Nanoscience and Nanotechnology for the Middle Years

By Wan Ng

Capturing students’ interest in science at the junior levels is crucial to not only improving the uptake of science at senior levels but to promoting science literacy in all students in order to prepare them for a society that is very science and technology driven. This paper presents nanotechnology as an emerging science that is both factual and imaginative to motivate science learning with middle years students. Its objective is to present a trialled module on nanoscience and associated technologies that is suitable for middle years students. The paper will also present the views of 139 Year 6 students on learning about nanotechnology, and in particular those aspects of the topic that left an impression on them at the end of a nanotechnology day.

Introduction
Capturing students’ interest in science at the junior levels is crucial to improving the uptake of science at senior levels and promoting science literacy in all students, in order to prepare them for a society that is very science and technology driven. Nanotechnology is already having an impact on society, and this will increasingly be felt as its products increase in number and become more commercialised. In a relatively short span of about twenty years of research, over 800 ‘manufacturer-identified nanotechnology-based consumer products’ are reported by the Project on Emerging Technologies (PET) to be on the market. Nanoscale materials are now found in food, medicine, fabric, electronics, cosmetics, cars, homes and gardens. We already educate our students to be critical thinkers about biotechnology [e.g. in-vitro fertilisation, cloning, GM food], nuclear versus other energy options, drugs and their impact on the individual and on society. We now need to provide them with some understanding of nanotechnology, which some regard as the fifth industrial revolution (Tredre, 2004) and which will have a significant effect on our middle years students’ future lives. The five industrial revolutions since the 1700s are summarised in Table 1.

Nanoscience and Technology Education
An enormous amount of information and educational materials on nanotechnology is available on the World Wide Web. As an emerging science, nanotechnology has the potential to capture middle years students’ interest in both factual and imaginative ways, and motivate their learning in the entire field of science. The aim of this article is to present a module on nanoscience and associated technologies that is suitable for middle years students. Years 6-9 students are particularly targeted, although there is no reason why Years 5 and 10 students could not participate in the activities and learning. The development of the module was part of a project called Emerging Sciences for Middle Years (ESMY), funded by the Australian Schools Innovation in Science, Technology and Mathematics, a federal government initiative. The activities in the module have been presented and trialled at professional development sessions for teachers, and aspects of the module have been trialled with Years 6 and 9 students on Nanotechnology Days run by the Faculty of Education at La Trobe University. This paper will also present the responses of Year 6 students towards learning about nanotechnology, and in particular those aspects of the topic that left an impression on them at the end of the day.

<table>
<thead>
<tr>
<th>INDUSTRIAL REVOLUTION</th>
<th>PERIOD</th>
<th>ASSOCIATED TECHNOLOGIES</th>
<th>COUNTRY/COUNTRIES WHERE REVOLUTION BASED</th>
</tr>
</thead>
<tbody>
<tr>
<td>1st</td>
<td>1780-1840</td>
<td>Steam Engine; textile industries; mechanical engineering</td>
<td>United Kingdom</td>
</tr>
<tr>
<td>2nd</td>
<td>1840-1900</td>
<td>Railways; steel industry</td>
<td>Europe; England; France and Germany</td>
</tr>
<tr>
<td>3rd</td>
<td>1900-1950</td>
<td>Electric engines; heavy chemicals; automobiles; consumer durables</td>
<td>United States</td>
</tr>
<tr>
<td>4th</td>
<td>1950-1988</td>
<td>Synthetics; organic chemicals; computers</td>
<td>Pacific Basin - California; Japan</td>
</tr>
<tr>
<td>5th</td>
<td>2010-present</td>
<td>Nanotechnology; molecular manufacturing</td>
<td>Developing World; China; India; Brazil</td>
</tr>
</tbody>
</table>

Table 1: Industrial revolutions (from Tredre, 2004)
As an introduction, an overview of the history and instrumentation associated with nanotechnology and a clarification of the meaning of nanotechnology and nanoscience will be presented in the next section. This will be followed by a suggested sequence of topics and activities for the learning of nanoscience and nanotechnology at different year levels. In the closing section of this paper, the views of 139 Year 6 students on learning about nanotechnology will be summarised.

