Language, learning and literacy in science and mathematics

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Abstract

The *Secondary Literacy Inservice Package for High School Science and Mathematics* was developed to assist teachers of science and mathematics to help their students become more literate in these two subject areas. We examine the meaning of literacy and its relationship to language and learning, and describe the outcomes from trialing the package.

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Concern for the role of language in learning generally has been prominent for some years now, and rightly so. It is not surprising then, that similar concerns have been identified in curriculum domains such as mathematics and science. The December 1992 issue of *ASTJ* was devoted to language and learning in science education. The guest editor (Barnett, 1992, p. 3) noted

> It used to be said that language was the province of the English teacher and the science teacher held no brief for it. But many science teachers are now finding that taking language into account in their teaching has a very positive impact on student learning, and ends up making teaching easier because of what is taught and learned.

Authors of the various articles noted that in our teaching, we constantly use language. We talk; we write. Our students listen, read and write; they may also talk. Such activities are often associated with the idea of literacy. Continuing interest in this area is indicated by a recent *ASTJ* article, *Improving learning through writing in secondary science: two examples* (Connor, Prain & Hand, 1994).

Similarly, in 1993 the National Council of Teachers of English (NCTE) issued a 'call for action' in the United States to take advantage of what has been learned recently about the pivotal role of language in learning:

> We reiterate, classrooms where language is used for learning are fundamentally different classrooms. They are places where students talk, read, and write frequently, places where they learn better and their learning lasts longer.

For those who are interested in pursuing these issues in their schools, we describe a professional development package to assist. The package is designed to help teachers to examine the links between language and learning, and begins to address ways of using them to advantage. We suggest that helping our students use various aspects of language (listening, talking, reading and writing) helps them become more literate. Before describing the package and its development, it is first necessary to examine the idea of literacy, a notion too often associated only with primary schools or English departments in high schools.

Literacy in science and mathematics

Literacy has long been a concern of developing societies, and even today, literacy rates are published for many countries of the third world. In more developed countries, such as Australia, literacy has tended to be associated with the primary school curriculum in general, and with the first two of the three Rs in particular. However, there is another, related meaning to the idea of a literate person, as reflected in the Macquarie Dictionary definition:

> **literate,** *adj.* 1. able to read and write. 2. having an education; educated. 3. literary, -*n*. 4. one who can read and write. 5. **a learned person.**

Indeed, the dictionary even defines a higher class (of men!) in terms of their literacy:

> **literati,** *n. pl.* men [sic] of learning; men [sic] of letters; scholarly or literary people. (Delbridge, 1981, p. 1026)

One meaning of literacy would seem to be concerned with the mechanics of communication, with reading and writing, while another is more concerned with the sense people make of their reading and what they write about. It seems important when thinking about literacy in school curricula to keep each of these two meanings of the term in mind.

It is of more than passing interest, too, that much of the concern with literacy, even in countries like Australia, which enjoys a higher literacy rate than many other countries, is in fact a concern for illiteracy, a concern with a perceived deficiency of some kind that is in need of remedying. Thus, the Macquarie Dictionary also includes the following as a separate entry (Delbridge, 1981, p. 882):

> **illiterate,** *adj.* 1. unable to read and write: *an illiterate tribe*. 2. lacking education. 3. showing lack of culture, -*n* 4. an illiterate person.

In this paper, we suggest that literacy is indeed of prime importance to both mathematics and science in the secondary school. However, the common meaning of the term, well-reflected in the dictionary definitions given above, is too limiting. So too is the focus on students whom we perceive to be in need of remedial help. We suggest that it is important to think about literacy in the particular disciplines of science and mathematics, and would argue that it is important to help **all** students become scientifically literate and mathematically literate. Further, it is our viewpoint that literacy is **both** a means and an end of science and mathematics education, an understandable preoccupation with literacy as a means to learning has discouraged us from paying attention to the ends as well.

