Transiting from school science to real engineering by employing materials science and engineering concepts within the school programme.

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Abstract
Many scientific principles can be learnt by an understanding of materials behaviour in different physical, environmental and chemical situations. In the primary school these principles are often implemented by utilizing everyday materials for use in art or hobby applications. In the high school, as students learn some basic science and mathematics, they can apply this knowledge to analyze the behaviour of materials as components or structures. This is often achieved from a constructivist approach where students *learn by doing*. A first year course in materials science and engineering was developed from recognition of the formal requirements of the Institution of Engineers Australia, and the realization of students' basic knowledge of scientific concepts and principles gained from junior and senior school. Students appreciate the experimental work which integrates their formal knowledge with real application and realize that they have used quite a lot of their school learning. . They comment that this often makes the formal knowledge delivered in lectures easier to understand

Introduction

The development of human civilization has essentially followed that of the technological changes associated with materials, eg. bronze age, iron age semi-conductor age[1-3]. Over fifteen years ago the National Science Foundation instigated a major review of materials science and engineering(MSE) – one of the recommendations being the teaching of MSE at both tertiary school level[4,5]. However, learning about materials is an aspect of study which is not confined just to the university but starts at a very young age, at home and in pre-school, especially during the early years of schooling - "materials" are taught as items for "making objects" within general studies or as a topic of scientific involvement. Implementing this approach at the primary level, Skamp[6] , postulates that the nature of materials is one of the three big ideas of science used to explain our physical world (the other two being forces and energy), and should be used to teach primary school children about science and the world around us.

Within the primary school science (involving aspects of MSE) is not taught formally as physics, chemistry, biology or other disciplines, but as a cohesive structure. The students are engaged in 'discovering and making things, objects or components, usually from materials... For example, in early primary levels, they have manipulated "playdough[7]" (eg. utilising rheological properties of polymers), used leather appliqué (eg. composite materials structure) and in later in higher levels built spaghetti bridges (eg. mechanics of structures), freezing and heating water(phase transformations), comparing the weight and nature of different

materials(structure and density), and static electricity (eg. creating static electricity on a plastic comb and bending water), without understanding or realising the scientific and engineering relationships[8]. Materials are studied as school subjects under the guise of art and technological (eg. projects to create new items from recycled materials) or even as history and geology (Copper Age, Bronze Age and Iron Age and developments in technology parallel territorial imperatives and invasions). Within these subject areas students are investigating, discovering and developing concepts about materials science and engineering in a non-traditional sense. It is these concepts which are utilised later in their high school science education and eventually when they study engineering, the concepts of MSE.

At the junior school level, an interesting and multi-focus approach is taken to the teaching of concepts of MSE, in many countries, eg USA[9], UK[10].. For example in Australia, especially, most if not all science curricula at the primary school level include a content strand related to materials[6]. In Victoria, the Victorian Curriculum and Assessment Authority (VCAA), which governs the syllabus and curricula, taught in all Victorian schools, has recognised the importance of MSE by incorporating many physical and chemical science aspects into the activities which students undertake within their primary curricula. Both within the current (2004) Curriculum Standards Framework II[11] and the newly initiated Victorian Essential Learning Standards [12], for the sciences; concepts of materials are spread over six levels of curricula which correspond to the first 10 years of schooling. During 2005 schools will use the *Victorian Essential Learning Standards* to plan their teaching and learning programs for introduction from 2006. The new Essential Learning Standards will replace the Curriculum and Standards Framework (CSF) as the basis for curriculum and assessment in Victorian schools. It proposes to allow flexibility and curriculum control at the class level (allowing experience of the learner), more opportunities for local innovation (experience of the teacher and learner), and less prescription of actual material taught, all pointing to a constructivist approach to learning and teaching. With a new emphasis on 'deeper learning'.