**Nanotechnology: A Brief Historical Perspective**

**Origin of the concept of nanotechnology**

On December 29th 1959, the Nobel Prize-winning US physicist Richard Feynman gave his now classic talk: "There's Plenty of Room at the Bottom" at the annual meeting of the American Physical Society at the California Institute of Technology (Caltech). He provided a vision of molecular machines building complex materials with atomic precision and the storage of information in miniaturised volume, using the example of writing "the entire 24 volumes of the Encyclopaedia Britannica on the head of a pin". His thinking on 'smallness' was inspired by 'the marvellous biological system' about which he said:

The biological example of writing information on a small scale has inspired me to think of something that should be possible. Biology is not simply writing information; it is doing something about it. A biological system can be exceedingly small, and the events are very tiny, but they are very active: they manufacture various substances; they walk around; they waggle; and they do all kinds of marvellous things—all on a very small scale. Also, they store information. Consider the possibility that we too can make a thing very small which does what we want—that we can manufacture an object that manoeuvres at that level! ([Feynman](http://www.zyvex.com/cv2000/feynman.html))

Feynman had theorised the concept of 'nanotechnology' but the actual word was invented by a Japanese Professor, Norio Taniguchi, at the Tokyo Science University. Taniguchi first presented the term in a paper On the Basic Concept of Nanotechnology, at a conference of the Japan Society of Precision Engineering in 1974. He used the word to mean production technology capable of achieving precision to the order of 1 nanometre or 10^-9 metre. In 1987, an approach to building things atom by atom (the bottom up approach) was proposed by Eric Drexler, an American engineer. In his controversial book, Engines of Creation: The Coming Era of Nanotechnology, he described devices such as molecular assemblers, assembler-based replicators, and mechanical nanocomputers.

**Instrumentation enabling nanotechnology**

The Scanning Tunnelling Microscope (STM) and the more recently developed Atomic Force Microscope (AFM) are powerful tools that provide high-resolution surface profiling and enabling manipulation at the atomic and nanoscale levels. The physicists who designed the STM in the early 1980s were Gerd Binnig from Germany and Heinrich Rohrer from Switzerland. They received the Nobel Prize for Physics in 1986. The AFM was developed by Gerd Binnig, Calvin Quate (US) and Christoph Gerber (Switzerland) in 1986. The advent of these instruments has enabled scientists and engineers to control and manipulate individual atoms and molecules with precision.

**Defining Nanoscience and Nanotechnology**

Nano means a billionth. A definition of nanoscience by the Royal Society, London (2004) is "the study of phenomena and manipulation of materials at atomic, molecular and macromolecular scales, where properties differ significantly from those at a larger scale".

For example, large particles of zinc oxide and/or titanium dioxide in sunscreen appear white while applied because they reflect all the colours of visible light while absorbing the harmful ultraviolet rays. By grinding the zinc oxide to very fine particles of about 20 nm in size, their properties change and they are able to absorb the harmful rays while allowing the visible light rays to 'slip through'.

The original meaning of nanotechnology embraces the "bottom up" approach to making nanoscale products. However, much of the work conducted under the name of nanotechnology is not nanotechnology in this traditional sense. A slightly broader definition of nanotechnology provided in the discussion paper by the Victorian Department of Innovation, Industry and Regional Development (DIIRD, 2004) is:

- the production of 'new' materials and devices from the precise placement and direct manipulation of atoms or molecules; and
- the development of products or substances that take advantage of and use the novel properties of materials less than 100nm in size. So, the production of the sunscreen mentioned above would be nanotechnology.

Although the terms nanoscience and nanotechnology are often used interchangeably on the World Wide Web, there is a distinct difference between the two terms.