In order to help science and mathematics teachers interact with the important aspects of literacy in their disciplines, we undertook the development of the *Secondary Literacy Inservice Package for High School Science and Mathematics*, as one of the activities associated with International Literacy Year in 1990. The Australian Government's International Literacy Year Program through the Department of Employment, Education and Training established a number of initiatives in the literacy area. A grant was made under this program to the Centre for Mathematics Science and Technology Education at Murdoch University to develop the package. The project provided us with the opportunity to examine, critically notions of literacy as applied to science education and mathematics education. The product of the grant was to be a professional development program for teachers of high school science and mathematics. Its purpose was to help teachers help students become more literate in science and mathematics.

It was necessary, as background to our work, to examine some of the views of literacy proposed by the science educators and those who work in the areas of language and literacy?

Scientific literacy as seen by the science education community

More than 25 years ago, Pella, O'Hearn and Gale (1966) reviewed the literature in an attempt to define what constituted a **scientifically literate** person. They began by identifying what they saw as the three reasons for teaching science: "to prepare scientists, to prepare technologists and to provide a background in science as part of a general education of the individual for effective citizenship" (p. 199). This third purpose, according to the authors, will result in a scientifically literate person. They reviewed the science and the science education literature for the period 1946 to 1964. Analysis of 100 documents led them to suggest that the scientifically literate person is one who is characterised by an understanding of the

> (a) basic concepts of science, (b) nature of science, (c) ethics that control the scientist in his [sic] work, (d) interrelationships of science and society, (e) interrelationships of science and the humanities, and, (f) differences between science and technology. (p. 206)

Bodmer (1989) has added his emphasis to an understanding of the nature of science when he wrote:

> Science must be seen not as an activity that always gives unequivocal answers. It should be shown to have its limitations, so that when scientists turn out to be wrong, people are in general in a better position to understand how that may happen. (p.12)

A third view is provided by Garfield (1988), who defined a scientifically literate person as one who has

> an understanding of the nature and limits of science, a mastery of basic conceptual knowledge in the major disciplines, and a sense of the social, cultural and ethical implications of science and technology. (p.3)

These are but some of many in the science education community who have grappled with the notion of scientific literacy. Some of the others include: Brown, Weber and Renner (1975) ; Elliott, Carter-Nagel and Woodward (1986); Fensham (1985); Maarschalk (1988); and, Shortland (1988).

These authors do not generally mention language, nor do they refer to the various conceptions of literacy held by those who work in the language/literacy areas. When those in the science education community speak of the scientifically literate individuals, it is often a **product** they have in mind. They do not usually discuss the processes by which this product is achieved, nor the role of language in achieving this product.

Communication in science classrooms

The views of scientific literacy reviewed above do not refer to language or to communication specifically, and might suggest that the science education community has ignored these areas. This is not the case.

For example, in the UK in the 1970s, the Science Teacher Education Project (STEP) materials included a discussion by Sutton (1974), which highlighted the importance of oral and written language in science classrooms. Those interested in a more recent account of his views can consult Sutton (1992). In the USA, Lemke (1990) has pointed to the crucial role played by language in developing students' understanding, or lack of understanding, of science. In Australia, Gardner (1974) identified some of the language difficulties of science students. The Australian Science Education Project team (ASEP, 1974) took up the specific problem of readability and designed each module so that its readability level was two grade levels below that of the intended audience. Thus a Year 10 module had a readability level that was suitable for Year 8. Such an approach, which had the worthwhile aim of giving students an easy introduction to the language of science, had the unintended effect of avoiding the problem. Students who studied a large number of ASEP modules were exposed to limited quantities of the formal science language which characterises the majority of science textbooks.

