Appendix 2A

Report on the Achievements of K-12 Engineering Education in Australia & its Positive Referential Values for the Evolution of a Potentially Viable K-12 Engineering & Technology Curriculum in the United States

For

HIGH SCHOOL APPROPRIATE ENGINEERING CONTENT KNOWLEDGE IN THE

INFUSION OF ENGINEERING DESIGN INTO K-12 CURRICULUM

(Under the General Topic of "Engineering Design in Secondary Education" and of

"Vision and Recommendations for Engineering-Oriented Professional Development")

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PART ONE
INTRODUCTION

An Inspiring Presentation

Peter Thompson (Head Teacher for Teaching and Learning at Bossley Park High School, Sydney, Australia), and Ruth J. Thompson (Head Teacher for Technology, at the same school), have given a PowerPoint presentation titled "*Engineering Education in Australian High School*," Thursday, March 26, 2009, during the International Technology Education Association 2009 Conference, at the International Convention Center, Room KICC 209, 4:00PM-4:50PM, in Lousville, Kentucky, USA. The presenters gave the attendants a CD that is rich in information on high school engineering education in Australia, with a total of 178 files (including articles, government documents, PowerPoint presentations, pictures and 3D digital animations).

Table 1A.
K-12 Schooling across Australian States

Year(s) In School	1	2	3	4	5	6	7	8	9	10	11	12	13
Australian Capital Territory	Primary School							High School				College	
	Kindergarten	Year 1	Year 2	Year 3	Year 4	Year 5	Year 6	Year 7	Year 8	Year 9	Year 10	Year 11	Year 12
New South Wales	Primary School							High School					
	Kindergarten	Year 1	Year 2	Year 3	Year 4	Year 5	Year 6	Year 7	Year 8	Year 9	Year 10	Year 11	Year 12
Northern Territory	Primary School							Middle School			High School		
	Transition	Year 1	Year 2	Year 3	Year 4	Year 5	Year 6	Year 7	Year 8	Year 9	Year 10	Year 11	Year 12
Queensland	Primary School								High School				
	Preparatory	Year 1	Year 2	Year 3	Year 4	Year 5	Year 6	Year 7	Year 8	Year 9	Year 10	Year 11	Year 12
South Australia	Primary School								Secondary School/High School				
	Reception	Grade 1	Grade 2	Grade 3	Grade 4	Grade 5	Grade 6	Grade 7	Year 8	Year 9	Year 10	Year 11	Year 12
Tasmania	Primary School							High School				College	
	Preparatory	Grade 1	Grade 2	Grade 3	Grade 4	Grade 5	Grade 6	Year 7	Year 8	Year 9	Year 10	Year 11	Year 12
Victoria	Primary School							Secondary College					
	Preparatory	Year 1	Year 2	Year 3	Year 4	Year 5	Year 6	Year 7	Year 8	Year 9	Year 10	Year 11	Year 12
Western Australia	Primary School								High School				
	Pre-Primary	Year 1	Year 2	Year 3	Year 4	Year 5	Year 6	Year 7	Year 8	Year 9	Year 10	Year 11	Year 12

All of the files contained in the CD have been thoroughly read and qualitatively analysed to help understanding the achievements of K-12 engineering education in Australia in the recent decades. This report will discuss some positive aspects of Australian K-12 engineering curriculum, in terms of its inspiring experience that could possibly serve as a reference for the development of a potentially viable U.S. K-12 engineering and technology curriculum based on solid analytic principles and skills.

Table 1B.
Comparison of K-12 Systems in Australia and the United States

K-12 System in Australia [1]		K-12 System in the United States [2]	
Level/Grade	**Typical age**	**Level/Grade**	**Typical age**
Primary School		**Preschool**	
Day care or a parent-run playgroup	NOT compulsory	Various optional programs, such as Head Start	Under 6
Kindergarten	4-5 year olds	Pre-Kindergarten	4-5
Preparatory/ Reception/ Kindergarten (QLD, NSW,VIC and ACT)	5-6 year olds	Kindergarten	5-6
		Elementary School	
Year 1	6-7 year olds	1st Grade	6–7
Year 2	7-8 year olds	2nd Grade	7–8
Year 3	8-9 year olds	3rd Grade	8–9
Year 4	9-10 year olds	4th Grade	9–10
Year 5	10-11 year olds	5th Grade	10–11
Year 6	11-12 year olds	**Middle School**	
		6th Grade	11–12
Secondary School			
Year 7	12-13 year olds (ACT, NSW, TAS, and VIC,) Middle School NT	7th Grade	12–13
Year 8	13-14 year olds	8th Grade	13–14
		High school	
Year 9	14-15 year olds	9th Grade (Freshman)	14-15
Year 10	15-16 year olds (high school NT)	10th Grade (Sophomore)	15-16
"Higher School"			
Year 11	16-17 year olds	11th Grade (Junior)	16-17
Year 12	17-18 year olds	12th Grade (Senior)	17–18

Table 1B (Continued).
Comparison of K-12 Systems in Australia and the United States

K-12 System in Australia [1]		K-12 System in the United States [2]	
Level/Grade	**Typical age**	**Level/Grade**	**Typical age**
Post-secondary education			
Tertiary education (College or University)	3-4 years to complete	Tertiary education (College or University)	Ages vary (usually four years, referred to as Freshman, Sophomore, Junior and Senior years)
Vocational Education and Training (VET)		Vocational education	Ages vary
Graduate education (Master’s and Doctorate)		Graduate education (Master’s and Doctorate)	
N/A		Adult education	

Notes:
[1] Source: Wikipedia. (2009). *Education in Australia*. From http://en.wikipedia.org/wiki/Education_in_Australia, and http://en.wikipedia.org/wiki/Tertiary_education_in_Australia
[2] Source: Wikipedia. (2009). *Education in the United States*. From http://en.wikipedia.org/wiki/Education_in_the_United_States

PART TWO
ADMINISTRATION of K-12 EDUCATION IN AUSTRALIA

Overview of K-12 Education in Australia

Administration of K-12 system in Australia: K-12 curriculum in Australia is, by the Constitution of the Commonwealth of Australia, a responsibility of the governments of the states. Systems of education manage the delivery K-12 educational programs at public schools (called "government schools") and private schools (run by Catholic and Protestant Christian churches or independent organizations). "High School in Australia refers to students aged from 12 to 18 years of age, where they can matriculate to University. Primary/Elementary school is 5 to 12 years of age" (Thompson & Thompson, 2009; slide 4). Australia has 5 states (Western Australia, South Australia, Victoria, New South Wales and Queensland), plus two territories (Northern Territory and the Australian Capital Territory, managed directly by the Federal government). There are a number of off shore protectorates such as Lord Howe Island and Christmas Island, governed by a nearby state. "Each state and territory develops its own curriculum for delivery by teachers in schools." "High School education, secondary education, in each state includes students in the 12 to 18 age range. Education is compulsory in all states and ranges from ages 15 and 17 years, with the latter being the majority. Over 90% of students stay to graduate high school and approximately 30% of these moves onto University. Prior to high school, students will have attended primary school from ages 5 to 12, and before that they may have attended, Kindergarten and preschool from 2 years, or younger" (Thompson & Thompson, 2009; p. 2). It appears that Australian system of K-12 education is very similar to what we have in the United States, in terms of state control and public-private partnership; in addition, both Australian and American K-12 systems last 12 years. The details of K-12 schooling in Australia, and of its comparison with K-12 system in the United States, are illustrated in Tables 1A and 1B.

Achievement of K-12 leading to successful higher education in Australia: "Currently 29% of the Australian population have a bachelor's degree in any discipline or better. The goal is for 40% by 2020. (Review of Australian Higher Education Final Report, Australian government 2008**).** 984,000 students attend higher education in 2006 (census data). 1,122,000 attended non government schools, 2271000 attended government schools. Australia's population at this point was 20.6 millions. USA was at 302.8 millions. (Australian Bureau of Statistics)" (Thompson & Thompson, 2009; p. 2).

K-12 Engineering and Technology Education in Australia

Grade promotion: In Australia, engineering and technology are extensively studied during the High School years, which cover years 8 to 12. The last two years of high school, i.e., Years 11 and 12, are referred to as "higher schools." Higher School Certificate is the exit high school credential in the state of New South Wales in Australia; it is a public examination in all subjects. Students typically study 12 "units." Mr. Peter Thompson's engineering students study 2 units for each subject (Engineering, English, Math, Physics, Legal Studies, and Music), for a total of 12 units. There are variations across schools. These students are in the Year 12 and are 18 years of age (or ranging from 17 to 19) (email from Peter Thompson, June 17, 2009).

At the end of “higher school” years, “Higher School Certificate Examinations” are administered, which cover the knowledge content learned during the Years 11 and 12. During the Question and Answer session, the presenters indicated that in Australia, “technology” is a “MANDATORY study” area in ALL high schools, while 10% of all high schools have an “engineering” program. Engineering education is a focus of Australian Federal government initiatives.

Well-defined and purposeful objectives and practices: K-12 engineering education programs in Australia are designed and implemented to specifically lead students to a university study with a degree level engineering program. In terms of course content, they cover both generic engineering design process and specific high school appropriate engineering analytic principles and skills, with three pedagogically well-developed subjects of

- “Engineering Mechanics:” Concentrated on statics, dynamics, strength of materials, with slight inclusion of fluid mechanics, aerodynamics, and mechanical devices design;
- “Engineering Materials:” Concentrated on materials properties, corrosion, types, treatment, and selection, covering metals, ceramics, polymers, and composites; and
- “Engineering Electricity/Electronics:” See Table 7C (p. 63) and table 8C (p. 69) for details).

“In addition to courses in metal, timber, graphics, electronics, media, in the junior and senior high school […] Technology curriculum area was defined by a National Declaration in 2001 as the areas of Industrial Arts, Computing, Home Economics, Agriculture, Media” (Thompson & Thompson, 2009; slides 5-7). There are four major areas of study in Australian K-12 engineering curriculum:

1. Technology, Industry and Society;
2. Engineering Materials;
3. Engineering Mechanics; and
4. Control Systems.

Engineering Materials and Engineering Mechanics are apparently the emphasis in curricular development and delivery, based on my thorough analysis of the CD given by Mr. Peter Thompson and Mr. Ruth Thompson after their ITEA presentation.

PART THREE
OVERVIEW OF THE POSITIVE ASPECTS OF K-12 ENGINEERING CURRICULUM IN AUSTRALIA

Many positive aspects of K-12 engineering curriculum in Australia could offer us with great referential values for the development of a potentially viable K-12 engineering curriculum in the United States, based on solid analytic principles and skills.

Incremental Sequence of K-12 Engineering Program That Matches K-12 Students' Age-Specific Cognitive Maturity Levels

Schools in Australia start to educate future generations of innovative engineers from Primary Schools (corresponding to American Elementary Schools). Both generic engineering design process and specific knowledge content are covered, methodically and incrementally, according to the age-specific cognitive maturity levels of the students.

<u>At Primary Schools</u>: Three geographic regions are cited in the presentation to explain the characteristics of the programs, both with emphasis on broad exposure to generic design process and to basic STEM knowledge content, in the generic areas of "Design, Creativity and Technology" (Thompson & Thompson, slides 9-10).

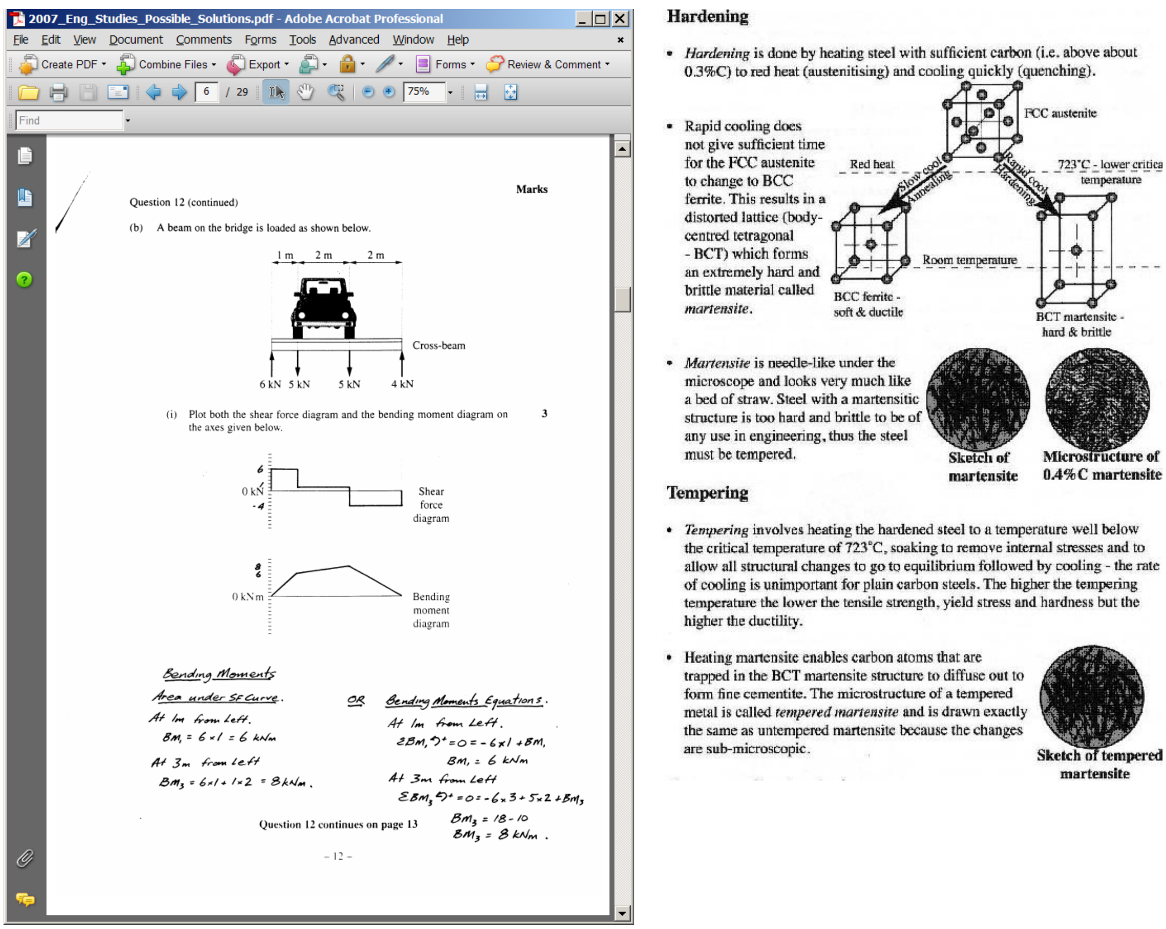
- <u>In South Australia</u>: (1) "broad-ranging techniques for manipulating materials to create products, processes and systems;" (2) "broad-ranging design skills to create innovative solutions to design briefs and problems."

- <u>In Victoria</u>: "Students develop the knowledge, skills and behaviours related to investigating and designing using appropriate planning processes and design briefs; creating and developing ideas, applying information, and seeking and testing innovative alternatives; producing, including the selection and safe use of appropriate tools, equipment, materials and/or processes to meet the requirements of design briefs; analysing and evaluating both processes and products including, where relevant, any broader environmental, social, cultural and economic factors."

