

Science literacy strategies anchored in nanotechnology

David Devraj Kumar, Susanne I. Lapp,
Philomena Marinaccio and Kimberly K. Scarola

A modern context such as nanotechnology brings new excitement to learning basic science knowledge

This article is about teaching science using literacy (reading, writing, speaking, listening and viewing) strategies anchored in nanotechnology. Motivating students to learn science remains a challenge in the United Kingdom and throughout the world. Using the nano world of science and technology can help provide motivation:

It brings a new excitement to many subjects... Students see amazing applications that result from nanoscience, and learn that an understanding of basic science is necessary to make them happen. For example, CDs wouldn't exist without nanotechnology; neither would the new colour-changing paints on luxury cars and motorbikes; transparent sunscreens

and many new cosmetics use nanoparticles; the technology behind stay-clean chinos (and even now school uniforms) is nanotechnology. These developments depend on a fundamental knowledge of chemistry, physics and biology. (Anon, undated).

ABSTRACT

This article addresses teaching science using literacy (reading, writing, speaking, listening and viewing) strategies anchored in nanotechnology. Motivating students to learn complex scientific concepts such as atomic structure can be challenging, but using a modern context such as nanotechnology brings new excitement to learning the basic science knowledge. Nanoscience pedagogy presents unique literacy challenges because of the technical vocabulary and abstract concepts involved. Encouraging students to use effective literacy strategies to help them gain a better understanding of scientific concepts has been helpful in our own contexts in the United States and we offer these suggestions to others in an adapted format. This approach provides students with scaffolded reading experience. Metacomprehension strategies are suggested for use before, during and after reading nanotechnology core texts to provide instructional scaffolding especially relevant to the needs of this content area. Exploratory, response and essay writing are highlighted as useful informal tools.



Figure 1 Compact discs wouldn't exist without nanotechnology (used with permission, © 2006, Kimberly Scarola).



Figure 2 Textiles, supplements, sunscreens – just some of the many products dependent on nanotechnology (used with permission, Project on Emerging Nanotechnologies, © 2006, David Hawxhurst, Woodrow Wilson Center).

Nanotechnology

The prefix ‘nano’ refers to sizes of the order of one-billionth of a metre or one-millionth of a millimetre, so *nanotechnology* refers to the various technologies used to produce materials at this scale (see Figure 3 for examples). Nanotechnology is one of the fastest growing technologies of the twenty-first century, as indicated by, for example, a 50 times increase in the number of publications on the subject between 1995 and 2004 (Kumar, 2006a). Nanotechnology ‘implies the ability to generate and utilize structures, components, and devices with a size range from about 0.1 nm (atomic and molecular scale) to about 100 nm (or larger in some situations) by control at atomic, molecular, and macromolecular levels’ (Roco, 1999: 131). A combination of developments in scanning tunnelling microscopy, solid-state physics and chemistry, molecular biology, molecular engineering and synthetic chemistry form a major part of nanotechnology. For example, nano-sized indium melts at a much lower temperature than the

bulk metal (Allen, 2002). Copper in extremely thin layers, in the presence of a magnetic field, becomes a poor conductor of electricity (Loder, 2005).

Figure 4 shows nanoscale writing of a passage from the *Encyclopaedia Britannica* on a plastic slide or biochip, using a scanning electron microscope at the Nanoscience Centre at Cambridge University: ‘Each letter is 250 nm tall. If one letter is considered to be equivalent to 8 bits then the storage density achieved here is around 1000 Gbit in⁻². Or you would be able to write the whole Oxford poetry dictionary on the area of one letter on this page’ University of Cambridge, 2004: 1). As Siegel (1999) said:

Nanostructure science and technology is a broad and interdisciplinary area of research and development activity that has been growing explosively worldwide in the past few years. It has the potential for revolutionizing the ways in which materials and products are created and the range and nature of functionalities that can be accessed. (p. xvii)



Figure 3 ‘The scale of things’ (used with permission, Office of Basic Energy Sciences, United States Department of Energy. http://www.science.doe.gov/bes/scale_of_things.html).