**Learning about Nanoscience and Related Technology in Middle Years Schooling**

Nanoscience is not new. Year 8 students studying atoms and molecules are beginning to study on the nano-scale level. Studying chemical reactions and understanding the phenomena of bond-breaking and bond-forming is another aspect of nanoscience. Hence as part of the learning of nano-science and technology, the use of molecular visualisation software such as RasMol and Protein Explorer to assist students to 'see' how atoms fit together to form the shapes of molecules would be useful. Being able to visualise chemical structures such as caffeine, aspirin, water and glucose also helps students to better understand the concept of 'chemical' and dispel the misunderstanding that the food we eat is not 'chemicals'. The nanotechnology activities suitable for middle years students include investigating nano-sunscreen and dye solar cells, both of which make use of titanium dioxide, so visualising its structure could make learning more meaningful for students.

Nanotechnology is an interdisciplinary science encompassing physics, chemistry and biology. Its interdisciplinary nature fits well within the Victorian Essential Learning Standards (VELS) framework. In the Appendix, an example of how nanoscience and nanotechnology fit into Levels 5 and 6 of VELS is also shown.

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A SUGGESTED SEQUENCE FOR LEARNING NANOSCIENCE AND NANOTECHNOLOGY FOR MIDDLE YEARS STUDENTS

Figure 1 shows a broad conceptual framework for learning about nanoscience and nanotechnology that is suitable for middle years students. It draws together some of the basic concepts of nanotechnology and shows their relationships. The main concepts include: (i) size can alter properties and (ii) rearranging atoms into different structures can produce different products with different properties (see Table 2 for different forms of carbon-only materials and uses).

Figure 1 is complemented by practical activities (shown in Table 3). Teachers should use their discretion to decide on the depth to which to pursue each topic.

As there is an enormous amount of content and other resources on nanoscience and nanotechnology on the Web, embracing more open-structured instructions and learning would cater for the diversity of student interests and abilities in most classrooms. Teachers should also bear in mind that searching on the Web can be frustrating for students (Ng, 2002) and if not appropriately guided, is potentially a waste of time leading to little learning. Designing the learning of nanoscience and nanotechnology as a Webquest (see Bernie Dodge and Tom March’s web pages for more information) and using the Jigsaw method of collaboration could encourage sharing of knowledge between team members and help them to understand the concepts better.

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**Figure 1** Conceptual framework for learning about nanoscience and nanotechnology.
<table>
<thead>
<tr>
<th>CARBON-ONLY MATERIALS</th>
<th>DIAMOND</th>
<th>4GRAPHITE</th>
<th>BUCKY BALL</th>
<th>CARBON NANOTUBE</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>NATURAL</td>
<td>SYNTHETIC</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**STRUCTURE**

- Jewellery
- Abrasive e.g., for grinding and cutting hard objects
- Pencil lead
- Lubricant
- Electrodes in cells/batteries
- Traps drugs or fuel for slow release in systems
- Super-molecular ball bearings as lubricants
- As catalysts and superconductors
- Very strong fibre
- Electronics (good conductors of heat and electricity)
- As sensors injected into cells for cancer drugs

Table 2: Carbon Allotropes

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### YEAR LEVEL

<table>
<thead>
<tr>
<th>VELS</th>
<th>6</th>
<th>7/8</th>
<th>9</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>LEVEL 4</td>
<td>LEVEL 5</td>
<td>LEVEL 6</td>
</tr>
</tbody>
</table>

### INTRODUCTION

A comprehensive resource that helps students conceptualise scale at the nanometre level can be found at: [http://www.nanosense.org/activities/sizematters/sizemandscale/SM_Lesson2Student.pdf](http://www.nanosense.org/activities/sizematters/sizemandscale/SM_Lesson2Student.pdf)

### SIZE

**Properties change with structure:** Show pictures of the structures of diamond, graphite, bucky balls and nanotubes. These are all made of carbon atoms, arranged differently and demonstrating different properties, and hence with different uses. See also [http://www.science.org.au/nova/02/024print.htm](http://www.science.org.au/nova/02/024print.htm)


**Properties change with size of materials:** Use sunscreen as an example. (See activities below.)

**Properties change with structure:** See column on left. **Properties change with size of materials:** See column on left.