Approaches to Incorporating Materials Science and Engineering in the Curriculum

A broad classification of the relationship between the levels of learning and school teaching levels as developed by the VCAA is given in Table1. Here, it is established that at each level of learning within the science curriculum, various concepts of MSE are introduced, as discussed in succeeding sections of this paper(a similar classification has been developed by the QCA in the UK[10] and recommended by various institutions in the USA[9,13]. The level of learning corresponding to a student's standardised intellectual ability, eg year 2 or year 6[14]. However, the curricula content at years 11 and 12[15] are very prescriptive and are the outcomes assumed to be a precursor to university studies.

Levels of learning	School teaching levels
Level 1 -	End of Preparatory Year
Level 2 -	End of Year 2
Level 3 -	End of Year 4
Level 4 -	End of Year 6
Level 5 -	End of Year 8
Level 6 -	End of Year 10

Table 1. The six levels of learning associated broadly with the years of schooling from Preparatory to Year 10

Early School Years

In the early school years (levels 1-3), the students are required to establish a firm foundation of knowledge, skills, attitudes, and values necessary for further learning. Especially in the sciences, which include physical, chemical, earth and biological aspects. These activities are grouped as either scientific or technological. The scientific aspects being highlighted by aspects of chemistry and physics, whilst the technological aspects are highlighted by a number of areas including Materials behaviour.

At these early ages of learning (levels 1-3), it is recognised that all children use their senses to form the basis of scientific investigative skills, for example, by looking, touching, smelling, tasting, listening. In the early years of primary school, the students are introduced to a range of scientific contexts. Natural and manufactured materials are explored directly and described with words associated with the senses of sight, touch, hearing and taste[9]. Students explore the physical world by observing the different things that electrical appliances can do the materials to which magnets are attracted, the shadows and rainbows as effects of sunlight and the different ways things move.

Underlying ideas for MSE

Shown in Figure 1 is a summary of underlying ideas teachers should have for the MSE content strand of science syllabi found in most primary (years 1-8) science courses[16]. It is these ideas which need to be translated for students to give them an understanding of the material world they live in.

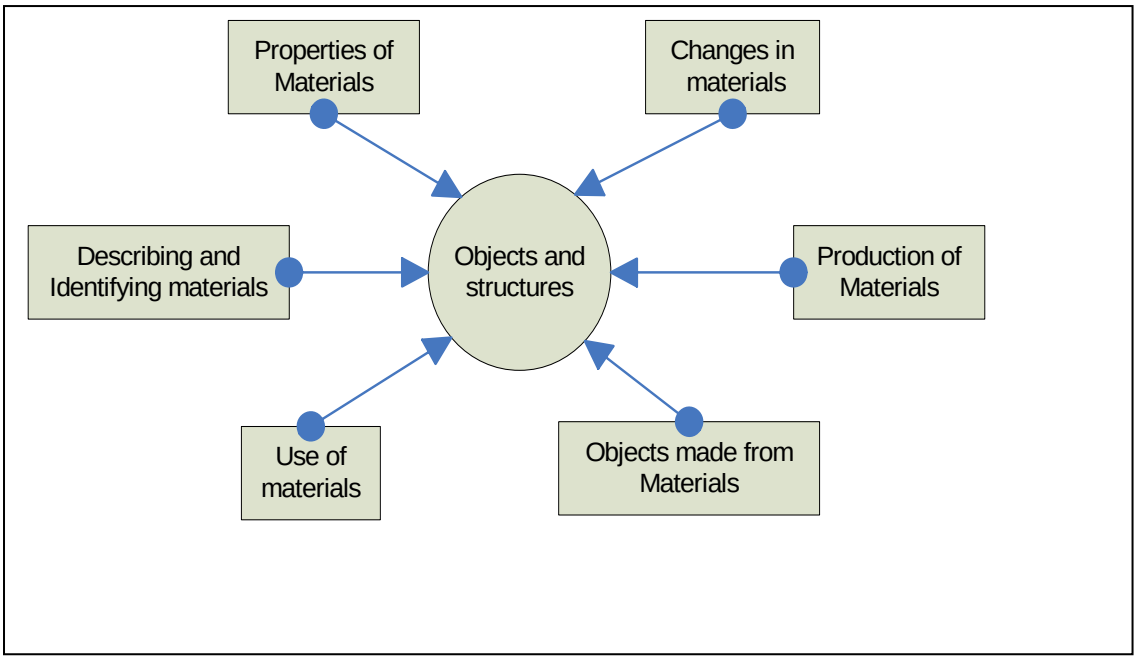

Figure 1. Underlying ideas teachers should have for the MSE content strand of the science syllabi