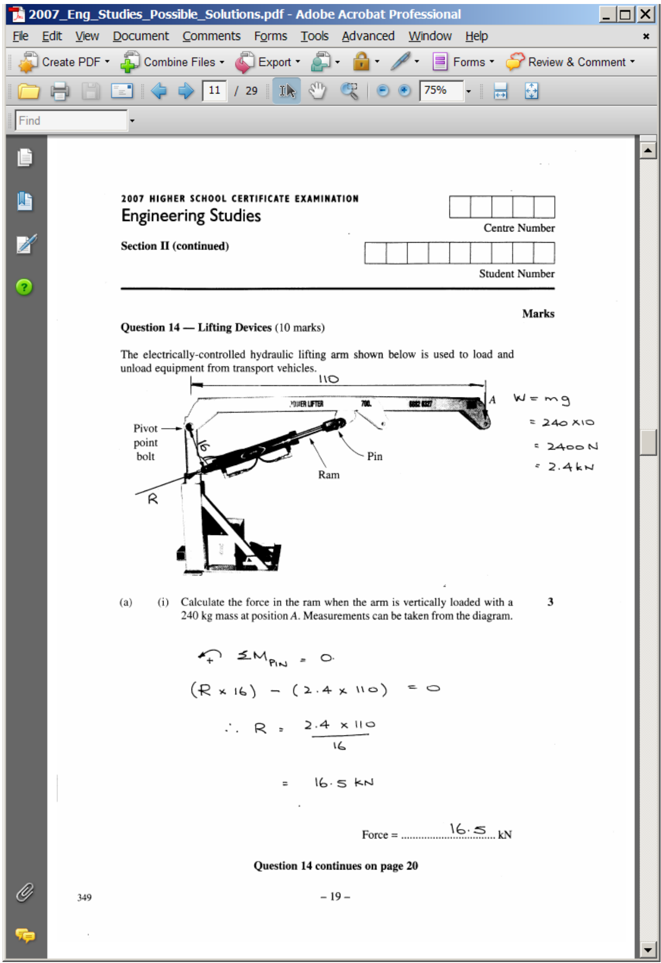
- <u>In New South Wales (the state where the presenters came from)</u>: Technology curriculum in Primary schools is linked with Science. The Science and Technology curriculum includes (1) "design and make products, systems and environments to meet specific needs;" (2) "assess, select and use a range of technologies;" (3) "the process of designing and making that people use in order to satisfy their wants and needs;" and (4) "the technologies people select and use, and how these technologies affect other people, the environment and the future."

<u>At High Schools</u>: Engineering Curricula is implemented in 10% of all high schools. Hard core engineering courses (well beyond engineering-associated technology such as CAD) have been implemented in Australia for years (Thompson & Thompson, slides 11-19). Apparently, Australia is currently among the most advanced nations on the Planet Earth in terms of implementing hard core engineering courses into high school curriculum. From a thorough analysis of the learning materials (or textbook pages) and

examination forms available from the CD given by the presenters, I have made a tentative conclusion that engineering curriculum in Australian high schools is primarily based on pre-calculus mathematics (geometry and trigonometry); and the declarative content knowledge featured in these materials match the academic and professional depth of those pre-calculus portions of relevant engineering courses (such as structural analysis and design), which are commonly found in undergraduate engineering lower-division curriculum, or in typical Fundamentals of Engineering (FE) exams administered in the United States. This could be illustrated by *Figures 1A* and *1B*.



Figures 1A. High School statics examination form (left) and material science learning materials (right) used in Australia (file name: 2007_Eng_Studies_Possible_Solutions)



2007_Eng_Studies_Possible_Solutions.pdf - Adobe Acrobat Professional

2007 HIGHER SCHOOL CERTIFICATE EXAMINATION
Engineering Studies

Centre Number

Section II (continued)

Student Number

Marks

Question 14 — Lifting Devices (10 marks)

The electrically-controlled hydraulic lifting arm shown below is used to load and unload equipment from transport vehicles.

(a) (i) Calculate the force in the ram when the arm is vertically loaded with a 240 kg mass at position *A*. Measurements can be taken from the diagram. 3

$\Sigma M_{PIN} = 0$

$(R \times 16) - (2.4 \times 110) = 0$

$\therefore R = \frac{2.4 \times 110}{16}$

$= 16.5$ kN

Force = 16.5 kN

Question 14 continues on page 20

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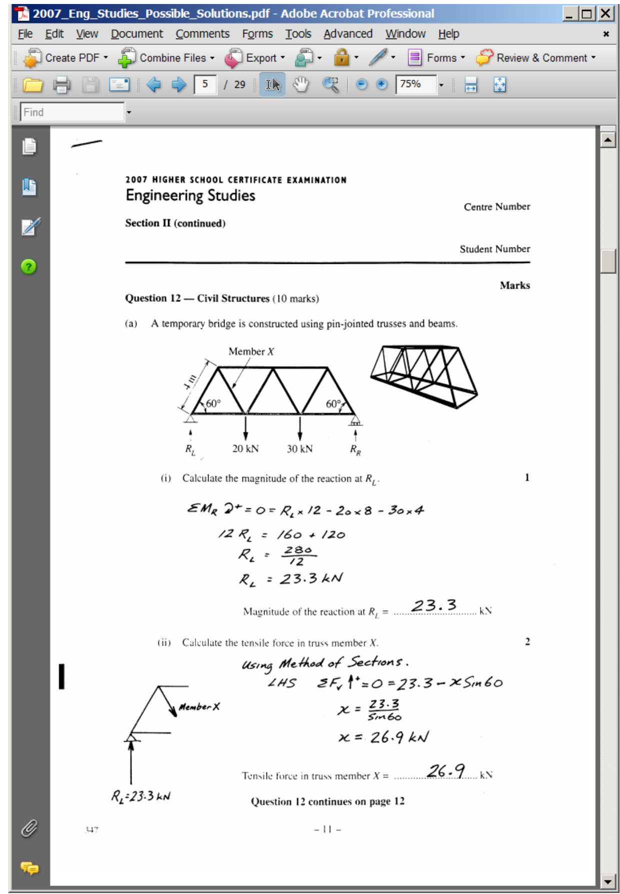

2007_Eng_Studies_Possible_Solutions.pdf - Adobe Acrobat Professional

2007 HIGHER SCHOOL CERTIFICATE EXAMINATION
Engineering Studies

Centre Number

Section II (continued)

Student Number

Marks

Question 12 — Civil Structures (10 marks)

(a) A temporary bridge is constructed using pin-jointed trusses and beams.

(i) Calculate the magnitude of the reaction at R_L. 1

$\Sigma M_R = 0 = R_L \times 12 - 20 \times 8 - 30 \times 4$

$12 R_L = 160 + 120$

$R_L = \frac{280}{12}$

$R_L = 23.3$ kN

Magnitude of the reaction at R_L = 23.3 kN

(ii) Calculate the tensile force in truss member *X*. 2

Using Method of Sections.

LHS $\Sigma F_y = 0 = 23.3 - x \sin 60$

$x = \frac{23.3}{\sin 60}$

$x = 26.9$ kN

Tensile force in truss member *X* = 26.9 kN

Question 12 continues on page 12

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Figures 1B. "2007 Higher School Certificate Examination" form for "Engineering Studies" (file name: 2007_Eng_Studies_Possible_Solutions)

The engineering courses taught at high schools across various states in Australia and cited by the presenters in different regions are shown in Table 2 below.

Engineering Programs in New South Wales, Australia, a Case Study

History and Recent Development

"Project-Based Learning" with an emphasis on engineering analytic principles and skills: In 1966, Industrial Arts was established in a New South Wales senior school, with a course about (1) Materials; (2) Mechanical Analysis; (3) Technical Drawing; and (4) History of Technology. "Integrated topics" such as Bicycles, Brakes, Bridges, Lawn Mowers were used, incorporating both theoretical aspect and practical application of engineering. In the New South Wales, Engineering Studies syllabus covered (1) Household Appliances; (2) Landscape Products; (3) Braking Systems; (4) Bio

Engineering. This model of curricular organization is very similar to Project Lead The Way, or "Integrative STEM," although in Australia, the name is "Integrated Topics."

Three years ago, the presenters' school developed the Industrial Technology Engineering for years 9 and 10 (ages 14 and 15), a 200 hour course that has 4 modules: (1) Structures; (2) Mechanisms; (3) Control Systems; and (4) Alternative Energy. "The course is 4 years old, numbers have doubled in the first 3 years that we have data for. Anecdotally, it is very successful" (Thompson & Thompson, 2009, slide 32).

Table 2.
High School Engineering Courses in Australia
(Source: Thompson & Thompson, slides 11-19)

Region in Australia (Slide No.) → Notes	**High School Engineering Courses (→ "Corresponding American Name" for the Course)**
Queensland (Age 11)	
→ *Engineering Technology Senior Syllabus, released in 2004.* While the depth of treatment of each area of study may be varied, emphasis should be placed on Engineering Materials and Engineering Mechanics. This is a "general engineering" program	Technology, Industry and Society (→ "Introduction to Science, Engineering and Technology")
	Engineering Materials (→ "Engineering Materials"
	Engineering Mechanics (→ Statics and Dynamics")
	Control Systems (→ "Mechatronics")
In 2008, a syllabus piloted in Aerospace Studies (a "special engineering" program)	Aeronautics and Astronautics
	Safety Management Systems
	The Business of Aviation and Aerospace
	Aviation Operations
Victoria (Age 12)	
→ "Systems Engineering" and "Mechanical and Electrotechnology systems." *The study is made up of four units.*	Unit 1: Mechanical engineering fundamentals
	Unit 2: Electrotechnology engineering fundamentals
	Unit 3: Systems engineering and energy
	Unit 4: Integrated and controlled systems engineering"
Western Australia (Age 13-15)	
Course include general design process, and specific engineering analytic content knowledge	Engineering Studies (→ "Introduction to Science, Engineering and Technology")
	Specialist Fields: Mechanical
	Specialist Fields: Systems and Control
	Specialist Fields: Electronic/Electrical

Positive Experience to Learn and Lessons to Avoid

Conclusions have been made on the performance of students in the Years 9-10 Industrial Technology (Engineering) program at Turramurra High School. This comprehensive and co-educational school with 970 students drawn from a mix of mainly middle income families is located in Northern Australia, in the north shore suburb of Sydney, in one of the most competitive educational markets in New South Wales in 2009. For the textbook, the school used *Introducing Technology* by Basil Slynko (Publisher: Thomas Nelson (2005. ASIN: B001Z5N1NW).

- <u>Positive experience to learn from</u>: Those that (1) match high school students' cognitive developmental maturity; (2) are "hands-on;" and (3) are well defined and "straightforward," with clear-cut "restrictions," have "worked" (Turramurra High School, 2009, slides 4-7) These include

- Just for fun: Bottle Racers;
- Structures: Tower design;
- Mechanisms: Electric car race;
- Control technology ("mechatronics"): "Rube Goldberg" machine. Studying control technology with Control Studio. In teaching this subject, The instructors focussed on Input, Process, Output, taught mechanical control technology as well as electronic, started with simple examples (a toilet) and then move on to a Light/Dark Indicator; and have avoided complicated systems such as "robotics" except as a theory and research topic; and used CAD/CAM with PCB Design and Make digital technology.
- Alternative energy: CO_2 racers, including drawing on TurboCAD;
- Engineering experiments: Corrosion, tensometer testing;
- Electronics: Drawing circuit diagrams using PCB (design and fabrication); computer related tasks;
- Material strength: Converting force/extension data into stress/strain graphs using Excel software;
- Processes: Researching bridge types (www.pbs.org/wgbh/buildingbig/bridge);
- Manufacturing;
- Tools.

- Lessons to Avoid: Anything that (1) exceed high school students' cognitive maturity level, or (2) are ill-defined "hasn't always worked." (Turramurra High School, 2009, slides 9-10). They include
  - Exercises requiring a high level of mathematics ability (for example, truss analysis);
  - Design challenges with little restriction (eg Rube Goldberg machine).

The Interdependence Orientation of Australia's K-12 Engineering and Technology Curriculum

Based on the *Industrial Technology Years 7-10 Syllabus in the Technology K-12 Curriculum* issued by New South Wales Board of Studies (a state government administrative agency for K-12 education), on June 2003, it appears that in Australia, the K-12 engineering and technology curriculum (1) is well structured with more specific government mandates (down to topical level, well beyond skeletal "guidelines" or "standards;" and (2) stresses on the interdependence among engineering, human society and ecology; and on the integration of engineering and technology with human and ecological issues, such as

- Occupational Health and Safety (OHS);
- Materials, Tools and Techniques;
- Design;
- Links to Industry (from *Figures 7A* through *7H* (pp. 41-47), which demonstrate Australian high school graduates' ability to design and prototype professional quality products, it is apparent that the goal has been well achieved);
- Workplace Communication;
- Societal and Environmental Impact (using alternative energy system is a strong emphasis in Australia's engineering education).

<u>The prominence of "alternative energy" as a curriculum objective</u>: Table 3 shows that "Societal and Environmental Impact" is one of the content areas of the engineering curriculum, throughout all 4 Core Modules for the Engineering Studies program. The "Environment" section of the "Cross-curriculum Content" requirement states that "All focus areas foster an awareness of the impact of industry on the environment and the importance of the use of alternative and sustainable resources. This enables students to make informed decisions in relation to the selection and use of materials and processes." (New South Wales Board of Studies, 2003; p. 17).

The Incremental Progression of K-12 Engineering and Technology Education in Australia throughout the "Six Stages"

The *Industrial Technology Years 7-10 Syllabus in the Technology K-12 Curriculum* published by New South Wales Board of Studies (a state government administrative agency for K-12 education), on June 2003 divides K-12 engineering and technology education into 6 Stages, each to accomplish certain part of the future engineers' journey, based on their station in the K-12 system, as shown in *Figure 2*:

1. Kindergarten to Primary (or Elementary) School: Broad exposure to science, engineering and technology, plus introduction to design process, through "hands-on" projects, from "play" or "educational entertainment" to deeper exploration of both natural and built objects and environment (Early Stage 1 through Stage 3, or Years K-6);

2. High School: Deep and extensive study of engineering-related technology, plus simple design projects, experiments, and other activities that lead to a serious and solid study of high school appropriate engineering analytic and predictive principles and skills, with well-organized course in "Engineering Mechanics," "Engineering Materials" and other areas, plus "practical design" projects (mainly, re-design or modification of existing products and structures, with some degree of creativity and innovation that could be realistically expected of high school students, applying previously learned STEM knowledge content in the solution of real-world design problem.

Detailed explanations of the Stages are available in the *Industrial Technology Years 7-10 Syllabus* (New South Wales Board of Studies, 2003, pp. 171-176). They incrementally build up students' STEM repertoire and design capabilities; and the whole process is more or less similar to the American K-12 systems, except that its high school engineering curriculum places more emphasis on solid engineering analysis principles and skills, which are tested by "Higher School Certificate Examinations" for "Engineering Studies," in addition to "Practical Project" of engineering design. As shown in *Figure 2*, the diagram of the *Industrial Technology Years 7-10 Syllabus* (New South Wales Board of Studies, 2003, p. 9) is placed sided-by-side with the *K-12 Engineering Road Map* developed under my previously presented *Proposed Model for Infusing Engineering Design into K-12 Curriculum* (Appendix 1), to show their similarities in basic program structure and underlying curricular development philosophy, as well as their slight differences that are mainly due to the differences between K-12 systems in Australia and in the United States, in terms of the boundaries among the stages (for example, in Australia, Years 8-12 is High School, while in the United States, High School covers Grades 9-12). Details of Australia's K-12 grading scheme and its comparison with U.S. system have been shown in Table 1A and 1B (pp. 1-2).