Figure 4 Nanoscale writing of a passage from the *Encyclopaedia Britannica* on a plastic slide or biochip, using a scanning electron microscope (used with permission, © 2004, Nanoscience Centre, Cambridge University, UK).

Scaffolded reading

When teaching areas of factual content, it is insufficient to teach solely academic content: teachers need to be responsible for content literacy as well. Nanotechnological pedagogy presents literacy challenges as unique to this discipline as the technical

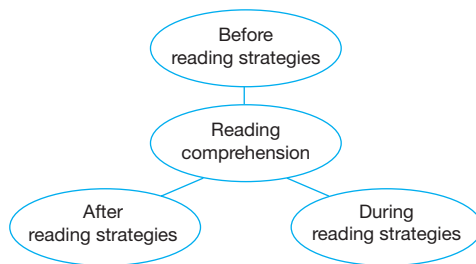


Figure 5 Strategies for improving reading comprehension in subject-content areas.

vocabulary and abstract concepts. Imagine the vocabulary and comprehension demands of defining nanotechnology as the controlled manipulation of matter at the nanometre scale (0.000 000 001 m). Therefore, nanoscience education needs to provide students with a scaffolded reading experience (SRE). We will suggest metacomprehension strategies for use before, during and after reading nanotechnology core texts to provide instructional scaffolding specific to the needs of this content area (Figure 5).

The pre-reading phase of an SRE for teaching expository text is when the reader needs to activate their prior knowledge, set a purpose for reading, make predictions and learn new vocabulary. For example, to activate schema prior to reading about

Table 1 Anticipation guide for introducing nanotechnology (Knop, 2005)

Agree	Disagree	
		Nanotechnology is research and technology development only at the macromolecular level.
		Nanotechnology is in the length scale of 1–100 nanometre range.
		Nanotechnology is the ability to control or manipulate on the atomic scale.
		A nanometre is one-billionth of a metre.
		The width of a human hair is approximately 1 nanometre.
		Federal funding for nanotechnology has increased substantially in the past few years.
		The United States is the only country to recognise the economic potential of nanotechnology.
		Nanotechnology has the potential to change our economy.
		Major applications for nanotechnology are years away.

transmission electron microscopy (TEM), students should brainstorm prior knowledge about light microscopes. Similarly, the teacher could divide the class into small groups and get students to brainstorm and write a list of as many words as they can that are associated with the concept. To encourage reading for meaning, teachers need to raise the curiosity of students and encourage them to set a purpose for reading. This ‘purpose for reading’ can be set by having students predict whether statements taken from the actual text to be read are true or false (see Table 1). Encouraging students to make predictions on information (Knop, 2005) activates their prior knowledge and helps them to establish a purpose for reading.

Innovations on this strategy include adding a Reaction Guide, where students confirm whether their predictions were correct and provide the page in the text where they found the information or use a combination of their background knowledge and the author’s message to defend their reasoning.

The vocabulary used in nanotechnology texts is often not part of students’ everyday reading and listening activities. Technical words often do not have specific concrete frames of reference. Vacca and Vacca (2005) suggest teaching content-area vocabulary by teaching technical vocabulary in relation to other related terms. In a Semantic Feature Analysis graphic organiser, students list the technical

vocabulary words down the left side of a table and list characteristics of these words or concepts along the top. For example, students could list different kinds of microscopes in the first column and include characteristics such as ‘uses magnetic lenses’, ‘uses light’, ‘uses glass lenses’ and ‘allows visualisation of thin slices of materials’ in the top row (see Table 2). When the content contained in intersecting columns and rows is correct students place a plus sign. If the information is not accurate they place a minus sign. By investigating likenesses and differences between content-related vocabulary students learn new words and refine previously held conceptions. This multi-phase strategy can be used before, during or after reading.

