WRITING STORIES TO ENHANCE SCIENTIFIC LITERACY

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Abstract

In response to international concerns about scientific literacy and students' waning interest in school science, this study investigated the effects of a science-writing project about the socioscientific issue of biosecurity on the development of students' scientific literacy. Students generated two *BioStories* each that merged scientific information with the narrative storylines in the project. The study was conducted in two phases. In the exploratory phase, a qualitative case study of a 6th grade class involving classroom observations and interviews informed the design of the second, confirmatory phase of the study, which was conducted at a different school. This phase involved a mixed methods approach featuring a quasi-experimental design with two classes of Australian middle school students (i.e., 6th grade, 11 years of age, n=55). The results support the argument that writing the sequence of stories helped the students become more familiar with biosecurity issues, develop a deeper understanding of related biological concepts, and improve their interest in science. On the basis of these findings, teachers should be encouraged to engage their students in the practice of writing about socioscientific issues (SSI) in a way that integrates scientific information into narrative storylines. Extending the practice to older students, and exploring additional issues related to writing about SSI are recommended for further research.

Introduction

> *It was kind of interesting writing about something I really didn't know about because I learned about the subject. It was just interesting.* (Student 9)

This comment from a 6th grade student was made in relation to her participation in a project that required middle school students to write stories about the socioscientific issue of biosecurity. The student not only acknowledged her interest in writing about the topic, but also that she learned something new. This is a heartening response in the context of international calls to address waning student engagement and interest in school science. Middle school students (i.e., grades 6-9), in particular, demonstrate lower levels of interest in science as they become less engaged in school science activities (Goodrum, Hackling, & Rennie, 2001; Osborne & Collins, 2001; Woolnough, 1994). This is an important issue for science educators because disengaged students are less likely to become informed future citizens who use natural, scientific and technological resources responsibly for a sustainable future (Linder, Östman, & Wickman, 2007; Tytler, 2007).

Many current school science programs privilege de-contextualized conceptual learning, often limited by a narrow selection of pedagogies and devoid of lively discussions of interest to students (Goodrum et al., 2001; Linder et al., 2007; Tytler, 2007). At the same time, scientific literacy remains a key goal of science education (Sadler, 2004b), and educators continue to call for the identification and development of teaching and learning strategies that promote scientific literacy, particularly across the middle years of schooling (e.g., Prain, 2006). One way in which this need may be met is to engage science students in stimulating activities that help them to identify with contemporary socioscientific issues (SSI) (e.g., global warming, clean fuels, GM foods, water availability and quality, biosecurity), through the creation of mixed-genre stories (we call *BioStories*) that embed scientific information in the narrative storyline. In this study we investigated whether scientific literacy of 6th grade students could be enhanced through writing about biosecurity.

Enhancing Scientific Literacy Through Writing

Roberts (2007) proposed two categories or visions of scientific literacy. Vision I focuses on the importance of science subject matter (i.e., scientific literacy as viewed from a scientist's perspective) while Vision II emphasises the role of science in the everyday lives of humans in society. The Organization for Economic Co-Operation and Development (OECD) (2006) privileges a Vision II orientation in creating contexts for the Programme of International Student Assessment (PISA) (Fensham, 2009). This is an unsurprising development given their recent emphasis on a 'willingness to engage in science-related issues and with the ideas of science, as a reflective citizen' (OECD, 2006, p. 23) in their definition of scientific literacy. The subscales of interest in science, science self-efficacy, familiarity with environmental issues, among others, were developed to assess this aspect of scientific literacy in the 2006 PISA student questionnaire.

Roberts argued, however, that there are dangers in over-emphasizing either Vision I or II in any science curriculum. For the purposes of this study, a view of scientific literacy as citizen preparation, which draws upon both Vision I and Vision II, has been adopted (Roberts, 2007). While our aim was to engage students with a socioscientific issue to develop positive affect toward science and science learning (Vision II), an emphasis also was placed on the development of conceptual science understandings (Vision I). For this reason, the current study examined the development of students' conceptual science understandings related to biosecurity, as well as their interest in science and science self-efficacy.

Interest in science is an important focus for curricular reform to engage middle school science students (e.g., Tytler, 2007). While a comprehensive review of the literature on interest in science is beyond the scope of this article (see, for example, Schibeci, 2009), this literature shows consistently that students' interest in science declines in the middle years, especially at the primary school-secondary school interface (Logan & Skamp, 2008).

Science self-efficacy refers to 'the beliefs in one's capabilities to execute courses of action required to produce given attainments' (Bandura, 1997, p. 3). This construct was chosen because it is predictive of science achievement (Bandura, 1986, 1997; Hampton & Mason, 2003; Pajares, 1997) and it is pertinent to the authentic tasks used in the *BioStories*' project (e.g., accessing and using information from websites).

Notwithstanding the value of Roberts's (2007) categories of scientific literacy, 'there is growing acceptance by the literacy education community that "literacy" should be conceptualized as a range of different types of social practices rather than as one universal attribute or individual learner capacity' (Hackling & Prain, 2005, p. 19). The practices of reading, writing and talking (i.e., the use of language) remain fundamental to communicating and coming to know science (Yore, Bisanz, & Hand, 2003).

Norris and Phillips (2003) asserted that coming to know science requires competency in two senses of scientific literacy: the *fundamental* sense of scientific literacy (reading and writing science content) and the *derived* sense (being knowledgeable, learned and educated in science). They argued, 'conceptions of scientific literacy typically attend to the derived sense of literacy and not to the fundamental sense' (p. 224). They also made the distinction between a simple fundamental scientific literacy (i.e., decoding texts) and an expanded fundamental scientific literacy (i.e., inferring meaning from text) (Norris & Phillips, 2003).