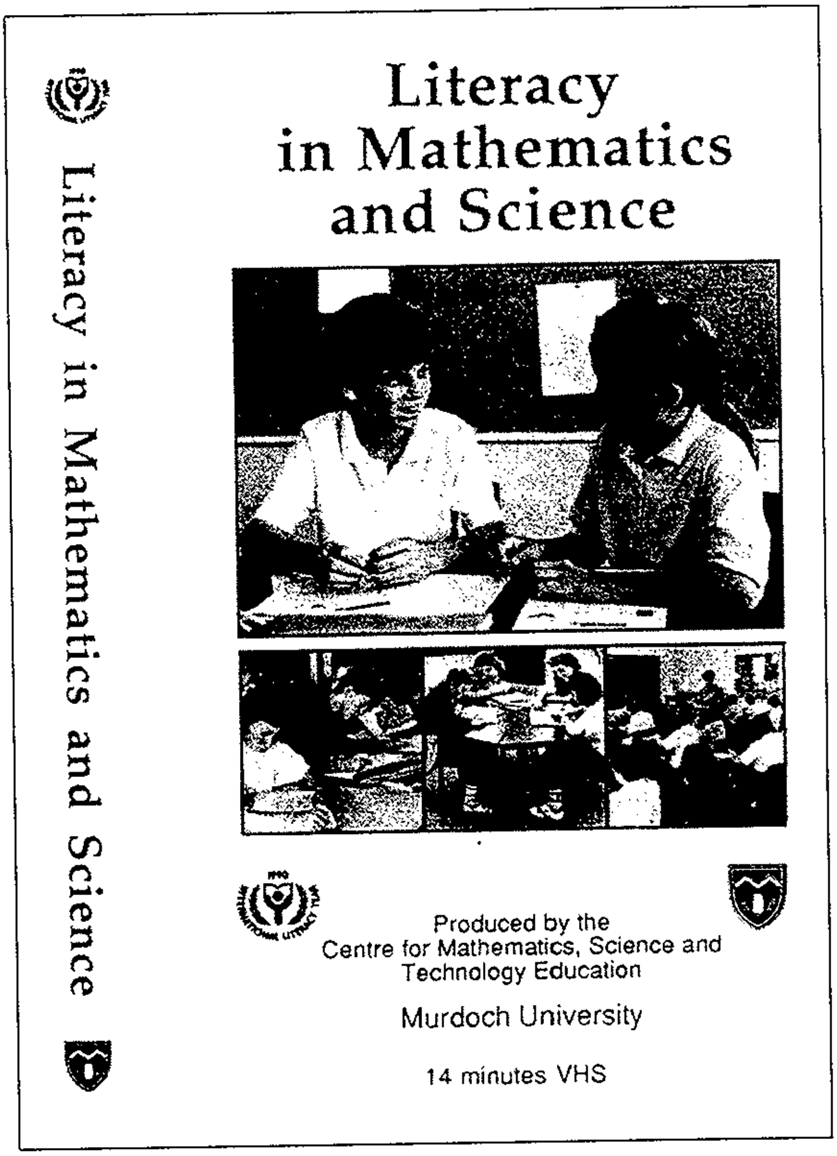
There is no doubt that science textbooks should be improved. However, we must realise that these textbooks serve two functions, which sometimes interfere with each other: to help students learn, and to present science and mathematics as these disciplines are understood by scientists. If students are to become literate, they must be helped to acquire the skills which will enable them to extract meaning from these textbooks. If we feed them an unending diet of textbooks in which the language is watered down, our students will never be scientifically literate.

Literacy, language and learning

It is clear that the science education community has been active in inquiring into the problems of scientific literacy and language in science classrooms, although the links between these two domains of inquiry have not been often made explicit. The language and literacy community, in general, identifies language strongly with notions of literacy. The science education community, on the other hand, has not. Among the few exceptions is the view expressed by Shahn (1988), who wrote:

> Being science literate requires more than factual knowledge. It requires an ability to relate often strange phenomena to a language framework, and to work with standard language in a sophisticated manner. In addition, in some areas it requires the use of mathematical skills that are fundamentally based on the ideas of proportionality and elementary statistical principles. (p.50)

Shahn is thus one of the few who make explicit reference to language. Another of the few who refer to language is Fleming (1989). He suggested that the term literacy be used to define the ability to comprehend, through reading the texts of others, what is new information and the ability to write, which entails revising inner speech and synthesising new information. The combination of reading and writing is, in Fleming's view, an "... empowering activity as it enables those who possess these



skills to move beyond one's culture and create new, more powerful cultural forms" (p.392).