During reading, students need to be active readers and learn to interact with the core text. The Reciprocal Teaching and Reciprocal Questioning (RTRQ) strategies of Palinscar and Brown (1984) involve teachers and students in reciprocal questioning, predicting and summarising techniques while reading sections of a text. The RTRQ strategy begins with the teacher assigning a section of text to be read by students and then, together, the teacher and students proceed through the RTRQ questioning stages, addressing key components of the strategy. An example is given in Tables 3 and 4. Here, the teacher sets the stage for the RTRQ strategy by asking students to read a portion of a newspaper article. The

Table 2 Semantic Feature Analysis graphic organiser for teaching technical vocabulary for studying nanostructure properties (Nanotech Facts, 2005)

	<i>Allows direct mapping of surface features</i>	<i>Allows visualisation of thin slices of materials</i>	<i>Uses magnetic lenses</i>	<i>Uses light</i>	<i>Uses glass lenses</i>
Transmission electron microscopy					
Scanning electron microscopy					
Scanning probe microscopy					
Atomic force microscopy					
Conventional microscope					

teacher then poses the question, 'Why do you think the government should fund nanotechnology research?' Students respond to the teacher's query by offering predictions and clarifying these predictions as they continue to read and respond to the text. At the end of the activity students summarise the reading section to confirm or disconfirm their predictions.

Once this portion of the activity is complete, roles are reversed and students have the opportunity to initiate a new follow-up question based on further reading of the same text. For example, students might ask, 'What is the worldwide government funding for nanotechnology?' The teacher and students continue to take turns making predictions and summarising different sections of text. Although this strategy works well with struggling readers, it is equally useful when reading difficult text at the secondary level. Teacher-modelling of questioning, predicting and summarising techniques provides the necessary scaffolding that these challenging texts demand.

During reading, students also need to determine what information is important to remember, and to organise this information in a meaningful way. The

use of a 'study guide', as illustrated in Box 1, helps secondary students to comprehend difficult text selections by providing instructional support and direction in developing effective reading strategies. This study guide was developed for an excerpt from an American nanotechnology core text (Clinton, 2000) and based on a speech by Dr Baltimore from the Science Foundation as he shares his views on the future impact of nanotechnology research.

Writing activities

To create additional opportunities for students to demonstrate their understanding of content-area reading, it is essential for teachers to integrate writing activities in their classrooms. Students who are encouraged to write about content-area topics and integrate writing and reading activities are more likely to learn additional content, to understand it better and to remember it longer (Vacca and Vacca, 2005).

There are a range of science-content writing activities, from exploratory to essay writing, which

Table 3 Reciprocal Teaching and Reciprocal Questioning strategy chart (teacher version)

Teacher initiating activity	Reading material: Newspaper article (<i>XYZ Times</i> , 2007) <i>Parliament agrees to increase funding for scientific research.</i> [paragraphs 1–4] Date: 30.3.2007	
Question	Why do you think the government should fund nanotechnology research?	
Prediction	British researchers have convinced members of Parliament to spend additional funds to research nanotechnology.	
Clarification	Nanotechnology is a cost-effective way to produce newer and better products for British consumers.	
Summary statement	British researchers have identified cost-effective ways to produce materials for public consumption.	
Was the prediction confirmed?	Yes [<input checked="" type="checkbox"/>	No
Details	After reading and discussing aspects of the article, we believe that Parliament has made the correct decision to increase funding for scientific research. According to the article, British researchers are exploring the potential impact of nanotechnology applications for public consumption. Preliminary research suggests that increased use of nanotechnology research will decrease the final costs of producing a product and consumers will witness savings of 20–30% on personal consumer items.	

Table 4 Reciprocal Teaching and Reciprocal Questioning strategy (student version)

Student initiating activity	Reading material: Newspaper article (<i>XYZ Times</i> , 2007) <i>Parliament agrees to increase funding for scientific research</i> . [paragraphs 5–9] Date: 3.4.2007
Prediction	Other countries are beginning to invest huge amounts of money in nanotechnology research.
Question	What is the worldwide government funding for nanotechnology?
Clarification	British researchers want to remain competitive with other international researchers.
Summary statement	For British researchers to remain competitive in the growing worldwide field of nanotechnology research, it is imperative that Parliament agrees to spend additional money to fund future nanotechnology research. See results from chart based on international scientific research funding (Japan, China, United States, and European Union).
Was the prediction confirmed?	Yes [<input checked="" type="checkbox"/>] No
Details	Nanotechnology research is beginning to dominate research interest among scientists worldwide. These researchers are constantly learning about new and better products that will benefit consumers; however, additional funding is needed to determine the most productive and cost-effective means of producing these products. British researchers realise that additional funding will help British industries remain competitive with other world markets as they begin to produce these new materials.