Writing, talking and reading about science are desirable goals of scientific literacy; however, they also hold great potential as ways of achieving scientific literacy (Hand, Prain, & Yore, 2001). In this respect, the purposes, writing types and readerships for writing in science could be broadened, particularly as students seek to elucidate networks of scientific concepts (Hand & Prain, 2002; Prain, 2006; Prain & Hand, 1999). In addition, diversified writing tasks, including more imaginative writing, have been shown to assist students' learning processes, improve learning outcomes, have strong motivating effects, and impact positively on students' attitudes and engagement (e.g., Hand & Prain, 1995; Prain & Hand, 1996, 1999).

The use of student-generated narratives in class can be a powerful tool in science instruction, as they engage students by humanizing science (Fensham, 2001; Hodson, 2009). Narrative writing is not traditionally associated with learning science, yet it is the genre with which most students are familiar (Wellington & Osborne, 2001). Using a familiar genre (such as narrative), Wellington and Osborne argued, 'at least begins the process of helping children express their thoughts in written language through being personally engaged' (p. 76). Moreover, for students who find it difficult to write scientifically or engage with more formal scientific and technical genres, narratives offer opportunities to connect personal experiences with science ideas (Hand et al., 2001; Hodson, 2009). Given such support for the use of narrative in learning science, the more challenging pedagogical question posed by Avraamidou and Osborne (2009) is: how can the conceptual complexity of scientific information be translated into 'everyday' language without minimizing its value?

A recent qualitative study by Ritchie, Rigano and Duane (2008) reported on the outcomes from a project where a 4th grade class wrote an original ecological mystery that integrated narrative and scientific genres, where mystery storylines were situated within ecological contexts. It found that the students' engagement and interest in the writing tasks were sustained across narrative and scientific genres, and that they demonstrated both written and spoken fluency in their use of canonically accurate scientific knowledge (i.e., a derived sense of scientific literacy). At the same time, the students also developed their literacy skills using narrative and factual genres (i.e., a fundamental sense of scientific literacy).

The practical limitation identified in this study—namely, extensive time commitment in co-authoring and editing a published chapter book—led us to develop the online *BioStories'* project at the heart of the current study. We wondered whether the outcomes observed in the eco-mystery project could be replicated when students engaged in writing more economical short stories that merged scientific information with a narrative storyline. As well, we set out to create more rigorous procedures and a research design that could lead to the production of compelling evidence for the wider application of this new strategy in science classes, as recommended by Prain and Waldrip (2009). Before detailing these procedures, we identify how writing about biosecurity in this way makes a unique contribution to the literature on SSI.

Writing about Socioscientific Issues

SSI education is based on a theoretical framework that focuses on the development of students' moral, ethical and epistemological orientations, with an emphasis on discourse and argumentation (Sadler & Zeidler, 2005; Zeidler, Sadler, Applebaum, & Callahan, 2009). It 'seeks to engage students in decision-making regarding current social issues with moral implication embedded in scientific contexts' (Zeidler, et al., 2009, p. 74), as a means of empowering them to deal with these issues. Furthermore, SSI activities provide students with opportunities to develop scientific knowledge through data interpretation, analysis of conflicting evidence, and argumentation (i.e., a process of making and justifying claims and conclusions) (Sadler, 2004a), and in-class interaction during these activities enables students to evaluate claims, analyse evidence, and assess multiple ethical viewpoints (Zeidler et al., 2009).

In the context of the current study, biosecurity serves as a *classroom discourse issue* as the context for the development of the 6th grade science students' conceptual science understandings and their interest in science. Classroom discourse issues is one of four pedagogical components of the conceptual framework proposed by Zeidler, Sadler, Simmons, and Howes (2005) (i.e., nature of science, case-based, classroom discourse, and cultural issues); it emphasises the critical role of discourse, on particular SSI, in the development of students' reasoning skills, and their views about science (Zeidler et al., 2005). Notwithstanding the importance of the four pedagogical components that comprise the SSI framework, students should also understand the scientific content of an issue, as would be demonstrated through their transformation of relevant scientific information for a different audience (as per *BioStories'* writing tasks, for example) before they can address moral and ethical ramifications as they adopt an informed stance on the SSI (cf. Sadler, 2004b). In this way, writing about SSI may be effective in contributing to the development of middle school students' scientific literacy (Sadler, 2004b).

While argumentation and inquiry have featured strongly in the SSI literature, the use of writing tasks that require students to transform scientific information from government websites into conversational prose suitable for a lay audience within an established storyline has not been investigated. Yet, the transformation of technical information into conversational prose is precisely the sort of real-life practice in which informed citizens engage when they communicate to others their justification for making particular personal decisions. Accessing, interpreting, and then writing about current environmental scenarios affords students opportunities to rehearse future real-life decision-making and communication practices, possibly enhancing their self-efficacy with these practices. Moreover, such practices are important outcomes for school science through which learners 'develop a sense of having something to say about these issues and to see themselves as legitimate participants in social dialogues' (Sadler, 2009, pp. 12-13).

The writing tasks used in the *BioStories*' project introduced the students to a number of exotic species that threaten native Australian ecosystems and/or agricultural industries. When SSI form the subject of students' diversified writing tasks, as in the case of the *BioStories*, their scientific literacy may be enhanced by 'developing their interest in and capacity to apply scientific thinking to social issues for the purposes of informed action and critique … [and] students learn to cross borders between specialist and more popular genres and readerships' (Prain, 2006, p. 190).

The current study pioneers such diversified writing about SSI in the development of students' scientific literacy that features both conceptual and affective orientations. The research questions that guided the research design were:

1. To what extent did the 6^{th} grade students familiarity with and understanding of biosecurity issues and related science concepts improve after they completed the writing tasks?
2. To what extent did the students' interest and self-efficacy in science improve after they completed the writing tasks?