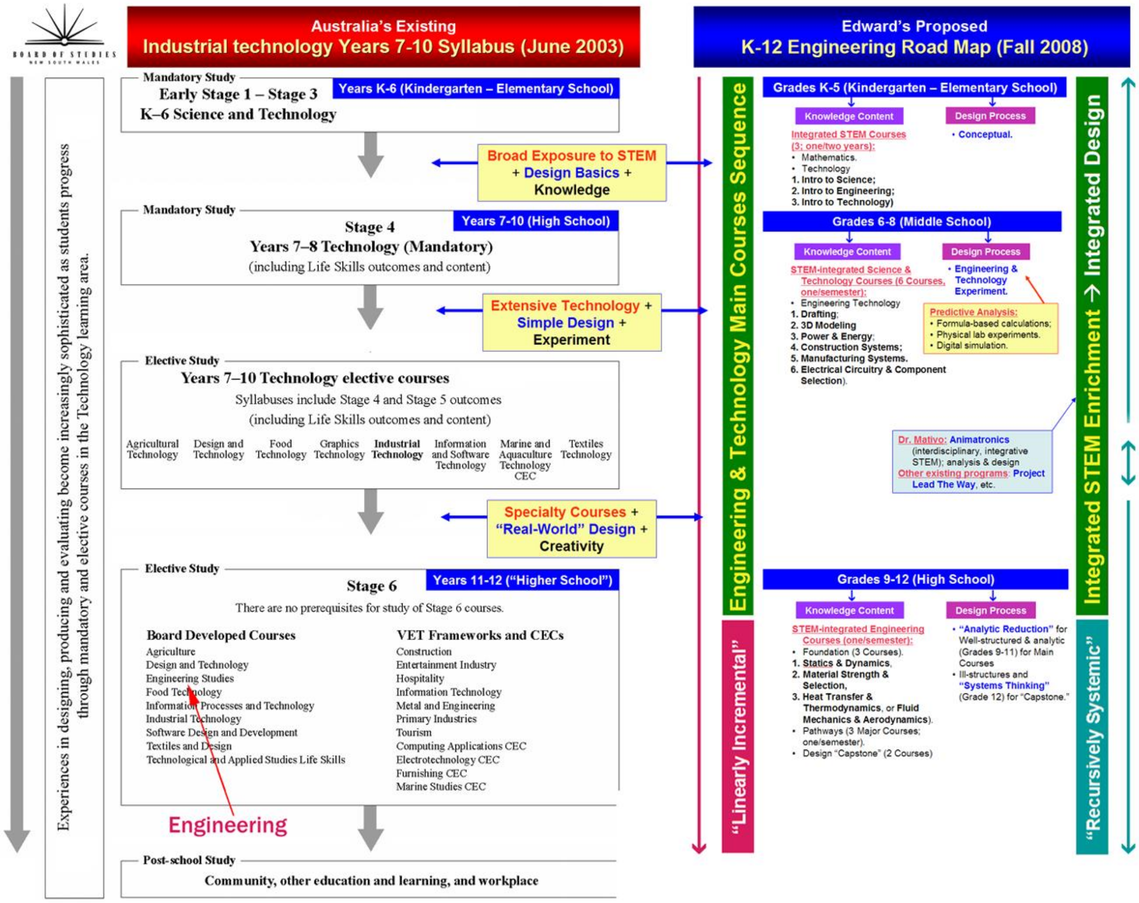


Figure 2. Similarities and differences between the Industrial Technology Years 7-10 Syllabus in the Technology K-12 Curriculum, and the K-12 Engineering Road Map developed under my previously presented Proposed Model for Infusing Engineering Design into K-12 Curriculum (Appendix 1).

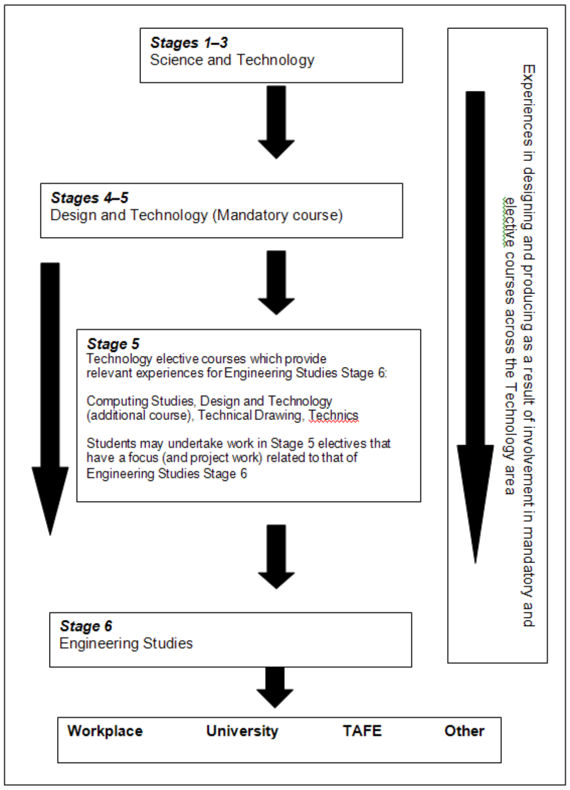


Figure 3A. Continuum of Learning for Engineering Studies Stage 6 Students (source: New South Wales Board of Studies Stage 6 Syllabus, 1999, p. 7)

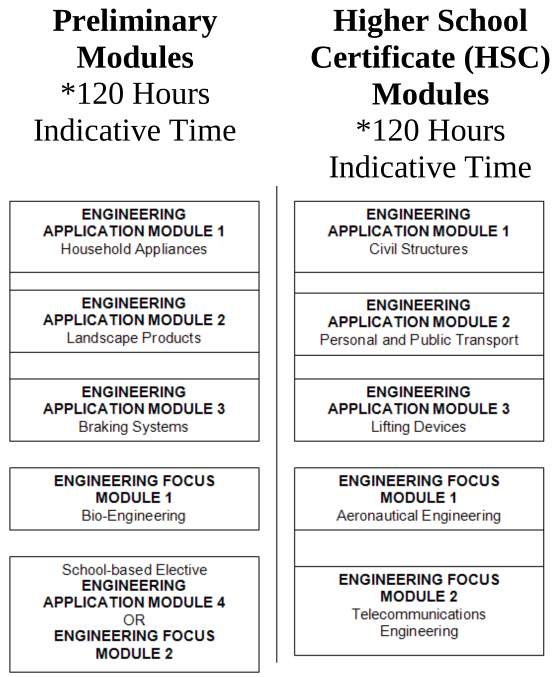


Figure 3B. Schematic view of Engineering Studies Syllabus Structure (source: New South Wales Board of Studies Stage 6 Syllabus, 1999, p. 10)

Modular Structure of K-12 Engineering Curriculum in Australia

Definition of Modules: "A module is a discrete unit of study that integrates knowledge and understanding of various elements of engineering;" in other words, it is an Australian version of "Project-Based Learning;" and it uses concrete "everyday" products" or "everyday systems" to teach a set of well-connected engineering analytic principles (with a focus on "engineering materials" and "engineering mechanics," i.e., statics and dynamics), plus engineering design process (with a focus on "re-design" or "modification").

"Compulsory" versus "Optional" Engineering Curriculum

The *Industrial Technology Years 7-10 Syllabus* "aims to develop in students an understanding of the interrelationships between technology, the individual, society and the environment, and to develop their ability to think creatively to devise solutions to practical problems" (New South Wales Board of Studies, 1999, p. 8). The curricular structure includes two types of Modules, as shown in *Figures 3A* and *3B*.

1. Compulsory "Core Modules:" 2 Modules, 50 hours each (corresponding to American term of "general engineering courses" or "engineering foundation courses;" and

2. Optional "Specialized Modules:" 2 Modules, not less than 50 hours each (corresponding to American term of "major courses"). "The core modules of each focus area include the design, production and evaluation of practical projects that develop basic understanding and skills. These are further enhanced through the specialized modules" (New South Wales Board of Studies, 1999, p. 10).

Compulsory "Core Modules" and optional "Specialized Modules" for high school Engineering and Technology programs in New South Wales area are shown in Table 3.

Table 3.
Focus Areas and Modules
(Source: New South Wales Board of Studies, 2009, p. 15)

Focus Area	**Type of Module**			
	Compulsory [(50) (2) = 100 Hours]		**Optional [(50+)(2) = 100 + Hours]**	
	Core Module 50 Hours	**Core Module 50 Hours**	**Specialized Module 50 Hours +**	**Specialized Module 50 Hours +**
Engineering				
Engineering	Engineering 1 Structures	Engineering 2 Mechanisms	Engineering 3 Control Systems	Engineering 4 Alternative Energy
Technology				
"Mechanical Technology"				
Automotive	Automotive 1	Automotive 2	Automotive 3	Automotive 4
"Materials Technology"				
Metal	General Metal 1	General Metal 2	Metal Machining 3	Metal Machining 4
			Fabrication 3	Fabrication 4
	Art Metal 1	Art Metal 2	Art Metal 3	Art Metal 4
			Jewelry 3	Jewelry 4
Polymers	Polymers 1	Polymers 2	Polymers 3	Polymers 4
Ceramics	Ceramics 1	Ceramics 2	Ceramics 3	Ceramics 4
Timber	General Wood 1	General Wood 2	Cabinetwork 3	Cabinetwork 4
			Wood Machining 3	Wood Machining 4
"Electronics Technology"				
Electronics	Circuits and Components 1	Circuits and Components 2	Circuits and Components 3	Circuits and Components 4
			Computer Repair and Construction 3	Computer Repair and Construction 4
"Construction Technology"				
Building and Construction	Building and Construction 1	Building and Construction 2	Construction and Renovation 3	Construction and Renovation 4
			Outdoor Structures and Landscaping 3	Outdoor Structures and Landscaping 4

Levels of High School Engineering Courses in Australia

"Preliminary" versus "Higher School Certificate" Modules: The *Stage 6 Syllabus, 1999* divides high school engineering courses into "Preliminary Modules" and "Higher School Certificate Modules." As shown in *Figure 3B* (p. 12), Engineering Studies Stage 6 comprises a Preliminary course made up of 4 compulsory modules and one elective module, and an HSC course made up of 5 compulsory modules.

1. The "Preliminary Modules" course: They seam to be focused on "simple" and "analytic reduction" type of engineering design, used as a foundation to build high school students' basic analytic and design abilities, using simpler "every day products" such as household appliances, landscape products, and braking systems, as physical artifacts.

2. The "Higher School Certificate" Modules courses: They seam to be aimed at training the high school students' abilities for solving more complex design problems under the "system thinking" model, using more complicated "everyday system" (instead of "products") such as civil structures, personal and public transport, and lifting devices, as physical artifacts (New South Wales Board of Studies, 1999; p. 10).

Types of High School Engineering Courses in Australia

"Application" versus "Focus" Modules: As shown in *Figure 3B* (p. 12), two types of Module are used to facilitate learning process.

1. Engineering Application Modules: "An engineering application module develops knowledge and understanding of engineering concepts and impacts through the study of engineered products." They cover (1) application of engineering analysis and design with "everyday products" (such as "Household Appliance," "Braking Systems," and "Landscape Products," and "Lifting Devices"); and (2) application of engineering analysis and design with "everyday structures" (such as "civil structures," "Personal and Public Transportation"). The "everyday products" typically include "Household Appliances" such as kettles, ovens, washing machines, refrigerators, cooktops, portable power tools, telephones, irons, vacuum cleaners; while the "everyday systems" typically include "Civil Structures" such as bridges, roads, buildings, community centers, parklands, children's playgrounds and equipment. In American terms, this corresponds to "traditional engineering fields" (mechanical, electrical and electronics, and civil). The keywords are "everyday application."

2. Engineering Focus Modules: "An engineering focus module develops a knowledge and appreciation of the role of engineers by emphasizing a study of the nature of the engineering profession and the scope of engineering

activities in a given field." These Modules corresponds to "specialized or emerging engineering fields" which are branches of "traditional engineering fields" with a narrow focus on specialized engineering problems (for example, "Bio-Engineering" is an emergent field; "Aeronautical Engineering" is a branch of mechanical engineering; and "Telecommunication Engineering" is a branch of electronics engineering. The keywords here are "given field."

Academic Requirements on High School Engineering Curriculum in Australia that Help to Bridge High School and University Engineering Programs: a Streamlined Process

According to the same *Stage 6 Syllabus, 1999*, "Three application modules and one focus module are prescribed for the Preliminary course, together with one module that will be developed as a school-based elective. If a focus module is selected by a school for study as the elective in the Preliminary course, it is to be developed from the engineering fields given below, but must not include any of the prescribed focus modules for the Preliminary and HSC years" (New South Wales Board of Studies, 1999; p. 10).

In addition, the prescribed focus modules in the Preliminary and HSC courses will be replaced periodically with modules developed from the following list, which could seamlessly streamline high school students enrolled in engineering curriculum straight into corresponding university engineering majors:

- Aerospace Engineering
- Aeronautical Engineering
- Agricultural Engineering
- Automotive Engineering
- Bio-Engineering
- Chemical Engineering
- Civil/Structural Engineering
- Electrical/Electronic Engineering
- Environmental Engineering
- Marine Engineering
- Manufacturing Engineering
- Materials Engineering

- Mechanical Engineering
- Mechatronic Engineering
- Mining Engineering
- Nuclear Engineering
- Telecommunications

Methods of Evaluation and Assessment in New South Wales, Australia

At the end of the program, the Higher School Certificate Examination is administered in the fields of (1) Civil Structures; (2) Personal and Public Transport; (3) Lifting Devices; (4) Aeronautical Engineering; and (5) Telecommunications Engineering; and the examination lasted 3 hour for award of the Certificate (Thompson & Thompson, slides 16-26).

The New South Wales Higher School Certificate mark consists of a mark for in school assessments (50%) and an externally examined written paper (50%). The examination includes Multiple Choice Questions and written part; and is divided into three Sections (Thompson & Thompson, slide 28):

- Section I (10 marks): 10 multiple-choice questions (based on application modules or "engineering analytic knowledge content" in American term);
- Section II (70 marks): 6 questions (each consisting of a number of parts requiring short structured responses, including: (A) 1 question, worth 10 marks, based on historical and societal influence and the scope of the profession; (B) 3 questions, worth 10 marks each, based on application modules; and (C) 2 questions, worth 15 marks each, based on focus modules);
- Section III (20 marks): Each question consisting of a number of parts requiring short structured responses (2 questions, worth 10 marks each, based on all modules and Engineering Reports).

Referential Values of Australian Experience in K-12 Engineering Curriculum

Australia's experience with K-12 engineering curriculum shows that

1. In terms of curriculum: Serious engineering education, based on solid analytic and predictive principles and skills, starts at Primary Schools in Australia, NOT after K-12! High school students indeed can handle the pre-calculus portions of typical lower-division undergraduate engineering course content.

Thus, the idea of infusing a substantial amount of pre-calculus based engineering analytic principles and skills, directly and systematically from various lower-division undergraduate engineering foundation courses, is a viable one to pursue. This covers various subjects such as statics, dynamics and engineering materials.

2. In terms of end-of-program testing instrument: High school graduates can be tested on appropriate portions of engineering analytic knowledge content, with "Higher School Certificate Examinations" for engineering that demonstrate professional quality that could match part of a typical FE (Fundamentals of Engineering) exam.

3. In terms of curricular content: Based on the above experience and lessons, the infusion of engineering analytic principles and skills into a potentially viable K-12 engineering curriculum must be based on strictly matching K-12 students cognitive developmental maturity levels, mainly, their pre-requisite mathematics and science preparations, and their ability at globally and synthetically analysing design problems.

Back in Fall 2008, when I developed my *Proposed Model for Infusing Engineering Design into K-12 Curriculum* (Appendix 1), I based my model on (1) the rational assumptions that if pre-requisites in mathematics, physics and chemistry are satisfied at previous grade levels, then high school students should be able to explore topics of engineering analysis and prediction, and (2) the scholarly findings on K-12 engineering and technology curriculums from the United States, Sweden and Finland, notably in the ability of K-12 students to engage in engineering design projects. These assumptions, no matter how rational they are, are not supported by prior empirical evidence yet, although they did appear as viable and get support from many engineering professors at the University of Georgia.

With this Australian model at hand, there appears to be empirical support that my Proposed Model would work, since it is in the similar direction, except that it would go deeper into the development of high school appropriate foundation and major engineering subjects, including all pre-calculus and beginning-calculus portions of (1) all undergraduate lower-division engineering foundation courses (such as fluid mechanics, strength of materials, engineering economics or decision-making, heat transfer and thermodynamics); and (2) some major courses (such as mechanism design and selection, which is important for practical product design). This might likely move beyond what Australian experience has already offered.

PART FOUR
INTEGRATION OF SOLID ENGINEERING ANALYTIC & PREDICTIVE PRINCIPLES & SKILLS WITH "PRACTICAL PROJECTS" OF DESIGN IN AUSTRALIAN HIGH SCHOOL ENGINEERNG STUDIES

Based on information available in Mr. Peter Thompson and Mr. Ruth Thompson's ITEA Conference presentation CD, the integration of generic engineering design process and particular engineering analysis principles and skills demonstrates the following characteristics:

- Teaching of engineering analytic knowledge content through simple activities with "everyday" objects;
- Focus on "everyday" and "practical projects/structures" to foster engineering design abilities;
- Reasonable expectation on students' learning outcome with "real-world" results.

