ABSTRACT
The purpose of this study was to collect data on the preparation of students’ knowledge in the area of materials science which is the building block for all engineers. The specific aim for this study is to determine how school science impacts on years 11 and 12 science studies in the areas of materials science, and further tertiary studies. The investigated data were analysed post hoc from public education records. The data were analysed to determine any trends and falling off in enrolments in the final years of high school. The data did reveal a trend in science enrolments falling off as students progressed into the later years of high school. Observations revealed that in advanced years of high school, the student population in science subjects were not well prepared for future studies in materials science at a tertiary level. It is suggested that science subjects be made more popular especially in the areas of materials science by syllabus changes, improving the way subjects are taught, and making materials science an appealing part of the syllabus.

Keywords: materials, primary school, curricula, secondary school

INTRODUCTION
In this work we investigate where and how the future engineer and scientist gains knowledge to prepare themselves for their potential roles as technological members of society where materials make modern living possible. Many scientific principles can be learnt by an understanding of materials behaviour for different situations. In the primary school scientific principles are often implemented by utilizing everyday materials used in art or hobby applications. As students progress in their learning of basic science and mathematics, they can apply this knowledge to analyze the behaviour of materials as components or structures. Hidden amongst all the scientific and technological concepts are the properties and applications of materials. Analysis of school curricula indicates that materials science is taught in various guises using examples of materials or disguised as mathematics, physics, chemistry, and technology.

At university, is discovered in courses about materials science, engineering, and technology. The integration of materials into tertiary studies is developed from the realization of students’ basic knowledge of scientific concepts and principles gained from junior and senior school about . Public record education data is collected and analysed post hoc and trends of science enrolments are determined. Content areas of materials science are investigated in the K-12 area school environment, and subjects lacking rigour in materials are investigated. Suggestions for improvements in highlighting the importance of materials are given. This paper will consider both quantitative and qualitative data ranging across K12 classes where materials science and technology based learning activities were
incorporated into traditional classroom activities in the early years of school (i.e. years K-10). Being exposed at school to further details and applications of materials in everyday life may enhance a students’ approach to understanding the importance of materials in science and technology. Materials, and the innovation and inventiveness surrounding their use, is vital given our society’s continually changing needs.

BACKGROUND
Students are able to use knowledge acquired at school in both their everyday life and to further their academic knowledge. 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, and is often considered a challenge (Abbaschian, 1990). Applications of materials are common in the media, in shows like Mythbusters (Discovery Channel, 2010) and Engineering Connections (Hammond, 2010), so that children and adults acquire some basic awareness. In 2011 the public station PBS is airing a new series “Making Stuff: Stronger, Smaller, Smarter, Cleaner,” highlighting the importance of materials improve the quality of life. (PBS NOVA, 2010).

It is during the early years of schooling - “materials” are taught as items for “making things with not as a topic of scientific involvement. Skamp (2007), 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 (NSF, 1989, 1990). Implementing this approach at the primary level is considered to be of prime importance, especially in highlighting the importance of re-using and recycling materials. Within the primary school science aspects of materials science and engineering (MSE) are not taught formally but integrated within the general overall curriculum, where the boundaries between science and technology are often unclear. It is not often easy to differentiate where science ends and technology starts. The environment in which students learn is a reflection of the MSE world, which is needed to discover the knowledge and solve the problems of society (Kranzberg & Smith, 1988).

Within the learning environment, the students are engaged in ‘discovering and making things, objects, or components, usually from materials. Materials are studied as school subjects under the guise of art and technological (e.g., projects to create new items from recycled materials) or even as history and geology e.g. Copper Age, Bronze Age and Iron Age and developments in technology and art parallel territorial imperatives and invasions, (Delmonte, 1985; Kranzberg & Smith, 1988). 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. To highlight this situation the National Center for Improving Science Education has worked to improve science and mathematics education for K-12 students (NCISE, 2010). A large part of this work includes preparing science and mathematics teachers for the classroom. They describe science as proposing explanations for observations about the natural world, and distinguish technology as proposing solutions. Students at all levels of education interpret both these explanations in their studies.