3. To what extent did the students' *BioStories* demonstrate a derived sense of scientific literacy?

Successful transformation of scientific information into narratives for a lay audience would be one indicator of conceptual understanding demonstrated by students. Interviews about written stories and responses to questionnaires also could indicate both conceptual and affective effects of the writing tasks used in the current study. These tasks and research procedures are described next.

Research Design and Procedures

The study was conducted in two phases, spanning two years. The exploratory case study (Stake, 2005) was implemented in a 6^{th} grade class in the first semester of 2007. A teacher well known for her expertise in science education taught this class from a well-resourced suburban Australian school. This exploratory phase involved classroom observations and interviews with students and the teacher (during and) at the completion of the project. Ritchie (i.e., first listed author) observed classroom transactions and interviewed participants. What we learned from the exploratory phase informed the design of the second, confirmatory phase of the study. This phase was implemented at a different school from phase 1 in the last six weeks of the 2008 school year with 55 students (average age was 11 years) from two similar 6^{th} grade classes that could be compared conveniently (i.e., treatment class, n=28; comparison class, n=27). Even though the school was geographically distant from the first school, it served a similar community. We chose to work with 6^{th} grade classes because this is the beginning of the primary-secondary school interface—a phase when children begin to lose interest in school science (Logan & Skamp, 2008).

The confirmatory phase of the study adopted a quasi-experimental, triangulation mixed methods design, in which both qualitative and quantitative data were generated to develop a deeper understanding of the research problem (Creswell, 2005; Mayring, 2007). Quantitative analysis of the students' written artefacts, and their affect toward science and science learning were complemented by qualitative techniques (namely, student interviews) that probed the students' conceptual science understandings and particular aspects of their interest in science.

Program Description

Participants in the treatment class(es) were required to write a series of two *BioStories* (i.e., short scientific narratives with a biosecurity theme), with the support of a *BioStories'* website, which the students accessed throughout the project. A screen image of the entry page to the website is represented in Figure 1. The website contained all necessary resources, including the *BioQuiz* (i.e., the online questionnaire all students completed before and after the project), digital resources (i.e., links to information about particular biological incursions supplied by Government Departments), story templates that guided student use of digital resources in the composition of stories (see Appendix A for an extract from one writing task), student artefacts (i.e., completed stories that were uploaded), and peer reviews of the uploaded stories.

Figure 1 about here

About 12 hours of class time was devoted to the tasks in the second phase of the study, but children could complete background reading and upload stories from their homes. The *BioStories*' tasks supplemented the usual science unit on microorganisms. The extra time required was found by substituting these activities for other literacy work in the planned curriculum. This decision was justified given the strong literacy emphasis of the project. Such an emphasis is ideal for the topic of biosecurity for which hands-on laboratory/field experiences would be inappropriate. The teacher received no special training other than given instructions on how to access the online resources, their purpose, and how students were likely to compose their stories. Under the guidance of Tomas (i.e., second listed author), the teacher modelled how scientific information could be integrated in narrative text by reading aloud sample extracts from the children's book published from the previous project (Ritchie et al., 2008), before the students commenced writing their first story. For example, the following sample illustrates how technical information about a hawksbill turtle can be merged with the narrative storyline about solving a series of turtle killings on the beach in the language of the characters—in this case, a park ranger/father who is communicating with his children:

> Dad got there first. 'It's a hawksbill. See its mouth. It's a bit like a beak. This is only the second hawksbill I've seen around here. No doubt about it, it's been stabbed to death. It's had time to dig the body pit and the egg chamber but not time to lay any eggs. Let's hope this wasn't its first batch.'
>
> 'What do you mean Dad?' asked Elisha. (Year 4 Students, 2006, p. 15)

Throughout the project, Tomas provided on-the-spot assistance to both the teacher and students during the tasks whenever necessary so that technical problems did not interfere with the writing tasks. However, there was no direct teaching of biosecurity during the unit.

The only involvement of the comparison class with the content and resources of the treatment was to register online to complete the *BioQuiz* questionnaire at pre and posttest occasions—possibly creating some awareness of and interest in the topic that would diminish, if anything, a treatment effect. In other words, the comparison class did not learn about biosecurity or related biological concepts formally during the study. Instead, it continued to work through the same scheduled unit on microorganisms that the treatment class completed (minus the supplementary activities). This included studies of fungi, bacteria and mould. The same specialist science teacher taught both treatment and comparison classes throughout the science unit (and supplementary *BioStories'* tasks in the case of the treatment class). This was an experienced teacher with a research background in the biological sciences. Under these design conditions, it is reasonable to attribute any improvement in students' familiarity with and understanding of biosecurity to their engagement with the *BioStories*' tasks. Yet, due to the integrated nature of the tasks (i.e., accessing websites, reading text, discussions with their peers and teacher, composing narrative text) and the naturalistic rather than laboratory context in which the study was conducted, it would not be possible with this small-scale design to attribute effect to content exposure or these particular activities alone.

There were two parts to the written component of the project. Part A, entitled *Crickey*! (see Appendix A*)*, required the children to work together in pairs to complete a story template that asked them to transform scientific information about a previously reported biological incursion into conversational prose (i.e., 150-200 words). The storyline centred on two characters (the late Steve Irwin and a 12 year-old girl by the name of Jennifer) that discuss the importance of quarantine and biosecurity as they observe a commotion at the Customs' checkpoint at an international airport. The students were allocated one of six biological incursions: chytrid fungus, citrus canker, tilapia, fire ants, cane toads and silverleaf whitefly. On completion of their stories, the students uploaded their work for peer review.

Like Part A, Part B required the children to transform scientific information into conversational prose, but this time, the story focused on what could happen if a new biological incursion (i.e., avian influenza or the varroa mite) breaks through quarantine barriers. The storyline here was set in a periurban[1] community where Jennifer provided expert advice (as she was now a university biology student) to her father how they could minimize the risk of an outbreak of avian influenza or varroa mite on their property.