Teaching Engineering Analytic Knowledge Content through Simple Activities with "Everyday" Objects

Focus on the "Practical Projects" and Aimed at the "Sequential Development of Skills"

Design process: Design is one of the major components of K-12 engineering and technology curriculum in Australia. The *Industrial Technology Years 7-10 Syllabus*, published by New South Wales Board of Study (2003), is based on realistic expectation of what students can accomplish, including

- Redesign or modification of existing design: Apply principles of design in the modification of products to enhance function and/or aesthetics (for Automotive, p. 23; for Ceramics, p. 45; for Electronics, p. 55 and p. 57; etc.);
- Design analysis: Identify the factors influencing the design of products (for Automotive, p. 23; for Building and Construction, p. 30, etc.);
- Design parameters: Account for design limitations in the development of projects (for Ceramics, p. 49);
- Design process: Work through a design process to develop and produce practical projects (for Ceramics, p. 51).

"Practical projects" that "should reflect the nature of the Engineering focus area and provide opportunities for students to develop specific knowledge, understanding and skills related to engineering," are used to "promote the sequential development of skills and reflect an increasing degree of student autonomy as they progress through the course," through an incremental progression of the delivery of knowledge content and training of design abilities from one Core Modules to the next (New South Wales Board of Studies, 2009, p. 67).

Typical Engineering Design Activities

Typical engineering design and prototyping activities in various engineering analysis courses in Australian high schools include those similar to what are available in American high schools, with an emphasis on functional design of simple, "everyday" products and systems that can perform "real-world" functions and are appropriate to high school students' cognitive maturity levels. Well-connected sets of engineering analytic principles and skills are delivered through these simple activities, teaching students how to design, digitally simulate, and prototype.

For Application Modules:

- Bridges: (1) Using metal and wood panels, and wood sticks; (2) using WestPoint Bridge Design and other software (*Figure 4A*);
- Mechanical devices: (1) Lifting Device; (2) Buggy and Stomp Control; (3) electrical motor with Coke cans and other materials; (4) Rube Goldberg Activity (*Figure 4B*);

For Focus Modules:

- Vehicle models: (1) Airplane models for the Aeronautical Engineering program; (2) vehicles using alternative energy (*Figure 4C*).

Figure 4A. Bridge model in metal and wood panels (left), in wood sticks (middle), and in digital simulation (right). Source: Thompson & Thompson, 2009, slide 30, 34 and 35.

Figure 4B. Electrical motor (top left), lifting Device (top right), Buggy (bottom left) and Stomp Control (bottom right). Source: Thompson & Thompson, 2009, slides 24, 31 and 36).

Figure 4C. Airplane models (left), and mechanism using alternative energy (right). Source: Thompson & Thompson, 2009, slides 39 and 40.

Figure 5. "Everyday product" (top) and "structures" used as referential sources (Thompson & Thompson, 2009, p. 13, and p. 17).

Focus on "Everyday" and "Practical Projects/Structures" to Foster Engineering Design Abilities

Typical Engineering Design Projects

It appears that "reverse engineering" or study of existing products and structures constitute an important part of K-12 engineering curriculum in Australia. As mentioned before, "modification" or redesign of existing products and structures serve to guide students into engineering design process. This point could be illustrated by (1) the referential resources for design projects (*Figures 5*); and (2) the selection of the best ones from Higher School Certificate Major Projects in 2003 and 2004 (*Figures 6A* through *6H*), which have been designed and prototyped by Australian high school students enrolled in various engineering and technology programs.

Table 4
Interdisciplinary Content for Engineering Application Module 1 (Household Appliances) (New South Wales Board of Studies Stage 6 Syllabus, 1999, pp. 17-18)

Students learn about	Students learn to:
Historical and Societal Influences:	
• historical developments of household appliances • the effect of engineering innovation on people's lives	• outline historical uses and appropriateness of materials in the design and production of household appliances
Engineering Mechanics and Hydraulics	
• mass and force • scalar and vector quantities	• use mathematical and/or graphical methods to solve engineering problems in household appliances
Engineering Materials	

• classification of materials
• properties of materials
  ○ physical and mechanical properties
• structure of materials
  ○ atomic structure
  ○ bonding
  ○ metals
  ○ ferrous metals including mild steel
  ○ non-ferrous metals including copper, brass and bronze
  ○ joining and cutting methods
• polymers
  ○ thermoplastics
  ○ thermosets
  ○ ceramics
  ○ types used
	• classify a variety of materials
	• identify the properties of materials and explain the reason for their selection
	• describe the structure and bonding of materials
	• distinguish between and explain reasons for the use of ferrous and non-ferrous metals as components in household appliances
	• compare the suitability of joining and cutting methods used on metals
	• distinguish between thermoplastics and thermosets
	• identify the types of ceramics used in household appliances

Engineering Electricity/Electronics	

• basic principles
  ○ potential difference
  ○ current
  ○ simple circuits and components
• electrical safety
  ○ related Australian electrical standards
• magnetic induction
• fundamental AC and DC circuits
• electric motors
	• explain the basic electrical principles of operation appropriate to household appliances
	• appreciate the importance of safety when using electrical household appliances
	• explain the working of an induction motor
	• distinguish between AC and DC circuits

Table 4 (Continued).

Students learn about	Students learn to:
Communication	
• freehand sketching • research methods including the Internet, CD-ROM and libraries • collaborative work practices • Engineering Report writing	• draw freehand, three-dimensional objects • conduct research using computer technologies and other resources • complete an Engineering Report based on the analysis of one or more household appliances, integrating the use of computer software

K-12 Engineering Design Pedagogy in New South Wales, Australia

Pedagogic strategy: Overall, it appears that K-12 engineering pedagogy used in New South Wales, Australia, is similar to an interdisciplinary model of Project-Based Learning; and has some unique characteristics (Thompson & Thompson, 2009, pp 14-16, and pp. 28-30).

- Design project or "Modules:" They are used as the general frameworks to link engineering analysis principles and skills, as well as "people skills" and humanities from different subjects into cohesive pedagogic structures, which are called "Modules;" for example, Engineering Application Modules (such as Module 1 for Household Appliances) all include (1) Historical and Societal Influences; (2) Engineering Mechanics and Hydraulics; (3) Engineering Materials; (4) Engineering Electricity/Electronics; and (5) Communication (see Table 4); while Engineering Focus Modules (such as Module 1 for Aeronautical Engineering) all include the above plus Scope of the Profession subject (New South Wales Board of Studies Stage 6 Syllabus, 1999, pp. 41-43). Details of the interdisciplinary knowledge content for Engineering Application Modules 1 (Household Appliances), published by New South Wales Board of Studies Stage 6 Syllabus, in 1999 (pp. 17-18), is shown in Table 5. In 2009, New South Wales Board of Studies published new guidelines for additional Modules (Table 5).

- "Everyday products:" Physical devices available in the households or the communities, such as those shown in *Figure 5*, are used as the vehicle to teach selected sets of engineering related knowledge content and skills.

    - For Household Appliances Module: The basics of materials science, including atomic bonding, heat treatment, mechanical analysis (equilibrium, forces and moments, vector addition and resolution of forces), engineering drafting and CAD, Engineering Reports writing, manufacture of components, electronics and electricity (induction and the fundamentals of motor design), and others are taught. "All of this in 6 weeks of school at the start of year 11 (16, 17 year olds) in approximately 24 hours of school study."

  - For mechanism design: Components such as motors, switches, levers and pulleys and PLC controlled robots are explored. Students also learn how to use prototyping equipment such as a Roland MDX40 milling machine, to fabricate components from engineering materials such as sheets of A4 acrylic before assembly and testing. Some schools also teach digital simulation.

  - For Control Systems: Lego Robotics, Basic Stamp, Picaxe, Control Studio. "Typically students are faced with a challenge and have to design and construct a device, sometimes in teams, to meet that challenge. First Lego League and Junior Robotics competitions are held in this context."

  - For Civil Structures: "It is common for students to analyze bridge design and create one for testing in class. Spaghetti, balsa and other lightweight materials are used to construct bridges for testing. Students are required to present work for each module that they study in the form of an engineering report. […] students tend to find the concepts of shear force, bending moment and the calculation of reactions difficult, but the requirements of the syllabus and then, the final examination require them to analyze the social and environmental impacts of engineering projects. This literacy expectation is what the students find most difficult in that they do not write enough."

- Extensive use of reverse engineering: "A typical approach would again focus on the analysis of existing products. In Landscape Products, a simple wheelbarrow, a garden hose and a shovel, would used to introduce engineering concepts to students. Though the syllabus is very much analysis of existing designs, many of the challenges presented to students ask them to predict or speculate about an improvement to these machines and products." The goal is solving real-world problems.

Pedagogic format: Classroom activities include (1) Watching video; (2) class discussion; (3) research through library and Internet; (4) classroom work and exercise; (5) laboratory experiment, analysis and report; (6) design and revision; (7) engineering drafting; (8) fabrication or prototyping; and (9) testing and analysis of design with tables and graphs (Engineering Studies High School, n.d., pp. 7-11).

Table 5.
Industrial Technology (Engineering) Module Content Chart
(Source: New South Wales Board of Studies, 2009, pp. 68-75)

Engineered Structures - Core Module 1	
Students learn about:	**Students learn to:**
Materials	
• the properties, structure and applications of materials including: ○ hardness ○ ductility ○ tensile and compressive strength • the elastic and plastic behaviour of materials • the basic structure and advantages of composite materials used in engineered structures • the corrosion and/or degradation of materials used in structures	• use materials in the design and production of structures based on an understanding of their properties • conduct experiments and tests to understand the properties of materials • use techniques to minimise corrosion and/or degradation of materials used in practical projects
Engineering Principles and Processes	
• the nature and purpose of structures: bridges, buildings, dams, chairs • elements that make up structures: beams, columns, braces fundamental quantities, derived quantities and their units: force, mass, acceleration • forces that act on structures: wind loads, live loads, weight etc • the effects of forces on structures: reactions, induced stress, deflection and motion	• design and construct simple structures for specific purposes • experiment with load applications on structures: destructive and non-destructive testing • determine the effects of forces on engineered structures
Design	
• design principles and processes • Australian Standards for engineering design • alternative design solutions appropriate to engineered structures • past, present and future challenges in engineering structures, eg Empire State Building, Sydney Opera House	• identify the functional and aesthetic aspects of the design of some structures • use elementary design principles and processes in the design and production of structures
Additional Content	
• use formulas to solve problems relating to simple engineered structures	• calculate forces and reactions on structures • calculate loads in members of structures • calculate induced stress in an axially loaded member • apply factors of safety to determine maximum allowable loads
Societal and Environmental Impact	
• the impact of engineering on society and the physical environment	• analyse a structure in terms of its effect on the community, eg dam, bridge • discuss some legal and ethical issues that apply to engineered structures

Table 5. (Continued).

Engineered Mechanisms - Core Module 2	
Students learn about:	**Students learn to:**
Materials	
• the properties, structure and applications of materials related to engineered mechanisms: • toughness • malleability • corrosion resistance • torsional and shear strength • the classification of engineering materials • typical materials used in mechanisms • the modification of materials to improve their mechanical and chemical properties: • heat treatment • cladding • reinforcement	• use materials in the design and production of mechanisms based on an understanding of their properties • experiment to understand properties such as: toughness, strength, torsion and shear, corrosion resistance, malleability • classify materials into groups, eg: metals – ferrous, non-ferrous, alloys, polymers – thermosetting, thermoplastic, ceramics – building ceramics, engineering ceramics
Engineering Principles and Processes	
• the nature and purpose of mechanisms • components that make up mechanisms • the function and operation of mechanisms such as levers, pulleys, gears and cams • friction and its significance to the operation of mechanisms • mechanical advantage, velocity ratio and efficiency in mechanisms methods of driving mechanisms	• dismantle and assemble mechanisms to understand how they work • design and construct mechanisms for specific purposes carry out experiments to demonstrate engineering principles
Design	
• design principles and processes • Australian Standards relevant to engineering design • the factors influencing the design of mechanisms including: ○ material choices ○ energy sources ○ structures • past, present and future challenges in the application of engineering mechanisms	• modify designs and follow a planned construction sequence in the development and production for projects relating to engineered mechanisms • observe standards in the development of engineered mechanisms
Additional Content	
• the relationship between components in complex mechanisms • moments • mechanical advantage, velocity ratio and efficiency for simple mechanisms	• develop projects using combinations of different mechanisms • apply the principles of and calculate moments in simple engineered mechanisms • calculate mechanical advantage, velocity ratio and efficiency for simple mechanisms
Societal and Environmental Impact	
• the impact of the focus area on society and the physical environment	• analyse an engineered mechanism in terms of its effect on society and/or the environment, eg lifting bridge, gearbox

Table 5. (Continued).

Control Systems – Specialized Module 3	
Students learn about:	**Students learn to:**
Materials	
• the properties, structure and applications of materials • testing materials for properties • the basic structure of metals, alloys, polymers, ceramics electromagnetic induction and induction motors	• use materials in the design and production of control systems based on an understanding of their properties test materials for properties and/or examine and analyse results of property tests
Engineering Principles and Processes	
• the nature and purpose of control systems, • types of control systems: mechanical, electronic, hydraulic, pneumatic • the principles of simple control systems using sensors, actuators and controllers • the applications of control systems, eg production processes, robots, washing machines, servo brakes • the function of feedback in a control system	• design and construct, or simulate, control systems for specific purposes • conduct experiments with a range of control devices and systems
Design	
• design principles and processes • past, present and future challenges in control systems • Australian Standards for engineering design	• apply principles of design in the development and production of projects related to control systems
Additional Content	
• elementary CAD applications • animations and simulations	• use a CAD program to produce simple engineering drawings • use a suitable software program to simulate more complex control systems
Societal and Environmental Impact	
• the impact of the focus area on society and the physical environment • legal and ethical responsibilities of engineers toward the environment and community	• analyse a control system in terms of its effect on the community and the environment, eg Sydney Coordinated Adaptive Traffic Control System (SCATS)

Table 5. (Continued).

Alternative Energy – Specialized Module 4	
Students learn about:	**Students learn to:**
Materials	
• the properties, structures and applications of materials • the relationships between structure, properties and the application of materials within engineering • the structures, properties and applications of composite materials	• use materials in the design and construction of projects based on an understanding and analysis of their properties • design a testing jig or apparatus to analyse properties of materials
Engineering Principles and Processes	
• the nature and purpose of alternative energy systems • various types of alternative energy systems such as wind, solar, wave, human, geothermal • advantages and disadvantages of alternative energy systems • electrical units and values of voltage, power, current and energy in relation to alternative energy systems	• plan and construct or simulate a working model, prototype or full-scale alternative energy system • examine the components of an alternative energy system • use an alternative energy system to power a device • compare the advantages and disadvantages of alternative energy systems
Design	
• design principles and processes • past and present achievements in engineering involving alternative energy	• follow a design process in the development and production of projects related to alternative energy • justify design decisions and choices of materials, processes and equipment • apply relevant Australian Standards to engineering designs
Additional Content	
• CAD and 3D modelling • calculations relating to energy sources	• use a suitable CAD or 3D modelling program to represent alternative energy systems • calculate simple quantities related to alternative energy systems
Societal and Environmental Impact	
• the impact of alternative energy on society and the physical environment	• analyse the use of an alternative energy source in terms of its effect on society and the environment, eg solar power, wind farms • identify and distinguish between renewable and non-renewable energy resources used by engineers

K-12 Design, Creativity and Technology Standards in the State of Victoria, Australia

System of Standards for the Performance of K-12 Students

In the State of Victoria, the standards for K-12 students' performance are hierarchically divided into various levels such as "domains" and "dimension." Chronologically, all of these parameters are grouped into 3 "Stages of Learning" and 6 "Levels" that (1) divide the 11 years of compulsory schooling into convenient periods of assessment against the different standards from Prep to Year 10 to enable teachers, school administrators and parents to form a clear picture of student progress; and (2) correspond to certain Years and ages of the K-12 students. The general descriptions of the Stages of Learning are from *Victorian Essential Learning Standards Level 1* (Victorian Curriculum and Assessment Authority. 2008, p. 3). The particular descriptions for the domain of Design, Creativity and Technology are from the webpage of *Victorian Essential Learning*

Standards maintained by Victorian Curriculum and Assessment Authority, at http://vels.vcaa.vic.edu.au/essential/interdisciplinary/design/index.html.