Visualising molecular structures: Learn about atoms and molecules. Use RasMol to view the structure of simple molecules e.g., water, carbon dioxide, ethanol, titanium dioxide, zinc oxide, diamond, bucky ball. The Introduction to RasMol worksheet at [http://www.rasmol.org/au/education/education/ projects/chem-modules.htm](http://www.rasmol.org/au/education/education/projects/chem-modules.htm) is a good way to start.

### INSTRUMENTS

- Evolving microscopy from magnifying glass to light microscopy (compound microscope) to electron microscopy (scanning tunnelling microscope) to atomic force microscope. The latter two allow nanoscale imaging.

- Investigate magnifying glass and digital microscope (200x maximum magnification). Look at a variety of objects and relate to "Size" above.

- Investigate compound and stereo microscopes. Look at a variety of objects and relate to "Size" above.

- Investigate compound and stereo microscopes. Look at a variety of objects and relate to "Size" above. Project: Research Scanning Tunnelling or Atomic Force microscopes.

Table 3: Suggested outline of concepts and activities for Years 6-9 students (Continues pg 20)

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<table>
<thead>
<tr>
<th><strong>HISTORY</strong></th>
<th><strong>APPLICATIONS</strong></th>
<th><strong>SOCIAL AND ETHICAL ISSUES</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td>Explore Richard Feynman’s ‘marvellous biological system’ idea as the origin of the concept of nanotechnology. Explore ‘cells’: what do they do? what do they have inside them? how the extremely tiny (and invisible) ‘things’ inside cells keep the whole body working. Find out about these people and write 2-3 sentences about each one: Norio Taniguchi, Eric Drexler, Gerd Binnig and Heinrich Rohrer, Gerd Binnig, Calvin Quate and Christoph Gerber.</td>
<td><strong>Nano-sunscreen:</strong> Investigate and compare the differences between zinc cream that stays white when applied and nano-sunscreen which disappears when applied. Learn about UVA, UVB and UVC and why they are harmful. Use UV-sensitive beads to investigate which materials, e.g., paper, cloth, aluminium foil, students’ sunglasses, plastic, cellophane, tinted moisturiser etc., block out UV rays most efficiently. Include testing different brands of sunscreen. For worksheet see: <a href="http://www.latrobe.edu.au/educationalstudies/solar/solar-curriculum.htm">http://www.latrobe.edu.au/educationalstudies/solar/solar-curriculum.htm</a>. Watch video on Sunscreen for Bottles at: <a href="http://www.csiro.au/mltimepea/gp61.html">http://www.csiro.au/mltimepea/gp61.html</a>. <strong>Nitinol wires:</strong> Investigate nitinol as a ‘smart material’, also known as memory wire. Set shape and heat wire with Bunsen flame, then when cooled reshape and test with hot water (see main text below). Watch video(s) on YouTube e.g., at <a href="http://au.youtube.com/watch?v=77jglXrh7s4">http://au.youtube.com/watch?v=77jglXrh7s4</a>. A useful worksheet with explanations and activities can be found at <a href="http://www.jsse.psu.edu/activities/nitinol/SmartMetal.doc">http://www.jsse.psu.edu/activities/nitinol/SmartMetal.doc</a>. <strong>Nitinol-wired fan</strong> (or thermobile): Demonstrate using hot water to turn the blades. Discuss in terms of energy transfer and energy usage.</td>
<td>What are the implications of producing things that are really, really small? Students to research the benefits of nanotechnology and discuss concerns about the technology. Examples of issues currently debated are: - job losses if window cleaners are replaced by self-cleaning glass - use of silver nanoparticles as anti-microbial agents - use of nanoparticles in cosmetics and sunscreen and whether these particles are small enough to penetrate cells and cause harm An informed look at these issues is necessary, so wide reading and research are important to find out what both sides have to say.</td>
</tr>
</tbody>
</table>