At these junior levels students describe investigations that compare observable properties of common household substances. They begin to identify differences between solids, liquids and gases and use this information to group materials into these categories. They realise that some

materials are difficult to classify, such as the flowing solid of talcum powder or the combination of a liquid and gas that make up a fizzy drink. They carry out experiments to explore reversible changes in common substances, such as water and chocolate.

Towards the end of the primary school, level 4, students develop their understanding of the properties of a substance, and those features that make it suitable to be used for particular purposes, such as building materials and adhesives. They compare properties of a range of materials. They investigate simple devices, for example, toys, games and household appliances, and design and build devices of their own and describe their operation. They recognise that forces act on objects and describe the effect on objects of simple combinations of forces, and relating this to the materials from which objects are made. They observe the effects of simple combinations of forces on objects and link these effects to their investigations of the motion of objects

Examples of MSE activities within a School Curriculum.

In developing a student's curiosity of the Material world, a range of activities may be introduced which have a direct bearing on the way MSE is taught and developed in the university, eg. in answering questions about a material, what difference is there between a material and an object. These questions are really very difficult to answer and a simpler approach might be to ask the following questions as shown in Table 2, before we can answer this. If we look carefully at these questions, they really are concerned with the basic elements of materials science and engineering as taught in university classrooms and utilised by scientists and engineers in the working world.

Question	Answer
What are objects made of?	An object is made of a material
What are materials?	A material is composed of substances
What is a substance?	A substance is composed of one or more elements
What are properties of objects?	Strong, weak light, heavy, breakable
What are properties of materials?	Strong, weak light, heavy, breakable
What observable properties distinguish objects and material?	Shape, size, weight

Table 2. Developing a student's curiosity of the Material world by asking questions

Middle School approaches to Materials Science and Engineering

Upon leaving primary school, students enter a new world, both educationally and emotionally. Within the education area, science takes on new aspects, and especially their understanding of materials. The time spent in middle school is comparatively short, just two years, but often it is at this stage that many students formulate their future studies. Fortunately, science is still a compulsory subject and MSE makes up one of the strands of study. At this level students learn that properties, changes and uses of substances are related to the basic structure of those substances. They begin to use particle bonding and models to explain many properties of materials, such as conduction of heat in solids and latent heat associated with changes in state. They describe heating and cooling effects in terms of the particle model applied to everyday examples. Following on from the science, the students

now investigate the engineering aspects of materials and structures. They describe interactions between magnetic and non-magnetic materials and between electrically charged objects. They understand a field as a region of space where an object experiences a force and use this idea to explain simple magnetic and electrostatic effects. These are concepts applied to the new areas of semi-conductor nano materials studied in later years as part of then MSE curriculum.

In addition to the general science strand in middle school, a number of students study the technological aspects of materials. What this means, is how to use materials in everyday life. Shown in Table 3 is an example of a curriculum incorporating materials technology[17]. Here the students learn about applications of materials, how to use materials safely, their appropriate selection and use, the various processing technologies utilised for manufacturing and how to be creative with materials

Working with materials enables students to:

- assess the form, function, potential and suitability of materials
- select and use materials in order to achieve desired effects
- understand the physical, chemical and aesthetic characteristics of materials
- use various types and combinations of materials
- understand and use tools and items of equipment that are suited to manipulation of material
- create specific products and effects using materials
- process, preserve and recycle materials
- appreciate the environmental impact of the use of different materials
- explore how materials were used and modified in the past and how emerging materials are being developed
- use materials safely and judiciously.