Even though each student worked collaboratively with a partner to research and compose their stories, each student was required to upload his or her own individual pieces of work so they could be read and reviewed by their peers. Figure 2 illustrates one student's uploaded story that focused on the consequences of an incursion of citrus canker. Students had an opportunity to read and respond to feedback from their peers online before composing their subsequent stories. Few students availed themselves of this feature of the website in 2008, so it had minimal effect on the writing outcomes.

Figure 2 about here

Quantitative Data Sources and Analysis

In the second phase of the study, students' responses to the *BioQuiz* (i.e., from both the treatment and comparison classes), and artefacts authored by students from the treatment class (i.e., *BioStories*), were analysed quantitatively for evidence of the students' developing derived sense of scientific literacy. The primary objective of the quantitative data analysis was to measure empirically the effects of completing the

[1] A periurban community is a semi-rural community located on the fringe of major population centres. This sort of community is particularly worrying for biosecurity agencies because it is inhabited typically by hobby farmers and tree-change residents who do not have access to the same resources and practices as commercial farmers.

writing project on students' scientific literacy (i.e., interest in science, science self-efficacy, and derived sense of scientific literacy).

The three-scale (15 items) *BioQuiz* used in this study was reduced from a larger five-scale (25 items) version adapted from the PISA Student Questionnaire (OECD, 2006). Using the student responses to the *BioQuiz* from three schools, an exploratory factor analysis of the 25 items was performed in SPSS (n=203). This analysis was necessary because a younger cohort of students was involved in the study than the 15 year-old Australian students for whom the items and subscales had been validated. The analysis yielded three factors with eigenvalues greater than one, accounting for 58% of the variance in the students' scores. The three factors were identified as *Interest in science* (Sample Item*: I am interested in learning about science*), *Science self-efficacy* (Sample Item*: Recognize the science that underlies a newspaper report on an environmental issue*), and *Familiarity with biosecurity* (Sample Item: *The need for biosecurity*). Item reliability analysis also confirmed that each item was most strongly correlated with the factors onto which they loaded. The factor structure demonstrated a better fit to the data with the items from the other two subscales removed, χ^2 (63) = 85.772, $p < .030$, compared to the inclusion of all 25 items, χ^2 (185) = 248.231, $p < .001$. The internal consistency of the *BioQuiz* factors at pretest was found to be more than adequate (*Interest* $\alpha = .853$; *Self-Efficacy* $\alpha = .812$; *Familiarity* $\alpha = .760$).

The familiarity scale was included because we assumed that students' understanding of related concepts would be associated with their growing familiarity with the topic. This decision was based on the assessment literature that has shown familiarity with the context and target concepts in test items enhances the correctness of respondents' answers (e.g., Gigerenzer, Hoffrage, & Kleinbölting, 1991). The students responded to each item using a four-point format specific to each subscale. These responses were then scored 1-4, so that higher scores represented more positive responses.

In addition to the analysis of the *BioQuiz* results, the *BioStories* authored by the students were analysed using scoring matrices that produced numerical scores that reflected students' developing derived sense of scientific literacy (Norris & Phillips, 2003) (Appendix B). A scientific content scoring matrix for the Part A *BioStory* and another matrix to assess a sample of the students' writing prior to their participation in the *BioStories'* project (i.e., written responses to two questions about Antarctic food chains, that related to an earlier unit of work the students had completed) were designed (all matrices and templates are available from the authors on request). Each criterion in the scoring matrices was assigned a score for the extent to which the student addressed the particular criterion (i.e., zero for no attempt, one for an incomplete or incorrect attempt, and two if the criterion was addressed completely and accurately).

The reliability of the scoring matrices was established by moderating judgments between two scorers: Tomas and a secondary science teacher with ten 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 to determine any significant changes in student performance. Dependent-samples *t* tests were performed in order to identify any significant differences between the mean scientific content scores obtained from the *BioStories* written by students from the treatment class.

Qualitative Data Sources and Interpretation

Qualitative (content) analysis of the student interviews was used in both phases of the study. After locating their *BioStories* from the designated website, each student was interviewed about what they had written, in much the same way as interview-about-events' protocols (Osborne & Freyberg, 1987; White & Gunstone, 1992).

Classroom observations and reviews of the students' *BioStories* were used to identify questions and issues for further exploration in the interviews. As well as probing student understanding of biosecurity and related biological concepts, these interviews established which aspects of the project they enjoyed the most or least, what they found challenging, and their experiences in transforming technical information into conversational prose. To illustrate how we ascertained information about the students' transformation of technical text into conversational prose we began by asking: 'How did you find fitting the science into your story?' In the case of Student 9, for example, the reply was: 'It didn't always fit because there was all this information and you had to get it into their words, like, you had to hear someone say it. You just couldn't just take it straight off the internet, you had to think about it first.' Furthermore, inspection of their stories showed the extent to which technical and narrative texts were merged, and whether the language used matched the characters and the storyline. As exemplified in Figure 2, the conversational prose (e.g., 'citrus canker is a disease, it can't be seen except after it's done its damage…') was transformed from more technical expressions found on the government websites (e.g., 'Citrus canker is a contagious disease of citrus [and some other plant species of the Rutaceae family] caused by the bacteria *Xanthomonas axonopodis* pathovar *citri*. Infected trees display unsightly lesions which can form on leaves, fruit and stems.').

Research Findings

In this section we provide evidence to support our thesis that writing *BioStories* (i.e., diversified text that merges scientific information with everyday conversational prose) on the socioscientific issue of biosecurity helped develop aspects of the students' scientific literacy. We make three claims, each related to a corresponding research question. First, we assert that the students' familiarity with and understanding of biosecurity and related biological concepts improved through their completion of the project that emphasised a sequence of diversified writing tasks and related activities. Second, we claim that the students' interest in science improved through their participation in the project. The third claim for which we provide evidence is that the students' *BioStories* showed an elevated derived sense of scientific literacy over other science written artefacts. Before these claims are substantiated, we report on the major findings from the exploratory case study, followed by the quantitative analyses of students' *BioQuiz* responses.