- Stage of Learning 1 (Years Prep to 4 - Laying the Foundations): "The curriculum focuses on developing the fundamental knowledge, skills and behaviors in literacy and numeracy and other areas including physical and social capacities which underpin all future learning." For Design, Creativity and Technology: "Students begin to understand that people use creative and inventive thinking to help them meet human needs and wants. In DCT students are encouraged to wonder, be curious and imaginative. They explore possibilities and concepts and verbalize their thought processes." This "Stage of Learning" covers "Standards" for three "Levels."
  - Level 1 - End of Preparatory Year;
  - Level 2 - End of Year 2;
  - Level 3 - End of Year 4.
- Stage of Learning 2 (Years 5 to 8 - Building Breadth and Depth): "Students progress beyond the foundations and their literacy and numeracy becomes more developed. An expanded curriculum program provides the basis for in depth learning within all domains in the three learning strands." For Design, Creativity and Technology: "Students are able to think conceptually and analytically. They become more complex thinkers who work with increasing independence when designing, planning and making products. They become aware of the impact of design and manufacturing on the wider society and the environment. They recognize that many issues can have an impact on the design of products and systems." This "Stage of Learning" covers "Standards" for two "Levels."
  - Level 4 - End of Year 6;
  - Level 5 - End of Year 8.
- Stage of Learning 3 (Years 9 to 10 - Developing Pathways): "Students develop greater independence of mind and interests. They seek deeper connections between their learning and the world around them and explore how learning might be applied in that world. They need to experience learning in work and community settings as well as the classroom. They are beginning to develop preferred areas for their learning." For Design, Creativity and Technology: "Students become discerning, discriminating and independent thinkers at this stage of their learning. As a result, they can discuss the place of design and technology in society as well as describe some of the economic and environmental benefits and implications of product and system design.

They further develop critical awareness of design and technology from the perspectives of both consumer and designer." This "Stage of Learning" covers "Standards" for one "Level."

- Level 6 - End of Year 10.

The following areas of "Learning" are subdivided into separate "domains" (or subjects in American terms):

- <u>Physical, Personal and Social Learning</u>: This includes (1) Health and Physical Education; (2) Interpersonal Development; and (3) Personal Learning.

- <u>Discipline-based Learning</u>: This includes (1) The Arts; (2) English; (3) Science; (4) The Humanities; (5) Languages Other Than English; and (6) Mathematics.

- <u>Interdisciplinary Learning</u>: This includes (1) Communication; (2) Design, Creativity and Technology; (3) Information and Communications Technology; (4) Thinking Processes.

Unique Characteristics of Australian K-12 Design, Creativity and Technology Standards

The State of Victoria in Australia has developed her own standards for Design, Creativity and Technology (DCT) for K-12 systems. Table 6 displays the *Victorian Essential Learning Standards: Design, Creativity and Technology - Standards*, an extract from the *Victorian Essential Learning Standards* published by Victorian Curriculum and Assessment Authority (December, 2005). These standards are very details-oriented, in terms of meticulously describing all activities required or recommended for each Level throughout the K-12 Years, far beyond mere proposition at generic, "theoretical," or "guidelines" level. For Years K-4, these Standards do not apply; instead, "Learning Focus" is used to guide STEM instruction. Details of the Learning Focus and Standards are shown in Tables 6A and 6B.

<u>Important features of the domain</u>: "Design, Creativity and Technology" is one of the domains under the "Interdisciplinary Learning" area. This domain "emphasizes engagement in designing, creating and evaluating processes, products and technological systems using a range of materials as a way of developing creativity and innovation. Creativity in this domain can be described as applying imagination and lateral and critical thinking throughout design and development processes." These standards feature the following:

- "Analyzing and evaluating […] own and others' products and/or systems."

- "Transforming ideas into creative, practical and commercial realities by optimizing the value of products and systems."

- "Planning and organizing production, and evaluating products in a real context."

- "Assessing the outcomes of design and technology processes, and the resulting products and technological systems in relation to environmental, social and economic factors."

- Combining "experiential, practical and applied knowledge as well as theoretical understanding."

- "Using a range of tools, equipment and machines to make functional physical products or systems. These materials include food, wood, metal, timber, plastics, textiles, ceramics, plants and soil/growing media, and components such as wheels and axles, pulleys and belts, gears, switches, lights, motors, connecting wires, batteries and printed circuits boards."

Structure of the domain: "The Design, Creativity and Technology domain is organized into six sections, one for each level of achievement from Level 1 to Level 6. Each level includes a learning focus statement and, from Level 3, a set of standards organized by dimension." The definitions of the terms are listed below.

- Learning Focus: "Learning Focus statements are written for each level. These outline the learning that students need to focus on if they are to progress in the domain and achieve the standards at the levels where they apply. They suggest appropriate learning experiences from which teachers can draw to develop relevant teaching and learning activities." For the Design, Creativity and Technology domain, "Learning Focus" are established throughout all 6 levels.

- Standards: "Standards define what students should know and be able to do at different levels and are written for each dimension. In Design, Creativity and Technology, standards for assessing and reporting on student achievement apply from Level 3." For the Design, Creativity and Technology domain, "Learning Focus" are established for levels 3-6. The Standards are sub-divided into three separated but interconnected "dimensions:"

    1. Investigating and designing: "Students identify ideas, problems, needs, wants and opportunities. A design brief can be a starting point or it can be developed to clearly define the idea, problem, need, want or opportunity and requirements for a solution. Students undertake research and investigation to identify the human, material, equipment, and/or energy resources available to meet the idea, problem, need, want or opportunity. Students combine practical and design skills with knowledge, skills and behaviors from other domains to select and record creative methods of generating and depicting design possibilities and options. They devise a

plan to outline the processes involved in making a product, and select and justify the option that best meets the requirements of the design brief."

2. Producing: "The *Producing* dimension involves students in the management of the production phase and includes the appropriate selection and safe manipulation and use of tools, equipment, materials/ingredients and components to carry out processes appropriate to the materials/ingredients or assembly of systems components to produce a quality product or technological system. Students explore, share and use both traditional and more innovative techniques. They reflect upon their progress and alter plans as appropriate. Progress and changes to plans are reflected upon and altered as appropriate."

3. Analyzing and evaluating: "Students compare the outcomes of design and production activities with earlier design work and planned intentions. Following the application of testing, improvements, modifications and alternative approaches are considered. This dimension also involves students in describing, analyzing and evaluating the impact and value of both their own and others' technological products, technological systems, processes and innovations (past, present and predicted future) on the individual, society and culture, the environment and the economy. This includes consideration of sustainability issues."

Activities associated with the three dimensions are linked and may be applied sequentially, or "linearly," where students move directly from investigating to designing, producing and evaluating. Alternatively, students may move between the dimensions as they solve a problem, in a non-sequential or "recursive" manner through the dimensions in this domain (source: *Victorian Essential Learning Standards Level 1*, 2008, pp. 67-69).

Vocational Credentials for the Domain of Design, Creativity and Technology (DCT)

In the State of Victoria, Australia, "as students approach the end of the compulsory years of schooling they begin to make choices about their preferred areas of and pathways for learning. […] The Design, Creativity and Technology domain provides students with opportunities to pursue a range of post-compulsory pathways […] Each of these pathways allows students to develop technical competence and begin to specialize in one or more areas of the domain. Students may also move into related employment, either during their senior secondary years (for instance, to take up an apprenticeship) or on completion of their schooling." As listed on the webpage of *Victorian Essential Learning Standards* webpage maintained by Victorian Curriculum and Assessment Authority, at http://vels.vcaa.vic.edu.au/essential/interdisciplinary/design/index.html, these "pathways" include:

- Victorian Certificate of Education (VCE): Leading to further education in

  - VCE Agricultural and Horticultural Studies;
  - VCE Design and Technology;
  - VCE Food and Technology;
  - VCE Systems Engineering.

- Vocational Education Training (VET) program: Recognized vocational training leading to
  - Certificate II in Agriculture;
  - Certificate II in Automotive Technology Studies;
  - Certificate II in Building and Construction;
  - Certificate III in Concept Development for Clothing Products;
  - Certificate II in Conservation and Land Management;
  - Certificate II in Electrotechnology (Shared Technology);
  - Certificate II and III in Engineering Studies;
  - Certificate II in Food Processing (Wine);
  - Certificate II in Furnishing (Pre-apprenticeship Cabinet Making);
  - Certificate II in Horticulture;
  - Certificate II in Hospitality (Operations);
  - Certificate II in Plastics;
  - Certificate II in Printing and Graphic Arts (Graphic Publishing);
  - Certificate II in Printing and Graphic Arts (General).

- Victorian Certificate of Applied Learning (VCAL): Students may choose relevant “themed courses” such as Agriculture/Horticulture, Engineering, Furnishing etc., plus industry specific training in related Vocational Education Training (VET) programs, to gain “Work Related Skills.”

Table 6A.
Victorian Essential Learning Focus: Design, Creativity and Technology – Learning Focus (Source: Victorian Curriculum and Assessment Authority. *Victorian Essential Learning Standards Level 2*, 2008, p. 71, and p. 75)

	Learning Focus
Level 1 → **End of Prepara-tory Year**	As students work towards the achievement of Level 3 standards in Design, Creativity and Technology, they investigate everyday, familiar products and recognize the basic characteristics and materials/ingredients from which they are made and how they are used. They explore the differences between natural products and artifacts, and learn that materials can be recycled and reused to produce new products. They play with and manipulate materials/ingredients in both a free and focused manner to foster development of their design and technical skills. They learn appropriate terminology, including the names of materials/ingredients and their characteristics and properties (for example, rough, smooth, shiny, soft, flexible), and processes such as measure, mix, cut, join. Students think and talk about why and how products are made. They respond to simple design briefs as a context for designing (for example, "There is to be a teddy bears" picnic, and your teddy will have to be protected from the sun'). Students use their imagination and curiosity to generate ideas, engage in technological processes and develop imaginative design solutions for simple problems. They learn to use simple pictures and models to represent design ideas to develop simple and authentic products, such as a healthy after-school snack. While designing usually precedes producing and evaluating, students may draw their design after the product is made. Their products may be developed as a result of exploring materials rather than from a drawing. Students independently, or in collaboration with peers or adults, explore the use of common materials such as paper, cardboard, glue, fabric, wood, soil and plants, plastic containers, string, paddle-pop sticks and food ingredients. They develop skills in the safe use of basic tools and equipment, such as safety scissors, mixing bowls, cups and rulers, to cut, join, shape, mix and follow instructions to construct simple products or models based on their design ideas. Students think and talk about how their designs will solve a problem or meet a need, and reflect on the steps they took to design and make their product. They discuss how they could make a product better.
Level 2 → **End of Year 2**	As students work towards the achievement of Level 3 standards in Design, Creativity and Technology, they come to understand that people use creative, imaginative and inventive thinking to help them meet human needs and wants. They enquire about and question their world, offering ideas and suggestions based upon their experience of working with materials/ingredients and systems components. They investigate what products and systems can do, how they work, and why they are the way they are. They play with and manipulate materials/ingredients, think about, discuss and describe their characteristics and properties (using terms such as *strong*, *hard*, *stretchy* and *sweet*) and why they are suitable for use in products and systems. In response to simple design briefs, students develop basic design ideas based on their experiences of working with materials/ingredients and components. They talk about their design ideas and thought processes and start to represent these visually by using models, pictures and words. They consider that more than one solution may be possible and begin to give reasons for changes in their thinking. Students begin to recognize relationships between individuals and communities, and products, processes and systems; for example, a transport system. Responding to open-ended design tasks, students develop imaginative and practical design solutions to problems, needs and opportunities; for example, making a simple decorated bag for carrying personal items, modeling playground equipment, or making pots to grow herbs for use in a food product. Students follow a set of instructions and may begin to contribute to planning the main steps to make a product. They explain what they are making and which tools and equipment they are using. They safely use tools and equipment to separate, assemble, join and combine everyday materials/ ingredients and systems components in a variety of ways. Students consider whether their design solutions work and are appropriate for the purpose for which they were designed. With guidance from the teacher and feedback from peers, they reflect on how they designed and made their products.

Table 6B.
Victorian Essential Learning Standards: Design, Creativity and Technology – Standards
(Source: Victorian Curriculum and Assessment Authority, 2008)

	Standards		
	Investigating and Designing	**Producing**	**Analyzing and Evaluating**
Level 3 → **End of Year 4**	At Level 3 students, individually and in teams, generate ideas based on a design brief, demonstrating understanding that designs may need to meet a range of different requirements. They use words, labeled sketches and models to communicate the details of their designs, and clarify ideas when asked. They identify simple systems components and common materials/ ingredients and explain the characteristics and properties that make them suitable for use in products. Students think ahead about the order of their work and list basic steps to make the product or system they have designed.	At Level 3, students use their list of steps and are able to choose appropriate tools, equipment and techniques to alter and combine materials/ingredients and assemble systems components. They use a variety of simple techniques/processes and a range of materials/ingredients to safely and hygienically alter and combine materials/ingredients and put together components to make products and simple systems that have moving parts.	At Level 3, students test, evaluate and revise their designs, products or simple systems in light of feedback they have gained from others. They identify what has led to improvements and describe what they consider to be the strengths and drawbacks of their design, product or simple system. They consider how well a product or simple system functions and/or how well it meets the intended purpose.
Level 4 → **End of Year 6**	At Level 4, students contribute to the development of design briefs that include some limitations and specifications. Individually and in teams, they use a range of methods to research and collect data in response to design briefs. They generate and communicate alternative design ideas in response to a design brief and use words, labeled sketches and models, to demonstrate that they are aware of environmental and social constraints. Students take account of the views of users/consumers and produce step-by-step plans and/or modify recipes for making products and/or simple mechanical/electrical systems. They describe how their intended product will function or be used, and what it will look like in the context of the requirements of the design brief. They identify evaluation criteria from design briefs and use them to justify design choices.	At Level 4, students use their production plan and select and work safely with a variety of materials/ingredients and systems components to produce functional products and/or systems. They use a range of measuring, marking, joining/combining techniques to alter materials and finishing/presentation methods, and operate tools and equipment competently, showing consideration of safety and hygiene, and record their progress.	At Level 4, students reflect on their designs as they develop them and use evaluation criteria, identified from design briefs, to justify their design choices. They modify their designs/products/systems after considered evaluation of feedback from peers and teachers, and their own reflection. They describe the impact products and technological systems have on people and the environment.

Table 6B. (Continued).

	Standards		
	Investigating and Designing	**Producing**	**Analyzing and Evaluating**
Level 5 → **End of Year 8**	At Level 5, students use various strategies and sources of information to investigate and research a range of factors relevant to more sophisticated design briefs to which they have contributed. During the design process they clarify their understanding of design brief requirements and their design ideas by gathering, responding to and providing feedback to others. They develop evaluation criteria from the design brief to inform their judgments during the design process. They use a variety of drawing and modeling techniques to visualize design ideas and concepts. Students demonstrate understanding of design elements and principles and use appropriate technical language. Students understand and logically sequence major stages of production, and calculate and list materials/ingredients and quantities needed for production. They record and communicate their ideas using a variety of media that includes information and communications technology equipment, techniques and procedures.	At Level 5, students work safely/hygienically with a range of tools and equipment, including some which are complex, and manage materials/ingredients, components and processes to produce products and systems, taking full account of the appropriateness of their properties, characteristics or expected outputs in meeting requirements of design briefs. They make modifications during production, providing a sound explanation for changes that demonstrates reflection, research, responsiveness to feedback, and use of evaluation criteria.	At Level 5, students select appropriate equipment and techniques to safely test and evaluate the performance of their products/systems. They suggest modifications to improve their products/systems in light of evaluation of their performance, function and appearance. They recommend improvements to the performance, function and appearance of others' product/systems. They describe and analyze the social and environmental impacts of their own and others' designs, products and technological systems.