BOX 1 Example of use of a ‘study guide’

‘My budget supports a major new national nanotechnology initiative worth \$500 million. Cal Tech [California Institute of Technology] is no stranger to the idea of nanotechnology, the ability to manipulate matter at the atomic and molecular level, ... you will find more enduring uses for nanotechnology. Just imagine, materials with 10 times the strength of steel and only a fraction of the weight; shrinking all the information at the Library of Congress into a device the size of a sugar cube; detecting cancerous tumors that are only a few cells in size. Some of these research goals will take 20 or more years to achieve. But that is why – precisely why – there is such a critical role for the federal government [in funding nanotechnology research].’ (Clinton, 2000)

Study guide

- The main idea introduced is ---
- It can be defined as ---
- An example is ---

The author elaborates on the idea by discussing the differences between --- and ---

teachers may incorporate into their courses. Teachers may wish to engage students in exploratory or first-draft writing before or after the students read content material. Exploratory writing helps students to collect together what they already know and connect it to what they will be reading. Essay writing, by contrast, is a more formal type of writing and requires that the students think more deeply about the subject that they are studying. Essays are usually longer and effectively integrate content information with accurate written form.

Exploratory writing

Brainstorming and clustering

Brainstorming and clustering are exploratory strategies for pre-reading and pre-writing because they help students establish a purpose as they think about ideas and concepts they are about to study. Although brainstorming and clustering can easily be implemented at the primary level, students at the secondary levels can also benefit from these techniques.

Brainstorming activities usually involve the entire class and the teacher models the activity for the students. Brainstorming begins as the teacher presents a new topic, idea or concept to students. For example, the teacher might ask the students to suggest as many ideas as possible about the topic. As students share ideas, the teacher records them on a whiteboard, so that all students see the ideas generated. Figure 6 illustrates the response when a teacher encouraged students to list issues associated with nanoscience technology in a 5-minute brainstorming session.

Once students have listed their ideas, they can begin to organise and extend their lists into groups or clusters of related ideas. Key words or 'nucleus' words or concepts are identified from the brainstorming lists and are then surrounded with other associated words (Figure 7). This technique allows students to

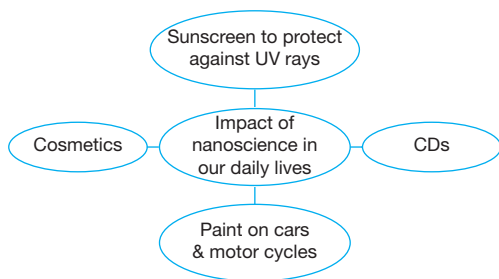


Figure 6 The results of a 5-minute brainstorming exploratory strategy.

gather ideas for writing and helps them connect the ideas within categories of information.

Teacher-led clustering activities provide students with opportunities to practise pre-writing strategies. Students should be encouraged to create their own clusters for writing as soon as they understand how to use this strategy effectively.

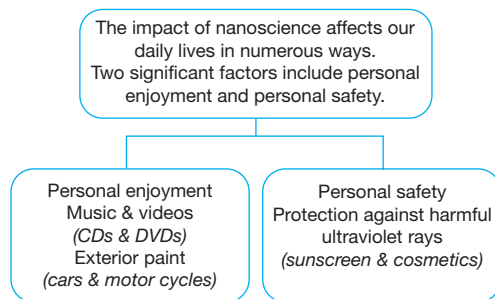


Figure 7 Using the clustering exploratory strategy after brainstorming ideas.

Letter-writing campaign

Another useful exploratory strategy that can be used in content-area writing is the 'Letter-writing campaign'. This role-playing strategy involves getting students to write letters in response to the material that they are studying. Students frequently discover that they incorporate a great deal of imaginative, interpretive and evaluative thinking as they compose their letters for a real audience. The example in Box 2 (overleaf) demonstrates how UK students used the above brainstorming/clustering pre-writing activity as a catalyst for writing a letter to the Prime Minister. In their letter, students request additional research funding to study the use of nanoscience technology in the prevention of skin cancer in the United Kingdom. Once students have completed and carefully edited the letter, it is sent off by the teacher and a reply awaited.