Outcomes from the Exploratory Case Study

Interviews with the 6th grade students in the exploratory case study showed that all 23 students could recall accurately the key facts about the biological incursion in their stories, and all but two students could articulate a deep understanding of the related biological concepts when their responses to the initial questions were probed. A typical example how a student demonstrated conceptual understanding of the environmental consequences of a large-scale breakout of chytridiomycosis in frog communities at interview was: 'Well it would mean that every bug that was eaten by frogs would probably grow in numbers and animals that would be affected by the [eco]system or life cycle of the frogs would stop being affected or either grow in large or grow smaller. Every animal that eats frogs like big birds and stuff, they would have to start looking for other food' (Student 23). A similar response was recorded during an interview with another student post-intervention who wrote a *BioStory* on chytrid fungus (Student 10—see turns 09, 13, 15):

09	Student 10	When I was researching this I found out it has made several species of frog extinct.
10	Researcher	So what? Is that a big deal?
11	Student 10	Well, it affects the ecosystem a lot.
12	Researcher	Okay, in what way?
13	Student 10	Well, something might eat the frogs and whatever eats the frog doesn't have as much food.
14	Researcher	Okay.
15	Student 10	And the things that frogs eat, they might get overpopulated.
16	Researcher	Okay, that makes sense to me.

This pattern was observed on stories that featured other biological incursions. Student 9 (whose reaction to writing *BioStories* launched our introduction), for example, could articulate a canonically correct explanation for the devastating impact tilapia has made on native species in natural waterways after we probed her initial response that this introduced species was detrimental to natural ecosystems.

11	Researcher	Why is it bad?
12	Student 9	Well basically it breeds really quickly and it sort of like the rabbits and toads they sort of take over the waterways and stuff like that.
13	Researcher	So, in what ways do they take over the waterways?
14	Student 9	Um, they cut off, ah, they don't cut off the supply of food, but make the food supply smaller for the fish. And the fish will die because they don't have enough food to eat.

15 Researcher How do they make the food supply smaller for the other fish?

16 Student 9 Well, they breed really quickly and all the numbers eat all the food in that area and they keep going eating the food.

Not only did Student 9 demonstrate an understanding of the ecological impact of the incursion of tilapia in Australian waterways, but also she expressed interest in learning about biosecurity and writing in this way. This was a common reaction to the writing tasks, best exemplified by an in-class conversation with Students 3 and 4, as shown below.

05 Researcher What do you think of the topic?

06 Student 4 It’s really interesting.

07 Student 3 It’s really fun to write about.

08 Researcher What do you like to write about?

09 Student 3 It’s you learn a lot about it. And you don’t realize how much you learn till you go home and tell your mum everything you learned and realize how much you know.

10 Researcher Wow okay.

11 Student 4 And if you know it all in your head and you can name all the facts it’s so easy to write about it and its really really fun and put in all the things that Steve [Irwin said].

This exchange demonstrated a genuine interest in the writing task and learning something new. In particular, Student 3 revealed enthusiastically her practice of explaining what she is learning at school to her mother when she goes home each day (turn 09). These comments not only show that these students were interested in the writing activities, but also reinforce the claim made earlier that the writing tasks helped the students develop an understanding of the relevant biological/ecological phenomena (e.g., turn 09).

Given such positive outcomes from the exploratory phase, it was important for us to attempt to confirm these results in a different school and under a more rigorous quasi-experimental design. The administration of and analysis of results from the *BioQuiz* in the confirmatory phase of the study was an important additional component to the study.

Analysis of BioQuiz Responses

Repeated measures multivariate analyses of variance (MANOVA) were conducted to explore the possible impact of two independent variables (i.e., time—the difference in means between pre and posttest; and condition—treatment and comparison) on students' *BioQuiz* scores (i.e., three dependent variables: *Interest in science, Science self-efficacy, and Familiarity with biosecurity*). Significant effects for time and time*condition were found. The critical time*condition effect was statistically significant (Wilks's Λ = .82, $F[1, 51] = 11.16$, $p = .002$, partial $\eta^2 = .18$), which suggests that the treatment and comparison groups behaved differently over the period of the *BioStories*' project on the *BioQuiz* items and scales. This interaction effect accounted for 18% of the variance in *BioQuiz* scores.

An investigation of the time*condition interaction revealed a significant difference between mean improvement in the *BioQuiz* scores for the treatment (M = 1.25) and comparison groups (M = .16), from pre to posttest (t = 3.406, p = .002—see Table 1). This result approached a medium effect (Cohen, 1988) in this case (d = .46). Means and Standard Deviations for each group are listed in Table 2. Together, these results indicate that the *BioQuiz* scores for the treatment group improved relative to the comparison group. More specifically, Table 1 shows that the treatment group improved in relation to the comparison group on all three scales, with the improvement on the *Familiarity with biosecurity* scale (p = .006), and the *Interest in science* scale (p = .019) being statistically significant, each with a modest effect. The *Benjamini-Hochberg-Yekutieli* procedure (Benjamini & Yekutieli, 2001) for controlling the false discovery rate (FDR) under dependency assumptions was applied with the mean estimate of p < .02 adopted for the purpose of determining statistically significant improvements across the project.

Table 1 about here

Table 2 about here

A between subjects effect of gender was found to contribute to 15.1% of the variance (F = 9.084, p = .004). Interestingly, post hoc analyses showed that while boys had higher mean scores than girls for the subscales of *Interest in science* (t = 2.804, p = .007) and *Science self-efficacy* (t = 2.476, p = .017), there was no gender difference in their *Familiarity with biosecurity* scores, nor with changes from pre to posttest. Although the small sample warrants caution in interpreting these results, it appears that the boys and girls in this study did not respond differently on the *BioQuiz* over the duration of the project. This suggests that this pedagogical intervention could be equally appropriate for boys and girls.