Table 6B. (Continued).

	Standards		
	Investigating and Designing	**Producing**	**Analyzing and Evaluating**
Level 6 → **End of Year 10**	At Level 6, students identify considerations and constraints within a design brief. They undertake research relevant to the design brief. They locate and use relevant information to help their design thinking and identify the needs of a variety of client/user groups. When designing, they generate a range of alternative possibilities, use appropriate technical language, and justify their preferred option, explaining how it provides a solution to the problem, need or opportunity. They make critical decisions on materials/ingredients, systems components and techniques based on their understanding of the properties and characteristics of materials/ingredients and/or of the relationship between inputs, processes and outputs. They effectively use information and communications technology equipment, techniques and procedures to support the development of their design and planning. Students take account of function and performance, energy requirements, aesthetics, costs, and ethical and legal considerations that address the requirements of design briefs. They identify a range of criteria for evaluating their products and/or technological systems. Students plan a realistic and logical sequence of the production stages, incorporating time, cost and resources needed for production.	At Level 6, students implement a range of production processes accurately, consistently, safely/hygienically and responsibly, and select and use personal protective clothing and equipment when necessary. They produce products/systems using complex tools, equipment, machines, materials/ingredients and/or systems components with precision. They clearly explain decisions about the suitability of materials/ingredients, systems components, energy requirements and production techniques based on their understanding of the properties and characteristics of materials/ingredients, and the inputs, processes and outputs of systems. In response to changing circumstances, they adapt their methods of production and provide a sound explanation for deviation from the design proposal. They make products/systems that meet the quality, aesthetic, functionality and performance requirements outlined in the design brief.	At Level 6, students use evaluation criteria they have previously developed, and critically analyze processes, materials/ingredients, systems components and equipment used, and make appropriate suggestions for changes to these that would lead to an improved outcome. They use a range of suitable safe testing methods in this analysis. They relate their findings to the purpose for which the product and/or system was designed and the appropriate and ethical use of resources. They synthesize data, analyze trends and draw conclusions about the social, cultural, legal and environmental impacts of their own and others' designs and the products/systems, and evaluate innovative new technology in the manufacturing industry.

Comparing Australian and ITEA Standards

For K-12 level engineering design related performance standards, *Standards for Technological Literacy Content for the Study of Technology*, published by the International Technology Education Association (ITEA, 2002), contained two chapters on design: (1) Chapter 5 - Design (pp. 89-112), dealing with understanding of the attributes of engineering design, and of the role of troubleshooting, research and development, invention and innovation, and experimentation in problem-solving; and (2) Chapter 7 - The Designed World pp. 139-197), dealing with understanding, selection and use of different groups of related technologies, such as medical technologies, biotechnologies, energy and power technologies, information and communication technologies, transportation technologies, manufacturing technologies, and construction technologies. The ITEA document is available for download from http://www.iteaconnect.org/TAA/Publications/TAA_Publications.html. Chapter 5 is more relevant to the issue of design process, while Chapter 7 is on general knowledge content about different technological systems that have been designed.

As shown in *Figure 6A*, there are some apparent differences between ITEA Design Standards, and Victoria's Learning Focus and Standards for K-12 Design, Creativity and Technology. The differences could be classified under the following categories:

- Design process: ITEA's Design Standards seam to be based on "Technology Education Design" model, while Victoria's Learning Focus and Standards tend to be closer to "Engineering Design" model, and incorporate all elements of the High School Engineering Design Process developed by the U.S. National Center for Engineering and Technology Education (*Figure 6B*).

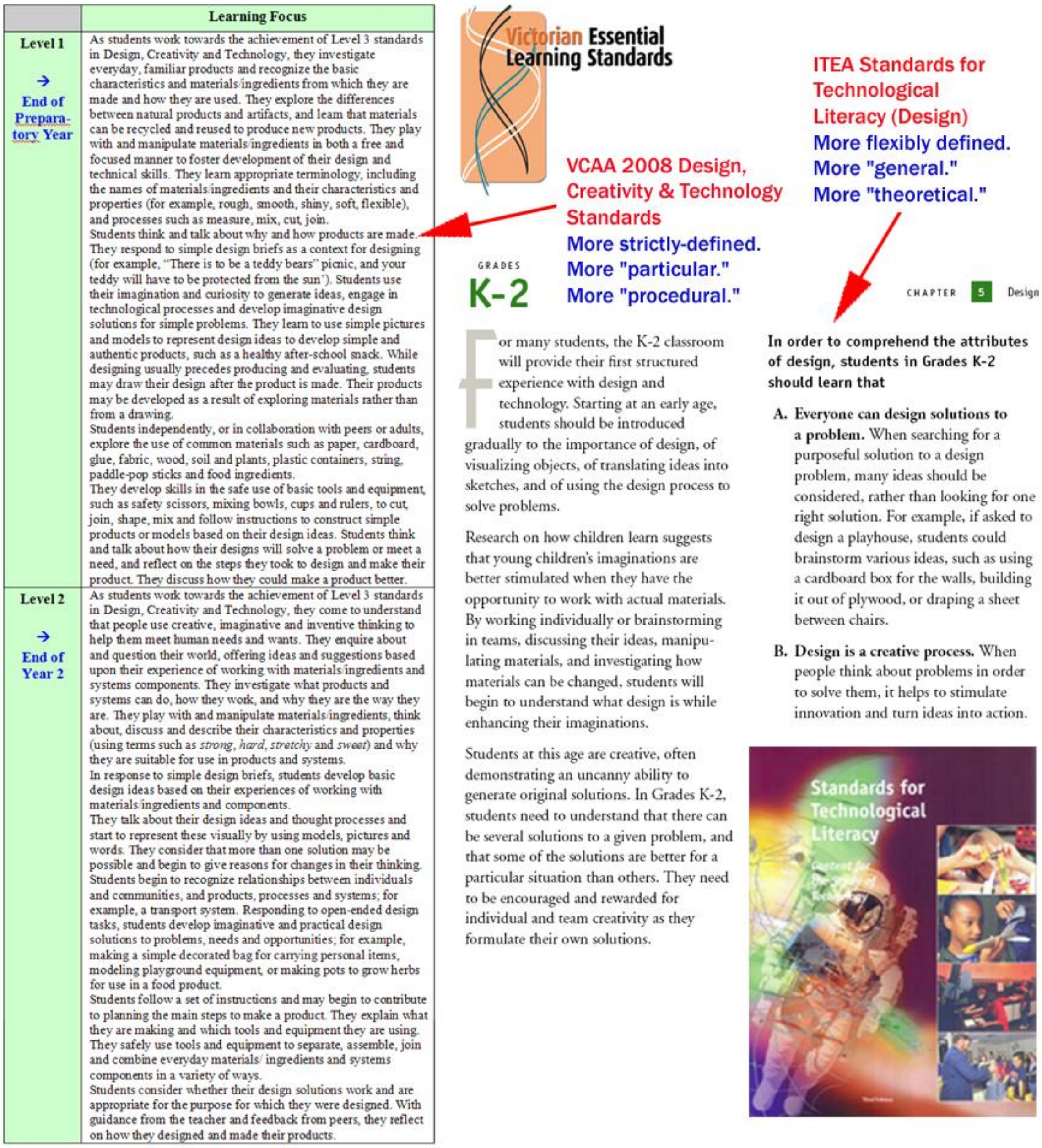
- Definitions of standards: ITEA's are more flexibly defined and thus offer greater leeway for interpretation; while Victoria's are more strictly defined and thus more "prescriptive" for teachers to follow through;

- Coverage of standards: ITEA's are more "general" with broadly described outcomes to be achieved in order to promote general design capabilities for all students; while Victoria's are more "particular" with prescription of tasks to be performed in order to achieve strict goal of guiding K-12 students to engineering and technology related careers;

- Details of standards: ITEA's are more "theoretical" with broadly described essential frameworks of design process; while Victoria's are more "procedural" with detailed description of design process, not only step-by-step, but also task-to-task;

- Implementation: In analogy, ITEA's Design Standards look like a set of world maps, and require teachers to think about how to use them; while Victoria's Learning Focus and Standards for Design, Creativity and Technology look more like a doctor's drug prescription, and are more "straightforward" for teachers to follow.

Both sets of standards share some common characteristics; they are both divided into different stages corresponding to K-12 students' Year or Grade levels; and they both cover the important principles of design.



	Learning Focus
Level 1 → **End of Prepara-tory Year**	As students work towards the achievement of Level 3 standards in Design, Creativity and Technology, they investigate everyday, familiar products and recognize the basic characteristics and materials/ingredients from which they are made and how they are used. They explore the differences between natural products and artifacts, and learn that materials can be recycled and reused to produce new products. They play with and manipulate materials/ingredients in both a free and focused manner to foster development of their design and technical skills. They learn appropriate terminology, including the names of materials/ingredients and their characteristics and properties (for example, rough, smooth, shiny, soft, flexible), and processes such as measure, mix, cut, join. Students think and talk about why and how products are made. They respond to simple design briefs as a context for designing (for example, "There is to be a teddy bears" picnic, and your teddy will have to be protected from the sun"). Students use their imagination and curiosity to generate ideas, engage in technological processes and develop imaginative design solutions for simple problems. They learn to use simple pictures and models to represent design ideas to develop simple and authentic products, such as a healthy after-school snack. While designing usually precedes producing and evaluating, students may draw their design after the product is made. Their products may be developed as a result of exploring materials rather than from a drawing. Students independently, or in collaboration with peers or adults, explore the use of common materials such as paper, cardboard, glue, fabric, wood, soil and plants, plastic containers, string, paddle-pop sticks and food ingredients. They develop skills in the safe use of basic tools and equipment, such as safety scissors, mixing bowls, cups and rulers, to cut, join, shape, mix and follow instructions to construct simple products or models based on their design ideas. Students think and talk about how their designs will solve a problem or meet a need, and reflect on the steps they took to design and make their product. They discuss how they could make a product better.
Level 2 → **End of Year 2**	As students work towards the achievement of Level 3 standards in Design, Creativity and Technology, they come to understand that people use creative, imaginative and inventive thinking to help them meet human needs and wants. They enquire about and question their world, offering ideas and suggestions based upon their experience of working with materials/ingredients and systems components. They investigate what products and systems can do, how they work, and why they are the way they are. They play with and manipulate materials/ingredients, think about, discuss and describe their characteristics and properties (using terms such as *strong*, *hard*, *stretchy* and *sweet*) and why they are suitable for use in products and systems. In response to simple design briefs, students develop basic design ideas based on their experiences of working with materials/ingredients and components. They talk about their design ideas and thought processes and start to represent these visually by using models, pictures and words. They consider that more than one solution may be possible and begin to give reasons for changes in their thinking. Students begin to recognize relationships between individuals and communities, and products, processes and systems; for example, a transport system. Responding to open-ended design tasks, students develop imaginative and practical design solutions to problems, needs and opportunities; for example, making a simple decorated bag for carrying personal items, modeling playground equipment, or making pots to grow herbs for use in a food product. Students follow a set of instructions and may begin to contribute to planning the main steps to make a product. They explain what they are making and which tools and equipment they are using. They safely use tools and equipment to separate, assemble, join and combine everyday materials/ ingredients and systems components in a variety of ways. Students consider whether their design solutions work and are appropriate for the purpose for which they were designed. With guidance from the teacher and feedback from peers, they reflect on how they designed and made their products.

For many students, the K-2 classroom will provide their first structured experience with design and technology. Starting at an early age, students should be introduced gradually to the importance of design, of visualizing objects, of translating ideas into sketches, and of using the design process to solve problems.

Research on how children learn suggests that young children's imaginations are better stimulated when they have the opportunity to work with actual materials. By working individually or brainstorming in teams, discussing their ideas, manipulating materials, and investigating how materials can be changed, students will begin to understand what design is while enhancing their imaginations.

Students at this age are creative, often demonstrating an uncanny ability to generate original solutions. In Grades K-2, students need to understand that there can be several solutions to a given problem, and that some of the solutions are better for a particular situation than others. They need to be encouraged and rewarded for individual and team creativity as they formulate their own solutions.

In order to comprehend the attributes of design, students in Grades K-2 should learn that

A. **Everyone can design solutions to a problem.** When searching for a purposeful solution to a design problem, many ideas should be considered, rather than looking for one right solution. For example, if asked to design a playhouse, students could brainstorm various ideas, such as using a cardboard box for the walls, building it out of plywood, or draping a sheet between chairs.

B. **Design is a creative process.** When people think about problems in order to solve them, it helps to stimulate innovation and turn ideas into action.

Figure 6A. Comparing Australia's State of Victorian Essential Learning Standards for Design, Creativity and Technology, with International Technology Education Association's Standards for Technological Literacy (Design). The Victorian Standards on the left are the same as featured in Table 6A; the ITEA Standard on the right are from page 93 of Standards for Technological Literacy Content for the Study of Technology (ITEA, 2002).

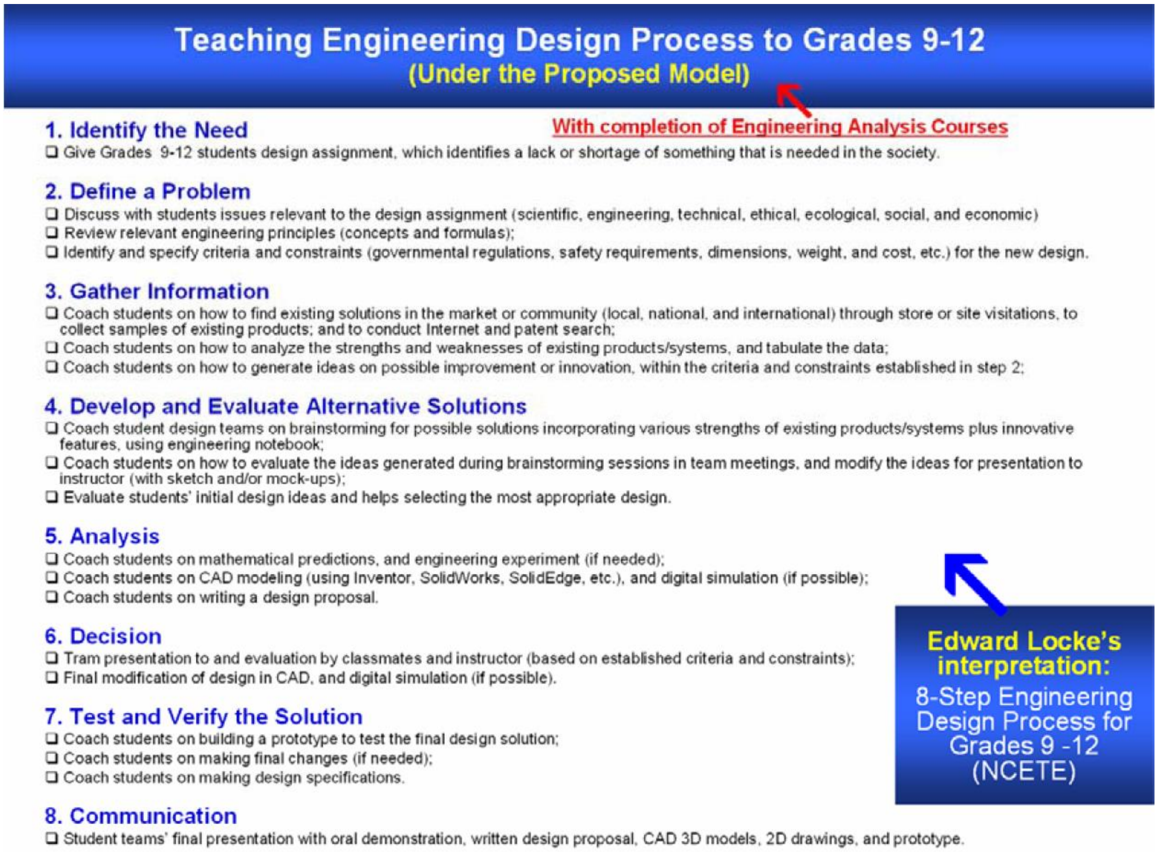


Figure 6B. High School Engineering Design Process developed by the U.S. National Center for Engineering and Technology Education.