Response writing

Writing in response to any learning event, such as reading, a lecture or an experiment, is an important technique with real-life purposes. Response writing allows students to develop their thinking and encourages them to think about new information based upon personal reflection (Fisher *et al.*, 2007). Professionals from all walks of life have used response writing to record everyday events in their lives and the issues that concern them (Tompkins, 1990). Response writing can be easily incorporated into science-content courses at the secondary level

BOX 2 Example of letter writing as an exploratory strategy

Dear Mr Prime Minister

Greetings from Middleton Secondary School. We are students in Mrs Mitchell's year 8 science course. We are studying the effects of nanoscience technology in our daily lives. We were all very excited to learn how nanoscience technology makes our lives much better. In fact, this technology improves the quality of CDs, paint on cars, cosmetics but, most importantly, creates sunscreens to protect people from the effects of harmful ultraviolet rays (UV) rays. Too many people die each year in the United Kingdom and abroad from skin cancer that develops when people are exposed to harmful UV rays. We would like to ask you, as Prime Minister of the United Kingdom, to consider spending additional money to further explore this very important link between sunscreen protection and nanoscience technology. Thank you very much for your consideration and we look forward to hearing from you very soon.

Very sincerely,

Mrs Mitchell's year 8 science course

Middleton Secondary School

as students begin to generate ideas, create a record of thoughts in response to what they are reading and learning, and clarify ideas and issues that they are studying.

Teachers may create useful prompts to encourage students to explore a range of ideas by creating scenarios to stimulate thinking. An example of a scientific scenario builds on our previous discussion related to nanoscience technology. In this example, the science teacher assigns students with a prompt in which they assume the role of a science researcher studying the impact of nanoscience technology on the negative effects of the sun's UV rays on humans. Students must think about ways in which they might use some of the money awarded to them (£5 million) from the Prime Minister's Nanoscience Grant. Response-writing prompts might include the following:

- What research would science researchers need to conduct?
- What materials would they need to purchase for their labs?

- What type of support staff would they need to conduct their research?

Students may require more guided development of their response-writing efforts and can elect to incorporate free-writing guidelines or prompts (Hancock, 1993). Free-writing prompts can be easily adapted to informational texts and can include several writing suggestions.

Students who complete informational response-writing prompts have the opportunity to carefully monitor their ability to grasp complex aspects of their reading. Students are encouraged to express freely their ideas and personal responses to the readings. They can include connections to other ideas that they have previously encountered in class discussions or other readings. Students are encouraged to actively critique and monitor their own understanding of material. Informational-writing responses can frequently be used to help initiate further classroom discussion or debate on a topic (Table 5).

Teachers can use student response writing as a gauge to determine whether students have a firm grasp of the content material or whether some form of remediation is necessary. Teachers can also use student response writing as a way of developing and enhancing students' understanding of a topic through metacognitive discussions and classroom demonstrations.

Essay writing

Exploratory and response writing are useful informal tools to assist students as they explore science content that they are reading and learning about in class. Essay writing, however, is a more formal and finished production of students' written understanding of the content. In essay writing, students are required to think more deeply about the subject matter, integrate their new knowledge with prior knowledge and express their thoughts in an organised and synthesised manner. Teachers should carefully scaffold essay-writing experiences for students by designing good essay assignments, which contain prompts that are explicit yet maintain students' interest and curiosity.

One effective technique for encouraging writing in upper secondary science courses is the Role, Audience, Form and Topic (RAFT) essay (Holston and Santa, 1985). The RAFT writing activity is a creative way for students to demonstrate their understanding of content. RAFT assignments allow students to communicate content-related details by choosing a viewpoint other than their own, an audience other than the teacher and a form other than the standard essay. Three possible sets of roles,

Table 5 Informational response-writing prompts

Pages read: _____	
Date: _____	
<i>Informational response-writing prompts</i>	<i>Student response</i>
What are my predictions while reading?	
What questions come to mind while I am reading?	
What are my feelings, thoughts and opinions about the reading?	
What am I thinking about as I read this section?	
How can I relate this reading to my own experiences?	
Is this information easy or difficult to understand?	
Do I want to learn more about this topic?	

audiences, formats and topics for a RAFT based on the reading of a nanotechnology core text are suggested in Box 3 (overleaf).

