013). An alternative is to employ multiple probes and alternative assessment instruments, including qualitative assessment tools such as interviews (Southerland, Smith, & Cummins, 2005; White & Gunstone, 1992). As shown by the findings in this study, interviews are useful tools for revealing alternative conceptions, and can also provide students with opportunities to talk through and resolve opposing conceptions (White & Gunstone, 1992). In a classroom situation, structured interviews may provide students with a useful forum through which to vocalise their science understandings in a way that cannot be fully realised through writing (Southerland, Smith, & Cummins, 2005). From a research perspective, mixed methods designs that complement quantitative analysis of written artefacts with interviews about these artefacts provide a more comprehensive evaluation of students' scientific literacy than either approach would individually. In a classroom situation, Fensham and Rennie (2013) suggest that using several modes of authentic assessment provides a valid way of capturing a broad range of science learning outcomes and is necessary to build a profile of students' achievement (see also, Mintzes, Wandersee, & Novack, 2005).

Evaluating students' scientific literacy in a writing-to-learn context also led us to consider the implications of this study for our understanding of the derived sense of scientific literacy. Sadler (2007) presents two competing perspectives of the derived sense of scientific literacy: cognitive and sociocultural perspectives. The cognitive perspective prioritises the development of cognitive attributes through science education, such as conceptual understandings and scientific processes. These attributes may be transmitted or constructed. In this context, he argues, 'the role and significance of language are minimised' (Sadler, 2007, p. 86). A cognitive perspective therefore encourages the development of a simple fundamental sense of scientific literacy, as language is simply a medium through which knowledge can be communicated. In contrast to this position, a sociocultural perspective of the derived sense of scientific literacy prioritises context, enculturation and practice (Sadler, 2007). In other words, engaging students in the practices of the scientific community is crucial, as the goal here is not the development of cognitive attributes, but rather, becoming members of the scientific community. From this perspective, the role of language as scientific practice is consistent with an expanded fundamental sense of scientific literacy, as science is negotiated through written and spoken language in a social context. Sadler argues that in this way, the boundaries between the fundamental and derived senses of scientific literacy become blurred, as the ability to infer meaning from written and spoken language and being knowledgeable in science are closely intertwined.

Similarly, in the context of this study, it can be said that students' expanded fundamental sense of scientific literacy also developed through their participation in the project, as the students successfully read and interpreted scientific information from expository-style websites, and transformed and communicated it in their hybridised narratives. In this way, the boundaries between the expanded fundamental and derived senses of scientific literacy become blurred, as suggested by Sadler (2007), as it was through this process of interpretation and transformation that the students developed conceptual understandings of biosecurity. Thus, while important cognitive attributes were developed, in-keeping with a cognitive perspective of the derived sense of scientific literacy, language played a central role in this context, as it was more than simply a medium for communicating knowledge; it acted as a resource for meaning-making, as students constructed and communicated their science understandings in a new genre in the context of their BioStories. This transformation contributed to their expanded fundamental sense of scientific literacy. This finding supports a hybridised perspective of the derived sense of scientific literacy proposed by Sadler (2007). The BioStories project offers a way of developing students' cognitive attributes, however, written language is a medium through which science is not only communicated, but also, negotiated and understood. The hybridised writing tasks centralise the role of written language in a socioscientific context.

While the results of this study support the inclusion of diversified writing tasks such as BioStories in science curricula as a way of developing broader notions of scientific literacy, at the same time, it reminds us of the methodological challenges of scrutinising students' written artefacts for evidence of their learning. Aside from the challenge associated with analysing students' writing quantitatively in a way that aligned with our research context (i.e. the expression of students' derived scientific literacy in hybridised stories about a socioscientific issue), the findings revealed that students do not always write what they know; evaluating their writing alone would have provided a limited insight into the depth of their understanding of biosecurity and related concepts, and thus, the development of their scientific literacy. This finding in itself is not remarkable, but what it does do is highlight the importance of employing multiple probes for research purposes, and encouraging students to communicate their understandings more fully by engaging them explicitly with the task criteria. Employing formative peer- or self-assessment strategies can strengthen the validity of evaluating students' stories for evidence of learning in writing-to-learn science contexts like this. Further studies that explore ways of analysing students' written artefacts quantitatively are also needed, particularly larger scale studies that call for more effective quantitative measures of scientific literacy.

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Appendix A

An extract from the Part A writing task.