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**ELABORATING ON THE SCIENCE BEHIND NITINOL AND RELATED ACTIVITIES**

Nitinol is an abbreviation for Nickel (Ni)-Titanium (Ti) Naval(n) Ordnance (o) Laboratory (l), indicating the elements in the material and the place of discovery in 1962 by William Beuhler and his team. Nitinol alloy is made up of 55% nickel and 45% titanium atoms and is commonly called ‘shape memory wire’ for its ability to bounce back to its original shape when appropriate heat is applied. The nickel and titanium atoms in nitinol are arranged in two types of crystalline structure, as opposed to one crystalline structure in most other solids. The arrangement of these structures is dependent on whether the nitinol is below or above its critical transformation temperature. Nitinol alloy can be bent and transformed to take a shape (e.g. of a tree) by heating it to a high temperature. This shape is called the austenite state. At temperatures below the critical transformation temperature, the nitinol alloy is flexible and the tree-shaped nitinol can be bent into any other

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Table 3: Suggested outline of concepts and activities for Years 6-9 students (Continued from pg 19)
shape, for example into a straight line. The flexible, bendable form is known as the martensite state. When the flexible (straight line) alloy is placed in hot water, or heated with a hair dryer, it transforms back to its originally-set shape of a tree, that is, back to its rigid austenite state. This process is known as ‘heat memory’ or ‘shape memory’. In the school laboratory, students can set the shape of nitinol wires by heating with the blue Bunsen flame.

A simple class experiment for middle years students to carry out with purchased nitinol wires is to take a small piece of the purchased straight wire and twist it into any shape they like. Dropping the shaped nitinol wire into a cup of hot water (from the hot water tap or a hot water urn) will return the wire to its original straight shape.

As a class demonstration, a nitinol-wired fan (Figure 2) can be made to work with hot water as the ‘power source’, converting thermal energy to mechanical energy. The fan has a piece of nitinol wire bent around the two wheels. When hot water is poured into the container in which part of the lower wheel and the nitinol wire around it is immersed, it is forced to change back to its original shape, that is to straighten out, spinning the wheel and the blades. As long as the water remains hot, the fan will continue to spin.

1. What was the most enjoyable part of the day?
2. What was the least enjoyable part of the day?
3. Tell us five things that you have learned about nanotechnology today.

Analysis showed that 52% of the students nominated the nitinol wire activity as the most enjoyable part of the day, with many of them being intrigued by its shape-changing ability. The percentage of boys and girls choosing this activity as most enjoyable was almost equal. Examples of what the students said included:

- it was cool that the bent wire turned back straight again.
- it was amazing about the wire becoming normal again!

The least enjoyable part of the day was the introductory lecture, with 21% of the students nominating this. Twenty-four per cent of the students indicated that they liked learning everything presented on the day. The percentage of boys and girls indicating these responses were very similar.

After an intensive day of learning about nanotechnology for Year 6 students, it is anticipated that, when asked to write down a few things they have learned, they will list the things that interested them most. Table 4 summarises the responses provided by the Year 6 students to this question (Number 3). Each response provided by the students was categorised into one of the themes that had emerged in analysis of the data. The resulting categories, as indicated in Table 4, were centred around the meaning of nanotechnology, information about atoms, scale and dimensions, sunscreen and ultraviolet rays, properties and makeup of nanotubes and the building of a Space elevator from Earth to Space. The students also made incorrect statements, or statements that demonstrated that concepts had not been learned. Examples of these statements included: ‘I learned about sunscreen’, ‘what nanotechnology means’ or ‘what atoms are’. The boys tended to do this more than the girls.