Table 3 Curriculum focus of Materials strand of Technology studies for middle level of high school[17].

Senior School Approaches to Materials Science and Engineering

By the time students reach years 11 and 12 of high school, they have usually decided which areas or discipline they wish to specialise in so that they are able to achieve their entry into a tertiary course. For those students who choose one or both of physics and chemistry, these contain specific units or sections dealing with materials[18,19]. For those students who are not so academically inclined, they also are able to choose subjects which contain substantial materials content. - albeit on a non-theoretical basis -commonly referred to as technology subjects[20]. Shown in Table 4 are specific details of the core senior subjects and the components allied to materials within the Victorian Curriculum (which has similar components in all other sectors of the Australian Education System).

From the details in Table 4, it is seen that although the science of materials has often been separated from the technology and it is only in the final two years of high school is there a marrying of the two, but without the integration of this into an engineering area. Even without being aware, students are incorporating numerous everyday activities into their

exploration and learning of MSE. These science and technology curriculum requirements are those which a materials engineer needs to understand in their work environment. Students have commenced their path to engineering whilst at primary school level, and for the privileged few, have continued at university to emphasize their career choice

One of the major difficulties with this situation is the current shortage of appropriate teachers of science in the later years of high school[21]. Notwithstanding this difficulty, what students are taught at the primary level reflects their studies at tertiary level, albeit in a more scientific sense. At university, most materials science and engineering (MSE) courses generally are based around five streams; atomic structure; phase transformation; mechanical properties; physical properties and materials selection; and include many aspects of physics and chemistry[22-24]

Year Level of School Activity and unit	**Physics Materials Related Content**	**Chemistry Materials Related Content**	**Design and Technology- Materials Related Content**
11 Unit 1	Nuclear and radioactivity physics; Energy from the nucleus.	Examines a range of chemical processes and activities through the study of common materials. The chemical nature of materials is explored through investigation of their properties and modifications.	Materials in design, development and production
Unit 2	Movement; Investigations: Aerospace	Examines a range of chemical reactions	Materials in design, development and production
12 Unit 3	Investigating materials and their use in structures: using data to describe and predict material behaviour; comparing different materials	Examining the large-scale industrial production of some chemicals	Manufacturing industries Industrial production processes;
Unit 4	Interactions of light and matter; Synchrotron and its applications,	Examines the relationship between the production and use of energy in living and systems.	Factors considered in establishing the purpose of a product, and its use

Table 4 Specific details of the core senior subjects and the components allied to materials within the Victorian Curriculum[18-20].

Links with Tertiary MSE

Traditional science courses at school level concentrate on the fundamentals of physics, chemistry and biology. However, at university, where physics is often re-badged in the academic sense to make it more attractive and chemistry is distributed amongst other subjects – they are often brought together the under the materials science and engineering banner to demonstrate applications in engineering. First year engineering classes use the bases of science to build a foundation in engineering eg [3,22,23,25]. However, the link between school based subjects and university professional subjects is often tenuous. Schools require outcomes not necessarily associated with university studies but prescribed by societal expectations and political expediencies. Conversely, entry to university engineering courses is dictated by school outcomes. Measurement of ability in science at school is proscribed by a normalised score- which may have no relation to a student's understanding and knowledge. It is only a ranking compared with other students in the same subject cohort. Recognising this situation, universities require a minimum standard score in sciences as an indicator of a student's ability to perform well in that subject and as an indicator for success in tertiary engineering subjects.