Familiarity with and Understanding of Biosecurity-related Concepts

Relative to the comparison class, students who completed the *BioStories' project* demonstrated a statistically significant improvement in their familiarity with biosecurity issues, albeit with a modest effect (t = 2.894, p = .006, d = .39). In addition to raising students' awareness of biosecurity issues, the students at interview confirmed the findings of the exploratory case study by demonstrating understanding of ecological relationships about which they wrote in the *BioStories*. Only one student from the treatment class could not recall much of the scientific information about which she wrote. Student 32, whose responses are listed below, did not describe the role of quarantine in dealing with a potential varroa mite outbreak, explaining that the farmer could deal with the problem relatively easily. This student appeared to underestimate the seriousness of a potential outbreak.

01	Researcher	If you were a farmer and you found bee mite on your farm, what would you do about it?
02	Student 32	I'd try and exterminate them.
03	Researcher	Try and exterminate them?
04	Student 32	Yeah.
05	Researcher	Easy done hey?
06	Student 32	Yeah.
07	Researcher	Anything else?
08	Student 32	I could get rid of all the bees and get some new bees.

Interest in Science

As shown in Tables 1 and 2, the treatment class improved relative to the comparison class from pretest to posttest on the subscale of *Interest in science* (t = 2.425, p = .019, d = .33) with a modest effect. While this result alone suggests the writing tasks had a positive effect on students' interest in science, the interview results reinforce our claim that students' interest in science improved upon completion of the project.

In order to explore the factors students attributed to their interest in learning science from the project, students were asked at interview what they enjoyed most and least about learning science in the *BioStories'* project. As shown in Table 3, the students identified 11 aspects of the project as being enjoyable, compared to only three aspects that they did not enjoy. In addition, the frequency of the affirming comments far outweighed expressions of any discontentment.

With respect to the features of the project the students enjoyed, the majority of the students cited four main aspects: learning something new about biosecurity and biological incursions; researching information; writing their *BioStories*; and the project was fun (Table 3). When asked what he enjoyed about the *BioStories'* project, for example, Student 36 explained, 'Well, I enjoyed the researching and writing, and learning about these things like the bee mite and bird flu, and how important biosecurity is'.

Table 3 about here

Just as Student 9's response demonstrated from the exploratory phase, many students from the confirmatory phase (i.e., 15—see Table 3) raised the issue of learning about something new as a positive aspect of the project, as illustrated below from the interview with Student 31:

Researcher	What did you think about the writing tasks?
Student 31	They were fun, finding the information. Yeah, they were fun.
Researcher	What did you enjoy most about learning science through *BioStories*?
Student 31	I found out what like, I didn't know about the bee mite or I didn't know about citrus canker.
Researcher	So you didn't know about these things?

Student 31 I didn't know about them, and I found it interesting finding out about those things.

When asked about aspects of the project they did not enjoy, 13 students explained that they enjoyed the entire experience. Ten students commented that they did not enjoy researching scientific information for their *BioStories*, mainly because they experienced difficulty locating the desired information from the websites, as the following excerpt exemplifies:

Researcher What did you enjoy least about *BioStories*?

Student 39 Searching for the information, because it was a bit hard.

Researcher Okay. What was hard about it?

Student 39 Getting the right website and trying to find the correct information.

Researcher Okay. So you had trouble locating the information?

Student 39 Yeah.

Five other comments of discontentment (made by four students who were challenged by locating information from the web quickly) related to the challenge of typing or incorporating scientific information into a narrative.

Improvements in Derived Sense of Scientific Literacy

Apart from ascertaining whether students' demonstrated conceptual understanding of related biological concepts at interview, we also were interested in assessing the students' *BioStories* for evidence of changes in a derived sense of scientific literacy. For this reason, we scored each student's *BioStories* against specially designed scoring matrices, as discussed previously. Dependent-samples t tests were performed in order to identify any significant differences between the mean scientific content scores obtained from the *BioStories* written by the students from the treatment class.

As the project extended for a longer period than was anticipated, due to various end-of-year activities at the school that interrupted science lessons, not all students uploaded all of the *BioStories*. Twenty-one comparisons were possible between scientific content scores for *BioStories* and the pre-writing samples as an indicator for any improvement in fundamental and derived senses of scientific literacy.

Statistically significant improvements were found in the scientific content scores from pre-writing (M = 28.57, SD = 30.91) to Part A (M = 78.88, SD = 20.51, t = -7.29, p = .000, d = 1.59), and from pre-writing to Part B (M = 71.15, SD = 18.67, t = - 2.87, p = .017, d = 1.16), both with large effects. These impressive gains, along with the evidence of conceptual understanding demonstrated during students' interviews, support our claim that students improved their derived sense of scientific literacy related to the issue of biosecurity upon completion of the *BioStories'* Project.

Discussion & Conclusions

The present study examined the development of 6th grade students' scientific literacy through their creation of stories that transform technical information about the socioscientific issue of biosecurity into conversational prose for a lay audience that fits within narrative storylines. As no single writing task can be used to engage all the dimensions of scientific literacy (Hand, Prain, Lawrence, & Yore, 1999), this study focused on students familiarity with and conceptual science understandings (a derived sense of scientific literacy, Norris & Phillips, 2003), the students' transformation of scientific information in stories about biosecurity (expanded fundamental and derived senses of scientific literacy), and the students' interest in science and their science self-efficacy.