The data in Table 4 shows that 15% of the total responses from the whole group were about the meaning of ‘nano’ as Greek for ‘dwarf’ and 18% of the total responses were about some description of atoms. There appears to be some differences between male and female students in these two categories, with a higher percentage of female students than male students demonstrating knowledge in these two categories. Most of the other categories had similar percentage responses from boys and girls.

It is interesting to note that the majority of the students’ responses about what they had learned on the day had been from the introductory PowerPoint lecture, the activity that many enjoyed the least. The meaning of ‘nano’, structures of diamond and coal, information about atoms, what nanotechnology is, nanotubes and the Space elevator had all been mentioned in the introductory lecture. On the other hand, information and knowledge gained from the nitinol activity that the majority of the students nominated to be the most enjoyable part of the day were not indicated. Only two students described nitinol as a memory alloys in the ‘wire and hot water’ experiment. A number of students indicated that they had learned about ‘the wire changing shape in hot water’. This is inaccurate as it is not just any wire that can do this but within the context of the day, the assumption that the students know that it is a special type of wire has to be made.

The fact that many of the students did not use the technical name ‘nitinol’ could suggest that ‘doing’ something does not necessarily mean understanding.

WHAT YEAR 6 STUDENTS REMEMBERED AT THE END OF A NANO TECHNOLOGY DAY

The views of 139 Year 6 students from two primary schools who attended a Nanotechnology Day run by pre-service teachers and academics from the Faculty of Education (Bundoora), La Trobe University were elicited through a questionnaire. There were 59 girls and 80 boys in the group. The activities for the day involved (i) an introductory PowerPoint presentation on the meaning of nanotechnology and the science of really small things and (ii) a series of rotated activities on (a) exploring size (b) investigating sunscreen and (c) investigating nitinol wire. At the end of the day, the students were provided with a questionnaire and asked to respond to several questions, three of which were:
As one student indicated:

The wire activity was interesting but we never learnt how the wire does that.

As the activities in the intensive Nanotechnology Day were only about 30 minutes long, follow-up needs to take place at school.

Overall, the Year 6 students appear to be able to grasp the general concept of the science of very small things and some of the technologies associated with it. More than two-thirds of the students commented positively about the learning, for example:

I learnt many things about nanotechnology today and have found it very interesting.
I have enjoyed it and wish to learn even MORE!
It was a really fascinating day.
This Nanotechnology Day is one of the best science days I have ever had.

The day left a few students asking further questions such as:

I wonder if one day our world will look like the show ‘Futurama’
I always had a question, starting from when we mentioned ‘everything is made of atoms’, what are atoms made of?

**Footnotes**

5. Nitinal can be purchased online at [http://www.teachersource.com/Energy/MemoryMuscleWire/MemoryWireSamples_pko10.aspx](http://www.teachersource.com/Energy/MemoryMuscleWire/MemoryWireSamples_pko10.aspx)