Part A: *Crikey!*

Since Steve Irwin's fatal encounter with a stingray in 2006, September 4 is usually a sad day for Jennifer. On this particular spring day strolling between biology lectures at uni, Jennifer fondly remembered her first meeting with the legendary environmentalist, affectionately known around the world as the *Crocodile Hunter*…

Suddenly, there was a commotion at one of the checkpoints. A customs officer was trying to persuade a reluctant passenger to part with some prohibited plants he had brought with him from the US.

'You know,' Steve started as he watched the passenger try to argue his way out of trouble, 'biosecurity and quarantine are so important to our country. We know how devastating it has been for our vulnerable ecosystems when **[Species X, *e.g., tilapia*]** got into the country somehow; it ruined **[native ecosystem or agricultural industry, e.g., *local waterways*]**,' he explained.

'How on Earth could something like that have such a terrible impact?' Jennifer asked.

'Well,' Steve continued energetically …

Your task: Write 200–250 words in order to complete the story. Your teacher will allocate you one of the following scenarios, from which to insert into the storyline above. Be sure to research your biological incursion by exploring the associated websites and reading the scientific information, before completing Part A. Your story must be **informative** and **include scientific information**. Remember, using the biological incursion allocated to you, Steve is trying to help Jennifer understand the importance of quarantine. In the conversation that you complete between the characters, aim to address the following information:

- State what the biological incursion is.
- Its country of origin.
- How it entered Australia.
- The problems it caused or continues to cause for native ecosystems or agricultural industries (i.e., its environmental, social and economic impacts).
- The difficulties scientists and farmers face controlling the pest, or how the pest was brought under control.

Appendix B

Derived scientific literacy scoring matrix: Part A

Criterion 1. The country of origin of the biological incursion.	
0	The story does not include the biological incursion's country of origin.
1	The country of origin is incorrect.
2	The story includes the biological incursion's correct country of origin.
Criterion 2. How the biological incursion entered Australia.	
0	The story does not explain how the biological incursion entered Australia.
1	The story incorrectly explains how the biological incursion entered Australia.
2	The story correctly explains how the biological incursion entered Australia.
Criterion 3. The problems the biological incursion has caused or continues to cause native and/or commercial species or ecosystems (environmental, social and economic impacts).	
0	The story does not address any environmental, social or economic impacts of the biological incursion.
1	The story incorrectly or incompletely addresses reasonable environmental, social and economic impacts that pertain to the biological incursion.
2	The story accurately addresses reasonable environmental, social and economic impacts that pertain to the biological incursion.
Criterion 4. The difficulties scientists and farmers face controlling the pest, or how the pest was brought under control.	
0	The story does not explain any difficulties faced by scientists and/or farmers in controlling the biological incursion, or how the pest was brought under control.
1	The story incorrectly or incompletely explains the difficulties faced by scientists and/or farmers in controlling the biological incursion, or how the pest was brought under control.
2	The story accurately explains the difficulties faced by scientists and/or farmers in controlling the biological incursion, or how the pest was brought under control.
Total score: ……… out of 8	

Appendix B

Derived scientific literacy scoring matrix: Part B

Criterion 1. What is avian influenza?	
0	The story does not identify what avian influenza is.
1	The story incorrectly identifies what avian influenza is.
2	The story correctly identifies avian influenza as a contagious or viral disease/infection.
Criterion 2. The organisms affected by avian influenza, or those at risk of infection.	
0	The story does not state the organisms affected by avian influenza, or those at risk of infection.
1	The story does incorrectly and/or incompletely states the organisms affected by avian influenza, or those at risk of infection.
2	The story does accurately state the organisms affected by avian influenza, or those at risk of infection.
Criterion 3. The problems that an outbreak of avian influenza would cause on a farm and in the wider community (social and economic impacts).	
0	The story does not address any social or economic impacts of avian influenza.
1	The story incorrectly or incompletely addresses reasonable social and economic impacts that pertain to avian influenza.
2	The story accurately addresses reasonable social and economic impacts that pertain to avian influenza.
Criterion 4. The difficulties scientists and farmers face controlling avian influenza.	
0	The story does not explain any difficulties faced by scientists and/or farmers in controlling avian influenza.
1	The story incorrectly or incompletely explains the difficulties faced by scientists and/or farmers in controlling avian influenza.
2	The story accurately explains the difficulties faced by scientists and/or farmers in controlling avian influenza.
Total score: ……… out of 8	