For example, in early primary levels, students manipulate playdough, compose with leather appliqué, construct with paper mache, or play with icy poles. Further work at the primary levels and kindergarten programs encourage exploration and invention in the visual arts. Kindergarten students make art by drawing, painting, moulding clay, weaving or stitching with fibres and fabrics, constructing three-dimensional objects, and so on, all utilising the properties and processes of materials science and engineering (Manitoba, 2006). All of these are activities which develop an appreciation and understanding of materials behaviour and implementation (Cantrell, Pekcan, Itani, & Velasquez-Bryant, 2006). In later years of high school student activities may include building spaghetti bridges, freezing and heating water, comparing the weight and nature of different materials and static without necessarily understanding or realising the scientific and engineering basis involving materials (Manitoba, 2006). Moulding clay utilises rheological properties of polymers, leather appliqué employs composite materials processing. In higher class levels building spaghetti bridges involves the integration of math and science with innovative techniques to encourage students to learn and is both
fun and challenging. This activity allows the students to browse and search for information required to complete their project.

In Australia, especially, most if not all science curricula at the primary school level include a content strand related to materials, albeit in a non-traditional mode. In Victoria, the Victorian Curriculum and Assessment Authority (VCAA), has recognised the importance of MSE by incorporating many physical, technical and chemical science aspects into the activities which students undertake within their primary curricula. Within the current Curriculum Standards Framework II incorporating the Victorian Essential Learning Standards outlines what is essential for all Victorian students to learn during their time at school from Prep to Year 10. The delivery of scientific educational skills incorporates concepts of MSE which are spread over levels of curricula and correspond to the first 10 years of schooling (DEECD, 2010; VCAA, 2009a, 2009b). These set of skills and knowledge are transferable across all aspects of life.

Incorporating Materials Science and Engineering (MSE) in the Curriculum
Data were collected post hoc from public education enrolment records in science subjects, and analysed to determine trends in enrolment and falloff if any (DEECD, 2010). The essential detailed enrolments in materials studies occur in years 11 and 12 where units of study in physic and chemistry involve the majority of MSE to which students are exposed in a formal sense (QCA, 2005; Roy, 1991).

RESULTS AND DISCUSSION
As given in Table 1 for Victorian students, there are thousands of students in the primary level and middle secondary level who all are exposed to some aspects of MSE in various guises in their science subjects. Despite most students not enrolling in physics or chemistry in years 11 and 12, because of their early exposure to matter, all students had a grounding in basic MSE. These student enrolment numbers are small when compared with the science content which all students must undertake in their early and middle years of schooling.

Table 1. Victorian Student Enrolments over the 1-12 levels (DEECD, 2010).

<table>
<thead>
<tr>
<th>Primary*</th>
<th>Secondary*</th>
<th>Year 12#</th>
<th>Physics#</th>
<th>Chemistry#</th>
</tr>
</thead>
<tbody>
<tr>
<td>2006</td>
<td>307576</td>
<td>222826</td>
<td>42887</td>
<td>6827</td>
</tr>
<tr>
<td>2007</td>
<td>306223</td>
<td>222290</td>
<td>41377</td>
<td>6831</td>
</tr>
<tr>
<td>2008</td>
<td>305005</td>
<td>223331</td>
<td>42294</td>
<td>6490</td>
</tr>
<tr>
<td>2009</td>
<td>306304</td>
<td>223422</td>
<td>41200</td>
<td>6697</td>
</tr>
</tbody>
</table>

*government schools #all schools

This Victorian trend data of “hard” science subject enrolment (physics and chemistry), 2006-2010 is shown in Figure 1 and is consistent with that found for all of Australian enrolment for the years 1976 to 2007 (Ainley, Kos, & Nicholas, 2008) There seems to have been only minor changes over the years investigated.
Towards the end of the primary school, 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. Ramirez (2010) has been in charge of a group of teachers and scientist and engineers who have developed a series of simple investigations in materials.