Another example of this change of focus is evident in the recent North American study (Dillon, O'Brien, Moje & Stewart, 1994) focussed on the literacy strategies of three science teachers in order to show how these were related to philosophies about the nature of science and learning in science. As for Shahn and Fleming, the authors needed a more expansive view of literacy:

> A broader view of literacy was necessary to examine the relationships between the teachers' philosophies and classroom-based literacy. Defining literacy as engagement with print via reading, writing and oral discourse moved this analysis beyond a focus on literacy strategies applied to textbooks. (p. 359)

These kinds of links between language and literacy, as we mentioned earlier, are common among the language and literacy community. When literacy is discussed by those who are not scientists, science educators, mathematicians, or mathematics educators, words like **reading, writing, listening**, and **speaking** are common. This appears not to be the case in the science education literature, apart from the few examples such as those identified above.

While some would argue that literacy should be interpreted in a general sense, irrespective of whether the term is being interpreted in terms of reading and writing skills or with general education, not all would hold with this. Authors such as Green (1988) would argue that to be literate is to have a set of subject-specific literacies. In their view, literacy always refers to some context, and thus we speak of a person as literate in science or history or mathematics.

The notion of literacies in different domains is supported by the observation by Grant (1990):

> People often treat science as if it were some sort of 'forbidden country'. In fact, one of the perennial irritations of those involved in the sciences is that it is somehow chic to be innumerate and totally ignorant of physics, mathematics and the rest, but at the same time taboo to be ignorant of the basics of say, literature. (p. 17)

Clearly, this implies that people can be literate in one domain, but not literate in other domains. What is it about a domain that might give rise to a specific kind of literacy?

We have found two notions, those of **genre** and **register**, to be helpful in this regard. The idea of **genre** arises from the observation that disciplines have their own characteristic ways of communicating. These genres are adopted by people literate in those disciplines and have to be learned by those who are not. Both science and mathematics have such distinctive styles of expression, which may well act as a barrier to effective communication for people who do not understand them. Acceptable genres for science and mathematics share a number of features in common; communication is often in the past tense, the passive voice, and the third person. There is a premium placed on economy of expression and impersonality. Scientific communication is often descriptive, to ensure that experimental details or data are described faithfully so that others could reproduce them precisely. Care is exercised to clarify the distinction between observation and inference, and a suitably detached and impartial tone adopted. Mathematical writing is more rarely descriptive, but rather attempts to provide a convincing justification for a set of conclusions. Again, there is a premium on impersonality and brevity, and it is common to use quite abstract symbolism to abbreviate an argument substantially.

Thus, the characteristic genres of mathematics and of science are in marked contrast to other genres of human expression. Many forms of writing are distinguished by an emphasis on persons rather than events or arguments, the use of the first and second persons, the present and future tenses, the use of deliberate ambiguity, irony or humour, and other features such as persuasion noticeably avoided in scientific and mathematical writing. The genres associated with journalism, advertising, fiction writing and business letters also differ markedly from those of mathematics and science. Furthermore, genres may, and do, change over time. Sutton (1989) cites the example of Darwin's writing, among others, to show how the genre has changed over time. Those interested in the origins of some of the characteristics of the genre of scientific writing will find his review interesting.

The idea of **register** is concerned with the specific language elements employed by a discipline such as science and mathematics. In the main, registers consists of words and phrases used in technical ways that must be understood if literacy is to be achieved. Some science and mathematics words and phrases are clearly part of the registers, since they are technical terms that have no other meanings. Examples include 'isotope' and 'integer'. However, many other register elements consist of everyday words and phrases, which at first appear to have a well understood meaning. However, contrast, the intended meanings of the two syntactically similar statements:

> In general, people who like science like some parts of mathematics.
>
> In general, the product of two odd numbers is odd.

Similarly, in science, the sentence:

> A circuit was made and tested.

uses the words 'circuit' and 'tested' in different ways from:

> They made a bike circuit in the park and tested it out with their friends.

Readers of this journal will be able to find many other examples of these kinds, since they are likely to be mathematically literate and/or scientifically literate and thus will have learned to make distinctions between register elements and more common, looser, usage.