Reasonable Expectation on Students' Learning Outcome with "Real-World" Results

Quality of Students' Design Projects

Senior year engineering and technology design projects in Australian high schools again have an emphasis on functional design of simple, "everyday" products and systems that can perform "real-world" functions and are appropriate to high school students' cognitive maturity levels; in addition, the best of them demonstrate professional qualities that look "industry-like," in all three strategic areas of good design and production: (1) creativity; (2) function; and (3) craftsmanship. In Australia, the IIATE Intech Exhibition of Outstanding Industrial Technology Projects from Higher School Certificate has been held for several years; and are shown in *Figure 7A* through *Figure 7H* (InTech, 2004; and InTech, 2005).

Figure 7A. Musical instruments designed and prototyped by Australian high school students' displayed in the InTech 2004 Outstanding Major Projects exhibition, which showed students' products from the 2003 Higher School Certificate program (top), and those found in Wal-Mart Store (bottom. Source: http://www.walmart.com/search/).

Figure 7B. Musical instruments displayed in the InTech 2005 Outstanding Major Projects exhibition (for the 2004 Higher School Certificate program).

Consumer products:

- Musical instruments: These projects demonstrate professional design qualities and craftsmanship that are close to or even rival those commonly found in Wal-Mart stores (*Figures 7A* and *7B*).

- Furniture: These projects demonstrate professional design qualities that are aesthetically as creative and attractive as those commonly found in Wal-Mart or IKEA stores (*Figures 7C* and *7D*).

- Other products: These include boats, toy horse, car body, and architectural models. They all display professional qualities that rival those found in undergraduate technology and product design programs (*Figures 7E*).

As far as I can remember, the quality of design and craftsmanship in the above Australian high school students' projects are competitive with those found in undergraduate senior-year industrial product design program at California State University Northridge when I was a student there back in 1993.

Figure 7C. Furniture designed and made by Australian high school students from the InTech 2004 Outstanding Major Projects (for 2003 Higher School Certificate).

Mechanical and electronics devices:

- Miscellaneous vehicle attachments and equipment: These products involve some simple mechanical and electronics components (*Figures 7F*). They are apparently functional working prototypes, and examples of "modification" or redesign of existing products, with certain amount of students' creative inputs. They reflect Australian high school students' abilities to synthesize engineering analytic principles and skills learned from various Application and Focus modules and to solve simple and yet "real-world" engineering design problems. Compared with products found in Sears Store (*Figures 7G*), some "aesthetic" or "style" enhancement might be desirable on these students' products.

Figure 7D. The most "artistic" furniture from Australian high school students (top with interior background) versus those from Wal-Mart stores (bottom with white background; source: http://www.walmart.com/search/search-ng.do?search_constraint=0&ic=48_0&search_query=guitar&Find.x=0&Find.y=0&Find=Find).

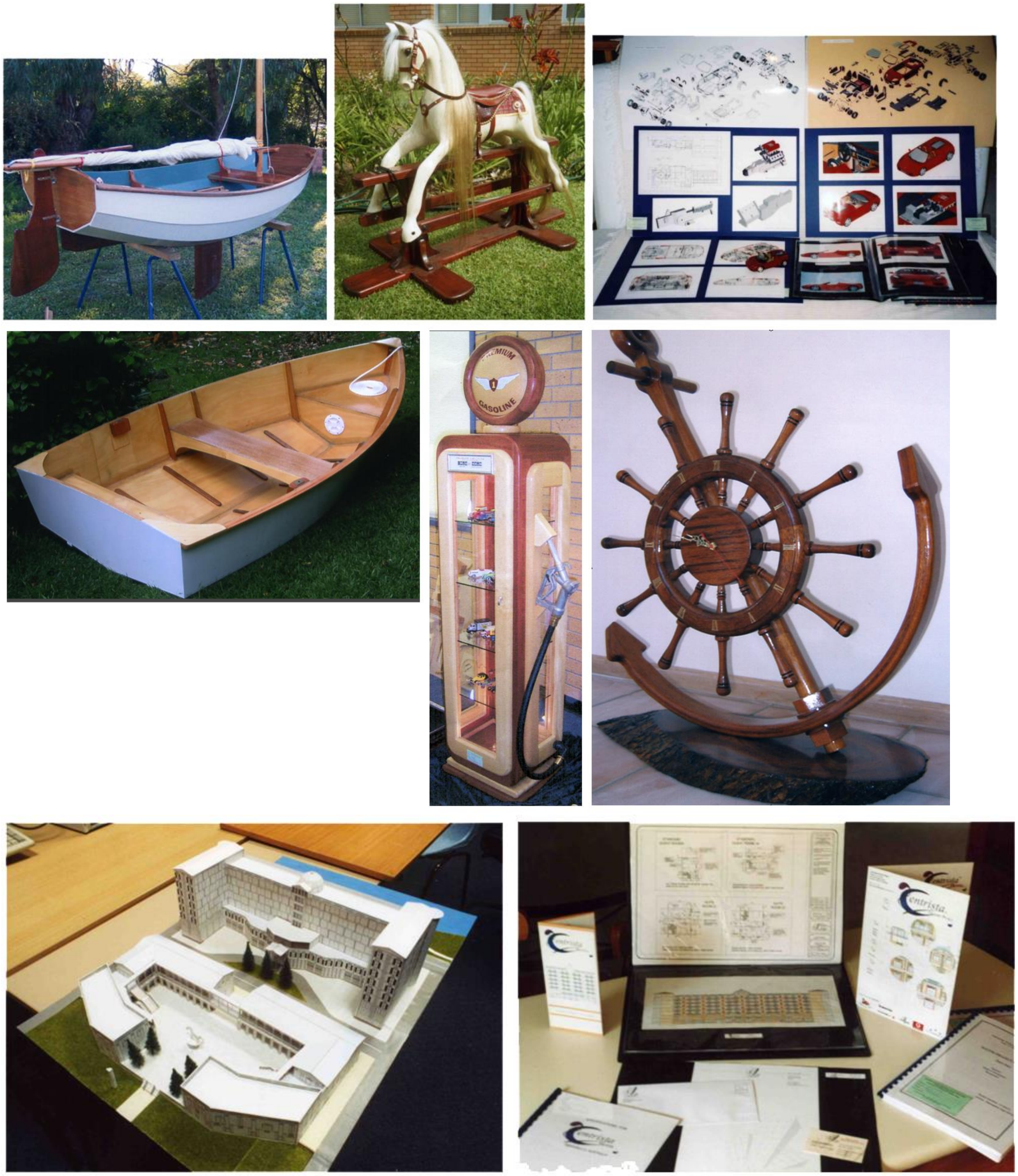


Figure 7E. Boats, toy horse, car body, and architectural models.

Figure 7F. Mechanical and electronics devices designed and fabricated by Australian high school students.

Figures 7G. Equipment found in Sears Store (Source: http://www.sears.com/).

Figure 7H. 3D animation video by Australian high school students.

<u>Three-dimensional digital animation videos</u>:

- As shown in *Figure 7H*, 3D animation video created by "P08T Aeolus Team Members" (Shaan Akhtar, Lincohn Bollen, David Dai, Min Kyu Lee, Jenny Liu, Mathew Payne, Harris Tung, Brendan Wood) from an Australian high school feature professional quality lighting and smoke effects, as well as sound and music, which rival what I have seen at Santa Ana College, Orange County, California, and at El Camino College, Torrance, California, among two-year community college students.

Referential Values of Australian Experience in K-12 Engineering Curriculum's Expectations, Pedagogy, Standards and Outcomes

Australia's experience with K-12 engineering curriculum shows that

- Pedagogy: The basics of engineering analytic and predictive principles and skills could be taught through simple activities with "everyday" objects; "real-world" engineering design process based on solid analytic and predictive principles and skills could be taught by projects that are focused on "everyday" and "practical projects/structures," which gives students opportunity to learn (1) well-selected sets of engineering design related knowledge content and skills; (2) "real-world" design practice through "reverse engineering" or study of existing products and structures; and (3) "real-world" engineering design through meaningful modification or re-design of existing products and structures. In real-world engineering, very few new products or systems are started from scratch or based on "pure" invention; in fact, the majority of new products and systems are based on the organic combination of (1) modified or redesigned of, or re-arrangement of existing features from existing products and systems; and (2) some creative or innovative features that existing products or systems do not possess. Wright (2004, p. 267) indicated that in the real-world corporate consumer product development process, (1) "imitation" is a common product development technique ("Think of products that are widely imitated. […] home computers, stereo receivers, clothing styles and toys"); (2) "adaptation" means developing an "improved" product by changing its operation (for example, an electronic typewriter was an adaptation of an electric typewriter which was previously adapted from a manual typewriter); and (3) "innovation" is a technique to create a totally new products. From available products in the marketplace, it is obvious that the majority of products fall under the categories of "imitation" and "adaptation." The mechanical and electrical devices designed and prototyped by Australian high school graduates (*Figure 7F*) also belong to these categories. Thus, these two techniques are obviously appropriate for guiding high school students enrolled in engineering pathways into "real-world" engineering design process, although reasonable expectation for "innovation" should be fostered. Wright (2004, p. 270) further indicated that "each company must make sure that they do not break patent laws;" they must (1) "develop their own technology;" (2) "pay to use someone else's ideas;" or (3) use technology that is not patented;" and that "there are thousands of ideas not patented. The patents of many other products have expired." Therefore, existing products could serve as valuable reference source for high school students' learning of engineering design process; and essential knowledge about patent laws could be taught to them as well. This pedagogy essentially falls under a multidisciplinary Project-Based Learning model, with a strong focus on solid mastery of engineering analytic principles and skills from various relevant subjects, plus a strong practical or "real-world" orientation.

- Eventual development of K-12 engineering design standards: Australia's Design, Creativity and Technology Learning Focus and Standards for K-12 engineering curriculum might serve as a valuable reference for the development of comprehensive and easy-to-use K-12 engineering design performance standards, based on the High School Engineering Design Process developed by the U.S. National Center for Engineering and Technology Education (*Figure 6B*).

- Students' learning outcome: Reasonable expectation on students' learning outcome could better yield "real-world" learning results. Although it is unrealistic to expect high school students to design complicated products and systems, which requires at least a four-year B.S. degree in engineering, it is nevertheless possible to expect them to design and prototype simple products and systems, with professional and "real-world" qualities; and this has been illustrated by Australian high school students' exit credential projects (*Figures 6A* through *6H*). My previously presented *Proposed Model for Infusing Engineering Design into K-12 Curriculum* (Appendix 1), developed back in the Fall Semester of 2008, at the University of Georgia, advocates similar ideas; and as Australian experience shows, these ideas could be tried and might work.

PART FIVE
MATHEMATICS AND SCIENCE EDUCATION AS FOUNDATIONS FOR PRE-COLLEGIATE ENGINEERING STUDIES

K-10 Mathematics Education in Victoria, Australia

Performance Standards for K-10 Mathematics Education in Victoria (Australia)

General time frame for standards and assessment: *Victorian Essential Learning Standards Level 1*, a document published by Victorian Curriculum and Assessment Authority (2008, p. 3), defined the Standards and Learning Focus of K-10 mathematics and science education, which are established for 3 Stages of Learning, and 6 Levels to cover 11 years of compulsory schooling. The definitions of these terms have been explained in details in pages 28-29 of this Report. The coverage is as follows:

- 1st Stage of Learning: Years Prep to 4 - Laying the Foundations.
    - Level 1 - End of Preparatory Year;
    - Level 2 - End of Year 2;
    - Level 3 - End of Year 4.
- 2nd Stage of Learning: Years 5 to 8 - Building Breadth and Depth.
    - Level 4 – End of Year 6;
    - Level 5 – End of Year 8.
- 3rd Stage of Learning: Years 9 to 10 - Developing Pathways.
    - Level 6 – End of Year 10.

Victorian Essential Learning Standards Level 1 (Victorian Curriculum and Assessment Authority, 2008, pp. 50-55) indicated that aims for essential learning in school mathematics are for students to

- "demonstrate useful mathematical and numeracy skills for successful general employment and functioning in society;"
- "solve practical problems with mathematics, especially industry and work based problems;"
- "develop specialist knowledge in mathematics that provides for further study in the discipline;"

- "see mathematical connections and be able to apply mathematical concepts, skills and processes in posing and solving mathematical problems;"

- "be confident in one's personal knowledge of mathematics, to feel able both to apply it, and to acquire new knowledge and skills when needed;"

- "be empowered through knowledge of mathematics as a numerate citizen, able to apply this knowledge critically in societal and political contexts;"

- "develop understanding of the role of mathematics in life, society and work; the role of mathematics in history; and mathematics as a discipline - its big ideas, history, aesthetics and philosophy."

"The Mathematics domain is organized into six sections, one for each level of achievement from Level 1 to Level 6. Each level includes a learning focus statement and a set of standards organized by dimension." There are 5 "dimensions" or topics under the mathematics domain. The way mathematics topics are grouped and named under the *Victorian Essential Learning Standards* are sometimes to some degree different from those used in the United States and in other countries that follow the traditional British or German models, such as China, for example. Thus, these "Australian-specific" terms are explained as follows.

1. <u>Number</u>: "The *Number* dimension focuses on developing students' understanding of counting, magnitude and order." The basic knowledge content includes the system of numbers, proportions of lengths involving sides and/or diagonals of right-angled triangles and rectangles and arcs of a circle, the four operations and exponentiation, through manual computations, using calculators, spreadsheets or other numeric processors.

2. <u>Space</u>: This is an Australian term for plane and solid geometry, which "focuses on developing students' understanding of shape and location. […] Students learn about key spatial concepts including continuity, edge, surface, region, boundary, connectedness, symmetry, invariance, congruence and similarity. Principal operations for computation with space include identification and representation, construction and transformation by hand using drawing instruments, and also by using dynamic geometry technology."

3. <u>Measurement, Chance and Data</u>: These words correspond to American terms of measurement, probability and data analysis (or statistics) respectively. "The *Measurement, chance and data* dimension focuses on developing students' understanding of unit, measure and error, chance and likelihood and inference. […] Students learn important common measures relating to money, length, mass, time and temperature, and probability – the measure of the chance or likelihood of an event. Other measures include area, volume and capacity, weight, angle, and derived rates such as density, concentration and speed.

Principal operations for computation with measurement include the use of formulas for evaluating measures, the use of technology such as dataloggers for direct and indirect measurement and related technologies for the subsequent analysis of data, and estimation of measures using comparison with prior knowledge and experience, and spatial and numerical manipulations."

4. Structure: These words correspond to American terms of set, logic, function and algebra. "Key elements of mathematical structure found in each of the dimensions of Mathematics are membership, operation, closure, identity, inverse, and the commutative, associative and distributive properties as well as other notions such as recursion and periodic behavior. While each of these can be considered in its own right, it is in their natural combination as applied to elements of number, space, function, algebra and logic with their characteristic operations that they give rise to the mathematical systems and structures that are embodied in each of these dimensions. Principal operations for computation with structure include mental, by hand and technology-assisted calculation and symbolic manipulation by calculators, spreadsheets or computer algebra systems, with sets, logic, functions and algebra."

5. Working Mathematically: This is the Australian expression of mathematics problem-solving methods. It "focuses on developing students' sense of mathematical inquiry: problem posing and problem solving, modeling and investigation. It involves students in the application of principled reasoning in mathematics, in natural and symbolic language, through the mathematical processes of conjecture, formulation, solution and communication; and also engages them in the aesthetic aspects of mathematics […] Mental, by hand and technology-assisted methods provide complementary approaches to working mathematically."