### Table 2. Underlying ideas Teachers should have for Teaching about Materials

<table>
<thead>
<tr>
<th>Scientific Strand</th>
<th>Technological Strand</th>
</tr>
</thead>
<tbody>
<tr>
<td>Properties of Materials</td>
<td>How strong is it?</td>
</tr>
<tr>
<td>Changes in materials</td>
<td>What is the effect of temperature</td>
</tr>
<tr>
<td>Production of Materials</td>
<td>How do I make it?</td>
</tr>
<tr>
<td>Describing and Identifying materials</td>
<td>What is it made from?</td>
</tr>
<tr>
<td>Using Materials</td>
<td>Where can I use it?</td>
</tr>
</tbody>
</table>

The students 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. A significant part of understanding the role of materials in society is choosing the “right” material for the right job. To do this selection procedure, students need to understand the relationship amongst materials properties, and their manufacture. The basis for this selection is a grasp of the physical and chemical nature of materials. Although numerous approaches shave been developed, that developed by Granta Design (2010) which has made the process simple by employing a computerised selection procedure and providing results in a visual relationship. Today’s computer savvy students seem to grasp this approach easier than the standard textbook tabular approach.

**Developing a student’s curiosity of the material world**

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. For example, in answering student queries about a specific material which may be very difficult to answer, a simpler approach might be to ask the questions and give the answers shown in Table 3. If we look carefully at these questions, they really are concerned with the basic elements of materials science and engineering and utilised by scientists and engineers in the working world.

Students are challenged to examine the things that make up the material world in a different way – through the eyes and ears of a “materialist”, an expert in materials. In a way materials is the study of what we use everyday such as clothes, transport, computers money, made from different materials (Cantrell, et al., 2006). Sokoloff and Thornton (1997) have developed active learning strategies which students and staff can implement in their studies of materials. Utilising their principles, students ponder, observe plan, experiment, correct discover and learn within their own knowledge space. This is an area which Roy (1991) had earlier suggested in his analysis of K-12 education strategies when applied to learning and teaching about materials.

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 models
to explain many properties of materials, such as structure, strength, conduction of heat in solids, and
electrical and magnetic properties. They immerse themselves in experiments, explore the WWW to
obtain the latest information, may reflect on the place materials have had in history in the development
of civilizations.

Table 3. Developing a Student’s Curiosity of the Material World by asking Questions.

<table>
<thead>
<tr>
<th>Question</th>
<th>Answer</th>
</tr>
</thead>
<tbody>
<tr>
<td>What are objects made of?</td>
<td>An object is made of a material</td>
</tr>
<tr>
<td>What are materials?</td>
<td>A material is composed of substances</td>
</tr>
<tr>
<td>What is a substance?</td>
<td>A substance is composed of one or more</td>
</tr>
<tr>
<td></td>
<td>elements</td>
</tr>
<tr>
<td>What are properties of objects?</td>
<td>Strong, weak light, heavy, breakable</td>
</tr>
<tr>
<td>What are properties of materials?</td>
<td>Strong, weak light, heavy, breakable</td>
</tr>
<tr>
<td>What observable properties</td>
<td>Shape, size, weight</td>
</tr>
<tr>
<td>distinguish objects and material?</td>
<td></td>
</tr>
</tbody>
</table>

Enhancing a student’s interest in the Material world
Following on from the early explorations in science, during the middle and later years of high school
the students investigate the societal and engineering aspects of materials utilising the principles of
active learning as the main source of acquiring knowledge (Delmonte, 1985; Kranzberg & Smith,
1988; Sokoloff & Thornton, 1997). For example, they may describe interactions between large beams
in buildings, or the effect of temperature on strength, the application of magnetic and non-magnetic
materials, and perhaps the development of highly technical objects and structures. The students learn
that an electrical field is a region of space where an object experiences a force and use this idea to
explain simple magnetic and electrostatic effects. These are just some of concepts applied to the new
areas of semi-conductor nano materials studied in later years as part of the MSE curriculum. In
addition to the general science strand in middle school, a number of students who may not be
academically included, study the technological aspects of materials. What this means, is how to use
materials in everyday life.

Highlighted in Figure 2 is an example of a suggested curriculum incorporating materials technology.
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

- 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.