<table>
<thead>
<tr>
<th>CATEGORY</th>
<th>EXAMPLES OF RESPONSE</th>
<th>TOTAL RESPONSES</th>
<th>MALES</th>
<th>FEMALES</th>
</tr>
</thead>
<tbody>
<tr>
<td>MEANING OF ‘NANO’</td>
<td>“Nano” is Greek for ‘dwarf’</td>
<td>567</td>
<td>11</td>
<td>20</td>
</tr>
<tr>
<td>DIAMOND AND COAL</td>
<td>Diamond and coal are made from the same atoms; diamond neat regular structure; carbon atoms in diamond and coal</td>
<td>5</td>
<td>5</td>
<td>8</td>
</tr>
<tr>
<td>ATOMS</td>
<td>All things are made of atoms; atoms are very small; atoms are different; you cannot see atoms; need powerful microscope to see atoms</td>
<td>321</td>
<td>15</td>
<td>22</td>
</tr>
<tr>
<td>WHAT NANOTECHNOLOGY IS</td>
<td>Nanotechnology is a branch of technology that deals with the manufacture of objects less than 100 nm; scientists want to create things with a bottom up approach; technology of incredibly small things</td>
<td>246</td>
<td>6</td>
<td>3</td>
</tr>
<tr>
<td>SUNSCREEN AND UV RAYS</td>
<td>Use nanotechnology to break down Zn molecules to make the sunscreen clear; three types of rays UVA, UVB and UVC; UVA can cause skin cancer; UVB burns you; sunscreen started in WWII; zinc oxide and titanium oxide in sunscreen; before nanotechnology sunscreen used light reflected off big particles and was white</td>
<td>9</td>
<td>10</td>
<td>9</td>
</tr>
<tr>
<td>NANOTUBES</td>
<td>Nanotubes are 100x stronger than steel; nanotubes are light but much stronger than steel; nanotubes are made of carbon atoms; nanotubes are superlight but amazingly strong</td>
<td>8</td>
<td>8</td>
<td>8</td>
</tr>
<tr>
<td>SPACE ELEVATOR</td>
<td>We might be able to go to Space some day through a cable from Earth to Space; NASA is studying how to build Space elevator</td>
<td>3</td>
<td>4</td>
<td>4</td>
</tr>
<tr>
<td>DIMENSIONS</td>
<td>A nanometre is a billionth of a metre; nanometre is 0.000000001 of a metre; DNA is 2 nm</td>
<td>5</td>
<td>7</td>
<td>7</td>
</tr>
<tr>
<td>OTHER APPLICATIONS OF NANOTECHNOLOGY</td>
<td>Nano materials are very light; nanotechnology might help to cure disease; nano materials are very strong</td>
<td>5</td>
<td>3</td>
<td>3</td>
</tr>
<tr>
<td>OTHERS</td>
<td>Nanotech; chemistry, biology, technology all need to work together; DNA is in all living things; metal called nitrol which remembers its shape; anything with heat has energy</td>
<td>7</td>
<td>7</td>
<td>7</td>
</tr>
<tr>
<td>STATEMENTS THAT ARE NOT APPLICABLE, MISCONCEPTIONS OR INCORRECT STATEMENTS</td>
<td>Statements that imply not having learned e.g. “what nanotechnology means” or “how sunscreen works”; incorrect statements e.g. nano things made from cells; coal and diamond have some structure; wire will straighten out when put in hot water</td>
<td>10</td>
<td>26</td>
<td>18</td>
</tr>
</tbody>
</table>

Table 4: What Year 6 students learned at the end of a Nanotechnology Day

*Total responses represent all responses given by students, with most students listing more than one thing learned about nanotechnology on the day. The categories of responses are not ranked. Only five students did not respond at all.*
## References


## Appendix

<table>
<thead>
<tr>
<th>Level</th>
<th>Science Knowledge and Understanding</th>
<th>Science at Work</th>
</tr>
</thead>
<tbody>
<tr>
<td>Level 5</td>
<td>Relate particle theory to nanoscience - basis of nanotechnology is atom. Building useful materials bottom up manner i.e. atom by atom or molecule by molecule. Make model of bucky ball and virus. Conduct investigation with sunscreen with nanoparticles and UV-sensitive beads - how properties of sunscreen with nanoparticles change (transparent) and UV beads (change colour in sun where UV present) Nanoscience concept related/originated from thinking about mimicking of cell processes. Nano-materials (non-living) impacting on human survival e.g. delivery of drugs Concept of scale (billionth in nanoscience) Nano-machines, nanobots</td>
<td>Design and conduct experiments e.g. sunscreen and write formal report. Undertake activities to develop understanding of the concept of scale - smallness. Use Rasmol to visualise structures at the atomic and molecular level. Make models of bucky balls and viruses.</td>
</tr>
<tr>
<td>Level 6</td>
<td>Properties change at nano-scale level – bucky balls vs graphite vs diamond. Smart materials - Sunscreen with nano-particles, nitinol, self-cleaning glass, smart fabrics that are self cleaning and have biosensor, drug delivery, gecko tape. DNA is nano-scale material. Processes and ‘machinery’ associated with production of proteins are nano-processes.</td>
<td>Conduct (including designing) simple practical activities e.g. nano-sunscreen with UV beads, nitinol properties in cold and warm water, self-cleaning glass. Write reports and explanations. Use Rasmol to visualise structures at the atomic and molecular levels. Make models of bucky balls and viruses, explain the relationships between diamond, graphite and bucky balls; viruses are biological nano-machines.</td>
</tr>
<tr>
<td>VELS and Nanotechnology</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