Preliminary MSE Tertiary Studies

At most universities the first year of most engineering courses encompass major scientific concepts learnt in high school physics and chemistry with mathematical skills often employed as the tool of analysis. These concepts are quickly expanded upon to involve practical applications in major engineering situations. The model utilised is based on Constructivist theories which are centred on what the student brings to the learning situation. In other words, what the students know about materials form their primary, middle secondary and higher secondary level studies which are then utilised in their tertiary studies. The principles of constructivism, interpreted within a MSE world can be explained as [26,27]:

- knowledge of MSE is constructed from the experience of the learner(*based on primary and high school activities together with their general knowledge)*
- learning is a personal interpretation of the world (*how materials interact and shape the real world)*
- learning is an active process of making meaning from experience and takes place in contexts relevant to the learner (*implementation of what the students have learnt in various activities and how they relate to their everyday life)*
- reflection is an essential part of learning (*consideration of materials as a basis many areas of learning including history, geography and technology as examples)*
- learning is a collaborative process(*group activities in making an object)*

Within a university context one of the greatest teaching problems is that students come form many different backgrounds. They have their own preferred learning styles for demonstrating their knowledge and understanding which has implications for teaching. Within a MSE context, there are often many modifications of a freshman's existing ideas which have been shaped by their own understanding, prior teaching, background and even culture.

This subject of MSE is taught in most engineering disciplines albeit under different pseudonyms. The subject name, materials science and engineering, together with the content are a new is for commencing engineering students. A general course combines the basics of chemistry (eg atomic structure, bonding, crystallography, elements of corrosion), physics (eg. electron theory, mechanics of structures, electrical and magnetic properties) and mathematical skills (eg. integration, ratios, differential calculus, and surds) to pursue the mechanical and physical behaviour of materials).

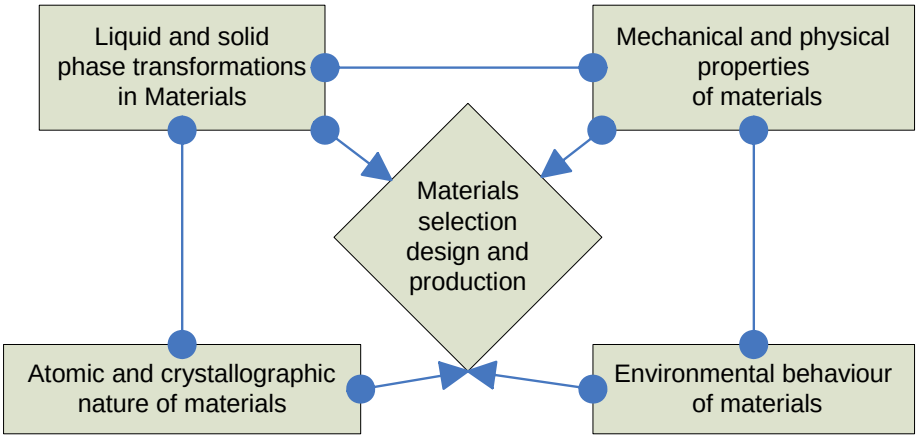

Figure 2. Typical core syllabus for an introductory course in materials science and engineering [28]

At Swinburne University of technology, the teaching area of materials science and engineering is used to combine the knowledge students may have gained in school from their involvement with science subjects containing elements of physics, chemistry and mathematics, together with historical facts allied to technological developments[28]. Examples of teaching school scientific concepts are expanded and formulated to develop a transition to engineering situations. These are given through case studies, laboratory work, oral presentations, tutorial activities, and the oft used written reports. A typical core syllabus is centred on five main areas, shown schematically in Figure 2.

It does not take much imagination to see that there is a direct correlation between the constructivist approach to teaching primary and secondary science utilising *materials* as shown in Figure 1 and that of the typical general syllabus used in freshman tertiary studies of materials science and engineering as shown in Figure 2.

What the students often do not realise is that they have already started to learn about these MSE areas at primary and high school level without realising the engineering relationships. By taking a constructivist approach at school, the students have achieved a “hands-on” approach to the selection, use and application of materials in many different spheres of their life.

Concluding Remarks

Materials are the stuff matter is made from. This is the concept that is taught in schools. By adopting a constructivist approach, students learn from their very early classes at primary level through to their advanced classes in high school how and why materials behave the way they do. They are taught how objects are put together, how they are that the characteristics of the physics, chemistry form the basis of an understanding of materials properties and behaviour, whilst the technological aspects are associated with the production and manufacturing aspects of components and structures.

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