Discussion and summary

Nanoscience is clearly one of the most exciting scientific concepts to date and its impact on our daily lives is significant. It should be the goal of all science educators to introduce students to the possibilities of this new and cutting-edge scientific application. In order to create this learning opportunity for students, it is imperative that curriculum materials be effectively designed so that this cognitively demanding information can be easily adapted for primary and secondary classrooms.

Currently, it is very difficult for teachers to implement reading and writing activities based on nanoscience and nanotechnology in science classrooms since curricula do not specifically address it. Curriculum materials addressing nanoscience have not yet been developed. Although curriculum developers scramble to introduce more challenging terminology and concepts in younger and younger grades, currently, there are no (widely available) science materials for primary and secondary levels that specifically address nanoscience and nanotechnology topics.

Curriculum designers must also consider the academic needs of the growing non-native speaking (NNS) students of English and adapt scientific materials and curriculum materials to meet their needs. Scientific topics geared to NNS students must be incorporated effectively into science curriculum standards. It behoves curriculum designers to incorporate effective reading and writing literacy strategies to facilitate student learning. One example of integrating effective reading strategies in an NNS science-content course would be to introduce NNS students to Closed Captioned Videos, which encourage the student to read the text captions while listening to the material. Combining reading and listening skills may prove to be useful for teaching scientific information to NNS students.

Finally, the role of adequately prepared classroom science teachers in the United States cannot be ignored (National Research Council, 1996). Teachers are the key to improving school science (National Commission on Teaching and America's Future, 1996) and their familiarity with, and knowledge of, scientific concepts is crucial in motivating and engaging students to learn more about science. Results from a nano quiz demonstrated an overall correct score of 57.3 per cent among prospective primary and secondary teachers, indicating teachers'

BOX 3 Possible scenarios for Role, Audience, Form and Topic (RAFT) essays**Composition 1**

Write a set of instructions from a red blood cell (that is in the 2.5 nanometre range) to a nanotechnologist who is doing his job for the first time. Make sure the instructions tell the new nanotechnologist how to perform his job effectively (*Medical News Today*, 2004).

Role: A red blood cell.

Audience: A new 'inexperienced' nanotechnologist.

Format: A set of instructions.

Topic: How to perform the duties of a nanotechnologist effectively.

Composition 2

Write a letter of apology from a 'jumbotron lamp', a nanotube-based light source that uses field-emitted electrons to bombard a phosphor (Jumbotron lamps light many athletic stadiums), to Sumio Iijima, who discovered a new form of carbon in 1991 – the nanotube. In 1995, it was recognised that carbon nanotubes are excellent sources of field-emitted electrons. By 2000, the jumbotron was a commercial product. As a jumbotron lamp, you will be describing possible reasons why you are not working (Nanotech Facts, 2005).

Role: A jumbotron lamp.

Audience: Sumio Iijima.

Format: A letter of apology.

Topic: Possible reasons why the lamp is not working.

Composition 3

Write a newspaper editorial from a cancer patient to the general public describing the underappreciation of the vital work done in discovering a revolutionary new form of non-invasive cancer therapy. The non-invasive cancer treatment uses a combination of harmless near-infrared light and benign gold nanoshells to destroy tumours with heat (*Medical News Today*, 2004).

Role: Cancer patient.

Audience: The general public.

Format: A newspaper editorial.

Topic: The underappreciation of the development of a new form of cancer treatment at Nanospectra Biosciences Inc.

lack of familiarity with some basic scientific concepts related to nanoscience (Kumar, 2006b). Without the participation of teachers in early and ongoing science literacy pedagogy, addressing nanoscience and nanotechnology information in the school science curriculum would be difficult.