## Level 5 Domains and Dimensions

### 1. Health and Physical Education
- Movement and physical activity
- Health knowledge and promotion

### 2. Interpersonal Development
- Building social relationships
- Working in teams

### 3. Personal Learning
- The individual learner
- Managing personal learning

### 4. Civics and Citizenship
Explore the responsibilities of global citizenship for individuals, organisations and governments and the roles and responsibilities of companies, producers and consumers in relation to sustainability. Explore ways in which countries work together to protect the environment.

<table>
<thead>
<tr>
<th>Level 5</th>
<th>Science Technology</th>
<th>Students:</th>
</tr>
</thead>
<tbody>
<tr>
<td>Latvia</td>
<td>Conduct experiments indoor and outdoors. Develop awareness of safety issues when conducting practical activities. Also develop awareness of safety issues associated with the concept of nanotechnology and products produced by discussion on issues (ethical and social) with peers/teachers and wider community, and research to inform their own understanding.</td>
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<tr>
<td>Level 5</td>
<td>Work in teams to design and/or conduct experiments. Carry out discussions in small groups or as a class.</td>
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<tr>
<td>Level 5</td>
<td>Are responsible for carrying out designated role in team work e.g. research project on applications of nanotechnology where tasks are delegated. Submit assignments on time. Participate in class discussion.</td>
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<tr>
<td>Level 5</td>
<td>Students:</td>
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## Integrating Physical, Personal and Social Learning into Nanotechnology

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<table>
<thead>
<tr>
<th>LEVEL</th>
<th>DOMAINS AND DIMENSIONS</th>
<th>NANOTECHNOLOGY</th>
</tr>
</thead>
</table>
| 1. Communication | • Listening, viewing and responding  
• Presenting | Students:  
• Communicate verbally (discussion, oral presentations), in written form (reports and essays), graphically (concept maps, animations) and mathematically (scale, data collection, graphs in practical reports).  
• Listen and respond in small group and whole class discussions  
• Could organise a Nanotechnology Fair to teach younger students about nanotechnology |
| 2. Design, Creativity and Technology | • Investigating and designing  
• Producing  
• Analysing and evaluating | Students could:  
• Research and design a model of a nanobot and justify their design  
• Research and design a model of a nano-factory, showing atom-by-atom building of a useful material |
| 3. Information and Communication Technology | • ICT for visualising thinking  
• ICT for creating  
• ICT for communicating. | Students:  
• Use RasMol as a visualising tool for nano-sized particles and develop skills in obtaining pdf files of other structures from the Web  
• Use RasMol molecular images for creating practical and research reports  
• Use concept mapping tools, PowerPoint and other multimedia software (e.g. Flash) to aid in communicating their understandings across to an audience |
| 4. Thinking Processes | • Reasoning, processing and inquiry  
• Creativity  
• Reflection, evaluation and metacognition | Students will:  
• be required to go outside normal range of experiences to develop understanding of abstract concepts and will need to be able to distinguish between fact and fiction based on concepts of nanoscience and nanotechnology taught in the classroom  
• be able to reflect on and evaluate understandings to assess the impact of nanotechnology on society  
• apply science skills and processes in designing experiments that are controlled, then discuss their limitations  
• apply higher order thinking skills in project work in which they will need to search for, evaluate and synthesise new materials |

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