It seems that so-called 'popular' accounts of science and mathematics are, in fact, popular for the precise reason that they remove many of the distinctively scientific features of text, the genre and the register, to render them accessible to the populace. However, if students are to become mathematically or scientifically literate, they need to deal with mathematics and science as it is communicated by mathematicians and scientists, and not need to rely on the popular versions. Students will need some focussed help in dealing with the genre and register of these two disciplines: such help will necessarily involve all of reading, writing, speaking and listening in these domains.

Secondary Literacy Inservice Package for High School Science and Mathematics

In the light of the fresh perspective on literacy sketched so far, the task of the project was to produce professional developmental materials that would help teachers to come to grips with the implications for their curriculum and teaching. In this section of the paper, we outline the process of developing the package, describe briefly its contents and the ways in which we envisage that it would be used.

Assumptions underlying the package

The genesis of the *Secondary Literacy Inservice Package for High School Science and Mathematics*, included the observations that **literacy** has been defined frequently as the responsibility of specialist language teachers, notably teachers of English, and that concerns for **illiteracy** have overshadowed concerns for literacy. We hope that the package will challenge these observations.

The package is based on the view that literacy involves four related aspects of reading, writing, speaking and listening. If we examine the typical daily pattern of activities in almost any science or mathematics classroom in Australia, at almost any level of schooling, we quickly find evidence of the central place of these aspects of literacy in education. Students are expected both to interpret information and to communicate information. Some information is written, such as that in a textbook, a reference book, a worksheet or a blackboard summary. Other information is spoken, some by the teacher, some by peers and some by other sources, such as audiovisual aids. Students communicate in writing and orally, to both the teacher and their peers as well as privately to themselves. These literacy aspects are critical to student success in mathematics and science. Indeed, as the NCTE (1993) noted:

> No matter what the subject, the people who read it, write it and talk it are the ones who learn it best.

We hold the view that specialist teachers of mathematics and science are the most likely people to whom students have access that are literate themselves in mathematics and science. We thus assume that mathematics and science teachers are best placed to help students become more literate in either of these two domains.

As well as a concern for literacy as a prerequisite for efficient learning, we also have a concern for literacy as a goal in itself. The idea of a literate person being one well-versed in literature needs to be extended, in our view, to the disciplines of mathematics and science. We would hope that school graduates could read popular accounts of scientific and mathematical endeavours, or make sense of a media presentation on recent discoveries in mathematics and science, even if they had no intention of pursuing careers in these areas. In the same way, we would hope that school graduates could attend a modern play or read a serious magazine, even if their careers were in quite different spheres of activity to the theatre and journalism. Of course, there are some students in our schools for whom literacy in mathematics and science has an even greater significance, since they intend to pursue careers that involve these disciplines. For such students, the school needs to provide the essential groundwork for the development of a high level of technical expertise, so that they can be helped to become autonomous consumers and producers of information in these fields.

Working through the package

The package has been constructed to provide a framework for attention to literacy in mathematics and science in an individual school. It is assumed that the teachers at a school will arrange the necessary time to meet for this purpose over a substantial period, of at least one school term. It seemed unlikely that deep change to the literacy practices of a science or mathematics department could even be understood, much less affected, by a short concentrated burst of attention, of the kind that much inservice work provides. We assume, too, that the group meetings will be interspersed with individual classroom activity and reflection, so that teachers in a school can discuss aspects of literacy from their own recent experience, and draw upon their own resources, such as the school's text material. We expect that such a structure caters for the unique characteristics of a school. Although some schools will have access to outside help, perhaps in the form of a consultant or a systemic inservice program, the package has been produced on the minimal assumption that teachers have access only to some time to meet together.

To make the package manageable, we have broken it into a series of six modules, each concentrating on a single aspect of literacy. Such fragmentation can be hazardous, since we can lose sight of the forest for the trees. However, the hazards are reduced by the continuing contact teachers have with their classes, in which all the aspects of literacy are of daily significance. The six modules are:

What is literacy?

Literacy in science and mathematics

Cooperative work in science and mathematics

Listening and talking in science and mathematics

Writing in science and mathematics

Reading in science and mathematics

We expect that teachers will adjust the package to suit their circumstances. We are aware that some schools have substantially different concerns from those at other schools. For example, schools with substantial numbers of students for whom English is a second language will naturally emphasise different aspects of literacy from those schools that don't have many students in this category.