Figure 2. Curriculum focus of Materials strand of Technology studies for middle level of high school.
**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. 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. Shown in Table 5 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).

Although the teaching of science of materials has often been separated from the materials technology, it is only in the final two years of high school there a marrying of the two. 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 (ABC NEWS OnLine, 2005; NSF, 1990; Stokes, 1990). As a consequence, there has been an initiative from the US Government to address this inadequacy in both maths and science (NEA, 2010) as well as the Australian government approach (Science Matters, 2010). 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 introductory 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 (Ashby & Jones, 2005; Callister, 2010). Traditional science courses at school level concentrate on the fundamentals of physics, chemistry which necessarily includes a section on materials properties and behaviour (e.g. Physics includes a unit associated with *Materials and their use in structures* and Chemistry includes a unit concerned with *Students investigating the uses of materials and how these have changed*. (VCAA, 2009a, 2009b). Specific examples of some of the core Physics and Chemistry and the components allied to materials are given in Table 4. 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.

**Table 4.** Specific Examples of the Core Physics and Chemistry and the Components allied to Materials (VCAA, 2009a, 2009b).
First year engineering classes use the bases of science to build a foundation in engineering. 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 (Nanjappa & Grant, 2003) can be explained as 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)
CHALLENGES, DILEMMAS AND RECOMMENDATIONS
Within a university context one of the greatest teaching problems is that students come from many different backgrounds. They have their own preferred learning styles for demonstrating their knowledge and understanding which has implications for teaching. This is especially so when attempting to teach MSE, there are often many modifications of a novice student’s conceptions ideas which have been shaped by their own understanding, prior teaching, background, and even culture.

The subject of MSE, together with its content is often novel for commencing engineering students. A general course combines the basics of chemistry (e.g., atomic structure, bonding, crystallography, elements of corrosion), physics (e.g., electron theory, mechanics of structures, electrical and magnetic properties) and mathematical skills (e.g., integration, ratios, differential calculus, and surds) to pursue the mechanical and physical behaviour of materials.

At my university 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. 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, such as building bridges (Mulholland, 2006), and the oft used written reports.

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 introductory tertiary studies of materials science and engineering. 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.

There is considerable work being done in teaching materials as one of the building blocks of science and technology across the educational spectrum, however, there are numerous challenges, and dilemmas encountered taking account of different teaching and learning approaches together with cultural differences. It is recommend that we excite young people in materials, science, and engineering, by developing and incorporating innovative teaching techniques; making it relevant to modern society; and illustrating how materials impact our everyday lives. Because students have a natural interest in materials around them (materials may offer a good context to engage otherwise disinterested students). Educators can show the link between Materials and Science (Physics/Chemistry) to stir an interest and so provide a reason for studying of Science and Technology. In addition, it is suggested that to strengthen the educators’ skills we develop appropriate training and education programs, similar to that employed by the American Society of Metals in their summer camp program for staff (ASM, 2010b) and materials camps which are for high school students with strong abilities in math and science who have completed years 10 and 11 of high school and who are challenged by the concepts of materials in their science and technology applications (ASM, 2010a).

CONCLUDING REMARKS
Materials are the matter is made from. This is the concept that is taught in schools. This paper highlighted how the considerable preliminary work on materials in schools and life generally forms the basis of students’ later work in science and technology. However, students may be unaware of this capital upon entering university. 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. School have an important function in teaching students how objects are put together, how the characteristics of 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. This preliminary education in “matter” and stuff lays the groundwork for their future as engineers in a socially responsible society. The development of materials within general learning at the primary stage, within science at the intermediate levels and
within physics and chemistry at the final stages of high school enhance students' knowledge and understanding of the world around them.

Observations revealed that in advanced years of high school, the student population in science subjects were not well prepared for future studies in materials science at a tertiary level. It is suggested that science subjects be made more popular especially in the areas of materials science by syllabus changes, improving the way subjects are taught, and making materials science an appealing part of the syllabus. For those continuing to tertiary studies in engineering, they have received a comprehensive preparation in one of the basic elements of engineering.

REFERENCES
Discovery Channel. (2010). Mythbusters: Discovery Communications LLC.