Statistical analysis of the *BioQuiz* data revealed that scores for the treatment class relative to the comparison class improved significantly from pre to posttest on the subscales of *Interest in science* and *Familiarity with biosecurity*, which indicates that the students' participation in the *BioStories'* project impacted positively on their interest in science and their awareness of biosecurity issues. These findings were also supported extensively by the interview data. Students' comments suggested that they enjoyed learning about something new, researching information, and writing their *BioStories*, while having fun at the same time. This outcome is consistent with the growing literature that shows SSI education improves students' interest in science (Sadler, 2009), and that this can be achieved by writing narratives that require students to transform technical information into conversational prose for a lay audience (cf. Avraamidou & Osborne, 2009), as predicted by Fensham (2001) and Wellington and Osborne (2001).

Statistical analyses of the students' *BioStories* revealed a significant improvement in their scientific content scores from their pre-writing sample to Part A and Part B *BioStories*, which indicates that the students demonstrated an improved derived sense of scientific literacy in their stories. Without any further improvement beyond Part A suggests an immediate, but sustained effect when engaged in such written tasks.

Prior to the current study, the use of diversified writing that integrates scientific information with narrative storylines to improve students' interest in science and perceptions of their science self-efficacy, had not been investigated in the context of SSI education. While argumentation and its value in developing students' scientific literacy features heavily in the literature regarding SSI education, the results from this study have shown that the composition of *BioStories* can be just as valuable in improving the students' derived (and expanded fundamental) sense of scientific literacy and their interest in science. That the students' perceptions of their science self-efficacy did not improve suggests that self-efficacy is either temporally very stable for students of this age or the *BioStories'* tasks in themselves are unlikely to lead to a greater sense of the students' capacity to complete the particular practices targeted by the question items. The interview results did indicate that some students experienced difficulty or found the task of locating relevant information from the websites for their stories bothersome. Perhaps this suggests that some students of this age require additional scaffolding or overt instruction how to identify relevant information from technical text. It might also mean that these students are not sufficiently mature to recognize their legitimate participation in such social dialogue (cf. Sadler, 2009). This leads us to ponder whether a different effect would be observed for older students; that is, those who are at the end of their middle school years (e.g., 9^{th} grade). We have targeted these older students in a follow-up research project.

Due to the emphasis on students' interest in learning science and their perceptions of science self-efficacy, the moral and ethical issues relevant to socioscientific decision-making in the context of biosecurity were not investigated; however, this could serve as the focus of future research. While argumentation presents great utility in the advancement of moral reasoning (Zeidler, 2007), the writing of narratives about SSI could offer potentially a useful alternative means for this development. Biosecurity lends itself to the development of moral and ethical reasoning. For example, it is unethical (as well as illegal) to breach quarantine regulations that would affect adversely human health, and natural and agricultural ecosystems, and an understanding of the related science is necessary to justify particular moral decisions. The *BioStories'* task requirements could be modified quite simply to facilitate students' exploration of these issues and the formulation of personal standpoints in the stories. It would be interesting to investigate whether such an approach would be effective in developing students' moral reasoning, a key feature of the SSI framework, while promoting student interest in science learning, an important finding of the current study.

While the results from this study should encourage teachers to try this new teaching strategy (i.e., *BioStories*) in their middle school science classrooms when teaching SSI, similar outcomes from studies that expand the treatment to larger student cohorts from varied classroom contexts, and with other SSI, would provide even more compelling evidence for the widespread use of this approach. Up scaling subsequent designs also could help to determine whether the topic (i.e., SSI) or the writing approach contributes most to the observed improvement in scores. The students in the current study accessed technical information from approved websites and uploaded their stories to a designated website; however, it would be possible for teachers without these online resources to implement the writing tasks in more traditional hard copy formats.

From the outcomes of this study, and recent theoretical justification for narratives in the science curriculum (cf. Avraamidou & Osborne, 2009), we are optimistic that writing scientific narratives on suitable socioscientific issues can contribute to the development of scientifically literate future citizens.

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Appendix A

Crikey! Part A—Extract

Since Steve Irwin's fatal encounter with a stingray in 2006, each 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 (XX; e.g.,) **Citrus Canker** got into the country somehow; it ruined (YY=) **Citrus Crops in Emerald**," he explained.

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

"Well," Steve continued energetically, "……………………."

Your task: Write 150-250 words in order to complete the story. Your teacher will allocate you one of the following scenarios, from which to insert the relevant XX and YY species above. Be sure to research your biological incursion (XX species) by exploring the associated websites and reading the scientific information, before completing Part A of "*Crikey!*"

Your story must be **informative**, and **include scientific information**. In the conversation that you complete between Steve and Jennifer, aim to address the following information:

- What the biological incursion is.
- Its country of origin.
- How it entered Australia.
- The problems it caused or continues to cause for native and/or commercial species or eco-systems (i.e. its impacts).
- The difficulties scientists and farmers face controlling the pest, or how the pest was brought under control.

Remember: Using the XX species allocated to you, Steve is trying to help Jennifer understand the importance of quarantine….

SCENARIO 2: XX= **Citrus Canker**, YY= Crops of citrus trees.

http://www2.dpi.qld.gov.au/citruscanker/

http://www2.dpi.qld.gov.au/citruscanker/18396.html

http://www2.dpi.qld.gov.au/citruscanker/18401.html

Appendix B

Scientific Content Scoring Matrix: Part A

Country of origin	
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.
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.
The problems the biological incursion has caused or continues to cause the environment, and the local and wider community (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 correctly and completely addresses reasonable environmental, social and economic impacts that pertain to the biological incursion.
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 correctly and completely explains the difficulties faced by scientists and/or farmers in controlling the biological incursion, or how the pest was brought under control.
Total score: /8	

Table 1. Time*condition (*N*=55) for the *BioQuiz* scales.

	Treatment ΔM	**Comparison** ΔM	***t***	***df***	***p***	***d***
BioQuiz (overall)	1.25	0.16	3.406	53	.002*	0.46
Interest	0.18	-0.05	2.425	53	.019*	0.33
Self-efficacy	0.33	0.12	1.351	53	.182	0.18
Familiarity	0.74	0.09	2.894	53	.006*	0.39

* Significant at the .02 level (2-tailed).