We envisage that a leader will be chosen by the staff who decide to work through the package. This person is not expected to be a 'language expert', as the package is expected to stand alone. Instead, the role of the leader is to coordinate the meetings, arrange for appropriate equipment and generally to ensure a smooth passage. During meetings, participants work collaboratively through a module. Each module is different, but generally there is material to read, videotapes to watch, ideas to discuss and the like. Between meetings, participants are expected to reflect on their classroom practice in the light of the module currently being worked through.

We acknowledge that mathematics and science are different disciplines. However, we think that there are advantages of science and mathematics teachers collaborating to foster literacy in their school. We can understand literacy in mathematics better if we have the opportunity to think about how it is different from literacy in science, as well as the opportunity to see the similarities. Further, the benefits of a group of mathematics and science teachers, who are usually teachers of the same students, getting together for professional development purposes are substantial, including the opportunity to better understand each other and the opportunity to learn of successful teaching practices across the discipline boundaries.

Trialing the package

In 1993, the complete package was trialed by staff of a government high school in Perth, Western Australia. The school had an enrolment of approximately 1200 students. As a consequence of this extended experience, a number of conclusions were drawn:

- The idea of appointing a separate leader/coordinator was a good one. In this particular case, the person concerned was actually not a member of either the mathematics or science department, but nonetheless took administrative responsibilities for the meetings, and conducted each of the sessions.
- Although the extended time line was of value, administrative and scheduling problems arose, and it was difficult to maintain momentum over such a period. The school suggested that a smaller number of sessions, appropriately spaced, may be a better way to work.
- It was of value for the science and mathematics departments to come together to work on the issues of literacy. Although the two groups had different points of view on many issues, the opportunity to deal with some of the differences, and understand them, was regarded as seeing the problems more clearly and wanting to find some practical resolution of them.
- The package was successful in terms of raising the consciousness of teachers about issues of language, literacy and learning. Although it did not resolve the problems identified, it helped teachers to reach a better understanding of the problems and wanting to address them.

In summarising the experience, the participants reported:

- We would certainly recommend this package to science and mathematics departments. It creates inter-departmental awareness that literacy belongs to all subjects as a tool for learning. It can break down insular barriers amongst staff and departments.
- The package certainly creates an awareness of the student's viewpoint of material and languages presented by both subject areas. This alone was worth the involvement and time.

Reviews of the package are published in *ASTJ* (Nixon, 1993) and the *Australian Mathematics Teacher* (Long, 1993).

Conclusion

In helping **all** our students become literate in science and mathematics, we are helping them become more effective learners. We are helping them to listen, speak, write and read in ways which will help them learn efficiently and effectively. Helping students with these aspects of language is not providing 'icing on the cake'. It is providing students with the means to learn. We hope that this process of helping students learn effectively will lead to the product commonly referred to as the **scientifically or mathematically literate person.** Our students will be able to listen, speak, write and read science and mathematics.

Literacy is important, both as means and as end. It is most likely to improve if we who are scientifically and mathematically literate ourselves do something specific about it. It is unreasonable, and unlikely to be successful in any event, to expect that other members of the school community will deal with literacy in science and mathematics. It is our hope that teachers will find this package helpful in this important task.

Postscript

We have now sent multiple copies of the packages to the heads of each State and Territory Education Department. Schools who wish a copy of their own can send $10, to cover the cost of a courier, to: T. Widger, Murdoch University Bookshop, Murdoch University, Murdoch, WA 6150. Please give an actual address, not a post box number.

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As a final note, the CSIRO has recently brought CREST to Australia and, with funding received from DEET plans to set up regional co-ordinators in science centres around the country to implement the scheme within each state. Once systems are set up, these co-ordinators would organise the establishment and assessment of CREST projects within participating schools in their areas.

With teachers who are willing to try innovative methods we can look forward to the same success here in Australia which the CREST scheme has enjoyed elsewhere in the world.

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