Science teachers and teacher educators must spearhead efforts to introduce nanoscience and nanotechnology within their science methods classes. If prospective science teachers see how nanoscience technology is effectively integrated into the school science curriculum, they will be

more inclined to motivate and interest their students in these innovative scientific applications. This article has sought to encourage readers to apply

literacy (reading and writing) strategies as one way of introducing students to the possibilities of nanoscience and nanoscience technology.

References

- Allen, L. H. (2002) Nanocalorimetry studies of materials: melting point depressions and magic nanostructures. *NNUN Abstracts*, **40**.
- Anon (undated) How is the nanotechnology relevant to the Scottish school curriculum? Available at: <http://www.euronanoforum2005.org/schools/Relevance%20of%20nanotechnology.pdf> Accessed 20 January 2006.
- Clinton, W. (2000) President Clinton's remarks on national investment in science and technology, 21 January 2000. Available at: http://clinton4.nara.gov/WH/EOP/OSTP/html/0022_5.html.
- Fisher, D., Brozo, W., Frey, N. and Ivey, G. (2007) *Fifty content area strategies for adolescent literacy*. Upper Saddle River, NJ: Merrill/Prentice-Hall.
- Hancock, M. R. (1993) Exploring the meaning-making process through the content of literature response journals: a case study investigation. *Research in the Teaching of English*, **27**, 335–368.
- Holston, V. and Santa, C. (1985) A method of writing across the curriculum that works. *Journal of Reading*, **28**, 456–457.
- Knop, K. (2005) Nanotechnology: a big future for small things. *Credit Suisse Emagazine*. Available at: <http://emagazine.credit-suisse.com/article/index.cfm?fuseaction=OpenArticle&aoid=94592&lang=EN> Accessed 20 July 2005
- Kumar, D. D. (2006a) Nano world of science and technology. *The Chemist*, **83**(1), 7–10.
- Kumar, D. D. (2006b, January) Nano quiz performance of prospective teachers. Presentation at annual meeting of the Association for Science Teacher Education, Portland, OR.
- Loder, N. (2005) Small wonders: a survey of nanotechnology. *The Economist*, 1 January 2005, 1–12.
- Medical News Today* (2004) Nanoshells cancer treatment proves effective in first animal test. *Medical News Today*. Available at: www.medicalnewstoday.com/medicalnews.php?newsid=9759 Accessed 20 July 2005.
- National Commission on Teaching and America's Future (1996) *What matters most: teaching for America's future*. New York: NCTAF.
- Nanotech Facts (2005) National Nanotechnology Initiative (NNI). Available at: http://www.nano.gov/html/facts/home_facts.html Accessed 20 July 2006
- National Research Council (1996) *National science education standards*. Washington, DC: National Academy Press.
- Palinscar, A. S. and Brown, A. L. (1984) Reciprocal teaching of comprehension-fostering and comprehension-monitoring activities. *Cognition and Instruction*, **1**, 117–175.
- Roco, M. C. (1999) Research programs on nanotechnology in the world. In *Nanostructure science and technology: a worldwide study*, ed. Siegel, R. W., Hu, E. and Roco M. C. Ch. 8. National Science and Technology Council (NSTC) Committee on Technology, Interagency Working Group on NanoScience, Engineering and Technology (IWGN). Available at: <http://itri.loyola.edu/nano/final/>
- Siegel, R. W. (1999) Executive summary. In *Nanostructure science and technology: a worldwide study*, ed. Siegel, R. W., Hu, E. and Roco M. C. pp. xvii–xxiii. National Science and Technology Council (NSTC) Committee on Technology, Interagency Working Group on NanoScience, Engineering and Technology (IWGN). Available at: <http://itri.loyola.edu/nano/final>
- Tompkins, G. E. (1990) *Teaching writing: balancing process and product*. Columbus, OH: Merrill.
- University of Cambridge (2004) *Nanoscience*. Available at: <http://www-g.eng.cam.ac.uk/nano/>
- Vacca, R. T. and Vacca, A. L. (2005) *Content area reading: literacy and learning across the curriculum*. Boston, MA: Pearson/Allyn and Bacon.

David Devraj Kumar, Susanne I. Lapp, Philomena Marinaccio and Kimberly K. Scarola all work at Florida Atlantic University, College of Education, Davie, Florida.