Table 2. Summary of descriptive statistics for the *BioQuiz* scales

Scale	Group	Pretest		Posttest	
		M	SD	M	SD
Interest	Treatment	3.07	0.54	3.25	0.49
	Comparison	2.84	0.62	2.79	0.68
Self-efficacy	Treatment	2.84	0.56	3.17	0.58
	Comparison	2.79	0.62	2.91	0.51
Familiarity	Treatment	1.88	0.65	2.62	0.82
	Comparison	1.88	0.62	1.97	0.69

Table 3. A summary of students' responses at interview, regarding aspects of the project they did and did not enjoy.

Aspects of the project that students enjoyed	Frequency
Learning something new about biosecurity and biological incursions	15
The project was fun	12
Researching information	7
Writing stories	7
Engaging with information technologies	4
Working collaboratively with a partner	4
Being creative	3
Enhancing their awareness of an important issue	2
Reading and commenting on peers' stories	1
Uploading their stories to the website	1
Being offered a choice of incursions to write about	1
Total	57
Aspects of the project that students did not enjoy	**Frequency**
Researching information, particularly difficulty locating desired information	10
Writing stories	4
Typing up stories	1
Total	15

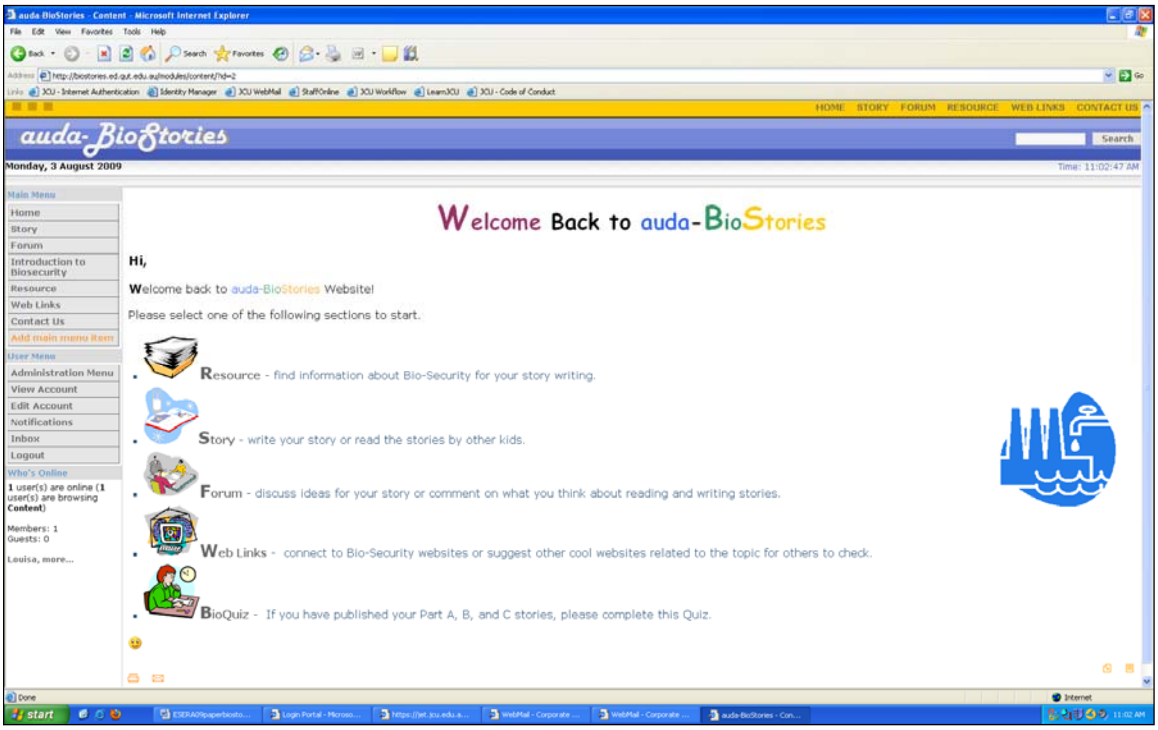

Figure 1: Entry page to *BioSories*' webpage. Students access the instructions for completing a *BioStory* by clicking on the Resource button.

The Citrus Canker

"Well," Steve continued energetically, "the citrus canker is a disease which damages citrus fruit and plants. These crops then cannot be sold to people and prices for fruit and plants go up, otherwise farmers will run out of money. It has a big affect on farmers and the citrus industries," explained Steve.
"Well," said Jennifer, "I didn't know how bad this disease was. How did this disease enter the country, Steve?" Jennifer asked.
"The citrus canker got into Australia through citrus plants and food from Asia and India. Scientists think the citrus canker most likely originated in South East Asia,"
said Steve.
"Why can't scientists bring it under control?" Asked Jennifer, interested.
"Well, since the citrus canker is a disease, it spreads quickly throughout Australia and scar fruit which can't be sold anymore. Also, because citrus canker is a disease, it can't be seen except after it's done its damage on the plants or food," said Steve. "There is two ways to stop citrus canker spreading. You have to burn the infected citrus plants and food and not let any pass through quarantine which can be very hard. The citrus canker can also travel in the wind and rain."
"Wow, I never thought quarantine was that important," exclaimed Jennifer, amazed.
"Well," replied Steve, "now you know the importance of quarantine and why you can't bring certain things into Australia from other countries."
"Thanks for telling me about the citrus canker Steve," said Jennifer.
"Any time," Steve replied.

<< The Citrus Canker Crikey part a >>

Topics

Citrus Canker and Crops of Citrus Trees

Figure 2. An example of a student's Part A *BioStory*, uploaded to the *BioStories'* website.