Connection to Australia's National Statements of Learning: Similar to the American system of academic standards under which each state formulates its own K-12 academic performance standards on the basis of a set of national standards, Australia has a two-level system. However, it appears that the Australian system might score greater degree of consistency across all states or conformity of state standards to national ones. "The Victorian Essential Learning Standards (VELS) incorporate the opportunities to learn covered in the national *Statements of Learning* (www.curriculum.edu.au/mceetya/the_statements_of_learning,11893.html) […] The Statements of Learning were developed as a means of achieving greater national consistency in curriculum outcomes across the eight Australian states and territories. It was proposed that they be used by state and territory departments or curriculum authorities (their primary audience) to guide the future development of relevant curriculum documents. They were agreed to by all states and territories in August 2006."

National Numeracy Benchmarks: Australia uses the *National Numeracy Benchmarks* for reporting achievement in three aspects of numeracy, i.e., (1) Number Sense; (2) Spatial Sense; and (3) Measurement and Data Sense, at Years 3, 5 and 7. Full details of the National Numeracy Benchmarks are available in *Numeracy Benchmarks Years 3, 5 and 7*, by Curriculum Corporation (2000) at <www.curriculum.edu.au/projects/numbench.php>.

K-10 Science Education in Victoria, Australia

Performance Standards for PK-10 Science Education in Victoria (Australia)

Aim of the "domain" of Science: *Victorian Essential Learning Standards Level 1* (Victorian Curriculum and Assessment Authority, 2008, pp. 58-61) focuses on social ethics and ecological sustainability, indicating that "a major goal of science education is to develop citizens who are capable of engaging in informed debate about science and its applications. Increasing emphasis will be placed on the role of science and the work of Australian and other scientists in addressing issues of sustainability at a local and global level. Science education provides opportunities for students to develop the skills and understanding appropriate to service and good citizenship. It also encourages students to articulate science values and accept the ethical principles embedded in science research."

Structure of the domain: Similar to the Mathematics domain, the Science domain is organized into six sections, one for each level of achievement from Level 1 to Level 6. Each level includes a learning focus statement and, from Level 3, a set of standards organized by two dimensions. "These two dimensions include the traditional science disciplines of biology, chemistry, earth science, environmental science, health sciences, neuroscience, physics and space sciences and the emerging sciences including biotechnology, green chemistry, nanotechnology, and synchrotron science."

1. Science Knowledge and Understanding: This dimension "focuses on building student understanding of the overarching conceptual ideas of science." These include understanding

    - the nature of the similarities between, and the diversity of, living things and their sustainable relationships with each other and their environment;
    - concepts related to matter – its properties and uses, and the production of different substances through chemical change;
    - concepts of energy and force as a way of explaining physical phenomena;
    - the place of the Earth in time and space and the interactions between the
    - Earth and its atmosphere;

- how scale is important in relating structure to function at microscopic and macroscopic levels.

2. Science at Work: This is an Australian expression for scientific methods (inquiry, research, experiment, and application).

Connection to Australia's National Statements of Learning: Same as for the Mathematics domain.

Comparison of Mathematics and Science Education in
Georgia (United States) and in Victoria (Australia)

K-12 mathematics and science education in Australia is to some degree similar to the United States. In both countries, state governments develop their own performance standards using national standards as a reference. There are similarities as well as differences between the two countries in this area. In Appendix 2B, *State of Victoria (Australia) versus State of Georgia (United States) Comparison Charts for K-12 Mathematics and Science Performance Standards*, the K-10 mathematics and science performance standards for the respective states are tabulated side-by-side to show their differences and similarities, which are divided into the following stages:

- Kindergarten to elementary or primary school: This covers "Georgia Performance Standards" for Grades K-5 in the State of Georgia in the United States (called "kindergarten" and "elementary school"), and "Victorian Essential Learning Standards" for Years K-6 in the State of Victoria in Australia (called "preparatory" and "primary school").

- Secondary school (1st part): This covers "Georgia Performance Standards" for Grades 6-8 in the State of Georgia in the United States (called "middle school"), and "Victorian Essential Learning Standards" for Years 7-8 in the State of Victoria in Australia (called "secondary school").

- Secondary school (2nd part): This covers "Georgia Performance Standards" for Grades 9-12 in the State of Georgia in the United States (called "high school"), and "*Victorian Essential Learning Standards*" for Years 9-10 in the State of Victoria in Australia (also called "secondary school"). Standards for "higher school" or Years 11-12 are not found yet from the "*Victorian essential Learning Standards*" website, and relevant data will be filled when available.

These differences and similarities could be summarized as follows:

For mathematics education (Appendix 2B, pp. 6-75): "Georgia Performance Standards" are divided into separate Grades (although for 6-8, the standards are applicable for all three Grades, i.e., 6, 7, 8); they group all mathematics subjects (number, geometry, etc.) for K-8 under one single category of "Math." For convenience of comparison, the standards have been divided into separate subjects. For 9-12, "Georgia Performance Standards" are divided into two different sequences of separate courses, although the standards are again applicable for all Grades of 9, 10, 11 and 12: (1) the "Accelerated Mathematics 1, 2, and 3;" and (2) "Mathematics 1, 2, 3, and 4. The "*Victorian Essential Learning Standards*" are not divided into separate Years (instead, they are divided into six Levels each covering several years).

- Kindergarten to elementary or primary school: They are essentially very similar, in terms of (1) knowledge contents; and (2) mathematics problem-solving skills (Appendix 2B, Table 1A for the subjects of Number, Four Operations & Algebra, pp. 7-20; Table 1B for the subject of Geometry, or "Space" in "*Victorian Essential Learning Standards*", pp. 25-30; Table 1C for the subject of Data Analysis, Probabilities & Statistics or "Measurement, Chance and Data", pp. 32-38).

- Secondary school (1st part): They are still essentially very similar, in terms of (1) knowledge contents; and (2) mathematics problem-solving skills (Appendix 2B, Table 1A for the subjects of Number, Four Operations & Algebra, pp. 20-24; Table 1B for the subject of Geometry or "Space," pp. 30-31; Table 1C for the subject of Data Analysis, Probabilities & Statistics or "Measurement, Chance and Data," pp. 38-40).

- Secondary school (2nd part): Apparently, "Georgia Performance Standards" are defined in greater details in both mathematics skills and problem-solving methods (Table 2A for the subject of Number, Operations & Functions, pp. 41-61; Table 2B for the subject of Trigonometry & Analytic Geometry or "Number" and "Structure," pp. 62-67; Table 2C for the subject of Data Analysis, Probabilities & Statistics or "Measurement, Chance and Data," pp. 68-72). For some subjects such as Linear Algebra and Vector Graphics, performance standards are not found in "Victorian Essential Learning Standards" website yet (Appendix 2B, Table 2D for Linear Algebra, pp. 73-74; and Table 2E for Vector Graphics, p. 75).

For science education (Appendix 2B, pp. 76-156): "Georgia Performance Standards" have more intensive and in-depth coverage of a greater variety of science subjects; and are described in greater amount of details.

- Kindergarten to elementary or primary school: Both "Georgia Performance Standards" and "Victorian Essential Learning Standards" cover a variety of science topics; and for convenience of comparisons, these topics have been divided into (1) Life Science; (2) Chemistry & Materials-Related Science; (3) Chemistry & Materials-Related Science; (4) Physics-Related Science; (5) Environmental Science; (6) Scientific Approach, and (7) Application of Science. In general, "Georgia Performance Standards" are defined in much greater amount of details, while "Victorian Essential Learning Standards" only give some general guidelines called "Standards" and "Learning Focus" (Appendix 2B, Table 3, pp. 77-104).

- Secondary school (1st part): Same similarities and differences are found as in kindergarten to elementary school (Appendix 2B, Table 3, pp. 105-114).

- Secondary school (2nd part): Both "Georgia Performance Standards" and "Victorian Essential Learning Standards" cover "essential" or general foundation science subjects for high school, such as Physics, Chemistry and scientific Approach. Again, "Georgia Performance Standards" are defined in much greater amount of details, while "Victorian Essential Learning Standards" only give some general guidelines called "Standards" and "Learning Focus" (Appendix 2B, Table 4A for Physics, pp. 115-118; Table 4B for Chemistry, pp. 119-121; Table 4C for Scientific Approach, pp. 123-125). For specific science subjects, "Georgia Performance Standards" not only are defined in much greater amount of details, but also cover many more subject matters; for example, for "High School Science Subjects Related to Natural Environment & Physical Universe" (Appendix 2B, pp. 126-141), "Georgia Performance Standards" are clearly defined for 7 subjects:

  (1) Environmental Science (Appendix 2B, Table 4D, pp. 126-128);

  (2) Ecology (Appendix 2B, Table 4E, pp. 129-130);

  (3) Earth System (Appendix 2B, Table 4F, pp. 131-133);

  (4) Geology (Appendix 2B, Table 4G, pp. 134-135); and

  (5) Oceanography (Appendix 2B, Table 4H, pp. 136-137);

  (6) Meteorology (Appendix 2B, Table 4J, pp. 138-139);

  (7) Astronomy (Appendix 2B, Table 4K, pp. 140-141).

  "Victorian Essential Learning Standards" only cover very limited amount of content knowledge under the generic title of "Science." For "High School Science Subjects Related to Living Organisms," again, "Georgia Performance Standards" are clearly defined for 7 subjects:

  (1) Biology (Appendix 2B, Table 4L, pp. 142-143);

  (2) Human Anatomy & Physiology (Appendix 2B, Table 4M, pp. 144-145);

  (3) Botany (Appendix 2B, Table 4N, pp, 146-147);

(4) Entomology (Appendix 2B, Table 4P, pp. 148-150):

(5) Microbiology (Appendix 2B, Table 4Q, pp. 151-152);

(6) Zoology (Appendix 2B, Table 4R, pp. 153-154); and

(7) Forensic Science (Appendix 2B, Table 4S, pp. 155-156).

"Victorian Essential Learning Standards" again only cover very limited amount of content knowledge under the generic title of "Science."

Overall Comparison on K-10 Mathematics and Science Performance Standards between Georgia (USA) and Victoria (Australia)

Judging strictly from the governmentally established academic performance standards for K-10 mathematics and science education, without making any inference to actual performance of pre-collegiate students in Victoria (Australia) and in Georgia (United States), which is beyond the scope of this Report, the following general conclusions could be tentatively drawn:

- For both mathematics and science, *Georgia Performance Standards* are defined in greater amount of details than *Victorian Essential Learning Standards*;

- For science, *Georgia Performance Standards* are defined for greater number of subjects than *Victorian Essential Learning Standards*;

- For mathematics, *Georgia Performance Standards* look more "traditional" in terms of categorizing and naming subject matter in stricter accordance to conventions developed by the traditional British system of education, which is still widely used in many countries including China and Singapore. Australia's *Victorian Essential Learning Standards* tend to break down the traditional way of categorization and naming; for example, using the word "space" to mean geometry, "chance" to mean probability, and "structure" to mean set, logic, algebra and functions.

PART SIX
ENGINEERING ANALYTIC AND PREDICTIVE PRINCIPLES AND SKILLS EXPLORED IN AUSTRALIAN K-12 ENGINEERING STUDIES

Many topics from various subjects of engineering, such as statics, dynamics, materials science, strength of materials, fluid mechanics, electronics and electricity, have been taught in Australia's high schools. An analysis of these topics could help understanding the extent to which the analytic portion of engineering design could be infused into a potentially viable K-12 engineering curriculum.

"Knowledge Content" and "Expected Outcome" for Various Engineering Subjects Taught through Project-Based Leaning Type of Engineering Modules

Table 7A, 7B and 7C list the sets of engineering analytic and predictive principles and skills from the three subjects of engineering, which have been taught though several Engineering Application Modules and Engineering Focus Modules. These subjects include (1) Engineering Mechanics and Hydraulics; (2) Engineering Materials; and (3) Engineering Electricity/Electronics. These Tables could help understanding how different sets of engineering analytic principles and skills from various subjects have been applied to different applications in Australia's high schools.

Table 7A
"Knowledge Content" and "Expected Outcome" for
Engineering Mechanics and Hydraulics
Source: New South Wales Board of Studies Stage 6 Syllabus (1999)

Engineering Mechanics and Hydraulics	
Students Learn About ("Knowledge Content")	**Students Learn To ("Expected Outcome")**
Engineering Application Module 1 (Household Appliances) → pp. 17-18	
Statics: • mass and force • scalar and vector quantities	• use mathematical and/or graphical methods to solve engineering problems in household appliances
Engineering Application Module 2 (Landscape Products) → pp. 20-21	

Statics:
• forces
  ○ nature and type of forces
  ○ addition of vectors
  ○ space and freebody diagrams
  ○ resultants and equilibrants
  ○ transmissibility of forces
  ○ 3 force rule for equilibrium
  ○ moments of a force
  ○ force/couple systems
  ○ equilibrium of concurrent forces
Mechanical Design:
• simple mechanisms – inclined plane, lever, screws, wheel and axle, pulley, gears
	• apply mathematical and/or graphical methods to solve problems related to landscape products
	• investigate and interpret the concept of equilibrium in the mechanics of landscape products
	• examine and analyze the function of simple mechanisms

Table 7A (Continued).

Engineering Mechanics and Hydraulics	
Students Learn About ("Knowledge Content")	**Students Learn To ("Expected Outcome")**
Engineering Application Module 3 (Braking Systems) → pp. 23-24	

Statics:
• friction (without calculations)
• work, power, energy (without calculations)
Strengthn of materials:
• stress and strain
  ○ stress (tensile and compression)
  ○ load/extension diagram
  ○ strain (tensile and compression)
Fluid Mechanic:
• Pascal's and Archimedes' principles
• hydrostatic pressure
• applications to braking systems
	• distinguish between force, stress and strain
	• experiment with and apply the basic principles of fluid mechanics to simple braking systems
	• investigate the structure and properties of appropriate materials used in braking systems
	• describe the manufacturing processes and application of composites to friction materials
	• conduct relevant mechanical tests on materials

Engineering Focus Module (Bio-Engineering) → pp. 26-27	
Mechanical Design: • orders of levers • mechanical advantage and velocity ratio ***Statics:*** • stress and strain (tensile and compression forces)	• apply mathematical and/or graphical methods to solve problems of bio-engineering practice
HSC Engineering Application Module 1 (Civil Structures) → p. 32	

Statics:
• stress and strain
  ○ shear stress
  ○ engineering and working stress
  ○ yield stress, proof stress, toughness, Young's modulus, Hooke's law, engineering applications
  ○ factor of safety
  ○ stress/strain diagram
• truss analysis
  ○ method of joints
  ○ method of sections
• bending stress induced by point loads only
  ○ concept of shear force and bending moment
  ○ shear force and bending moment diagrams
  ○ bending stress calculation (second moment of area given)
• uniformly distributed loads
Strength of Materials:
• concept of neutral axis and outer fibre stress
• crack theory
  ○ crack formation and growth
  ○ failure due to cracking
  ○ repair and/or elimination of failure due to cracking
	• apply mathematical and/or graphical methods to solve problems related to the design of civil structures
	• evaluate the importance of the stress/strain diagram in understanding the properties of materials
	• calculate the bending stress on simply supported beams involving vertical point loads only
	• describe the effect of uniformly distributed loads on a simple beam, without calculations
	• examine how failure due to cracking can be repaired or eliminated

Engineering Application Module 2 (Personal and Public Transport) → p. 36	

Statics:
• static friction
  ○ concept of friction and its use in engineering
  ○ coefficient of friction
  ○ normal force
  ○ friction force
  ○ angle of static friction
  ○ angle of repose
Dynamics:
• energy, power
  ○ potential energy, kinetic energy, work, power
	• apply mathematical and/or graphical methods to solve engineering problems related to transport
	• analyse problems involving static friction
	• differentiate between the concepts of energy and power and apply appropriate calculations

Table 7A (Continued).

Engineering Mechanics and Hydraulics	
Students Learn About ("Knowledge Content")	**Students Learn To ("Expected Outcome")**
Engineering Application Module 3 (Lifting Devices) → p. 39	
Statics: • conditions of equilibrium for non-concurrent coplanar forces ***Fluid Mechanics:*** • Archimedes' and Pascal's principles • hydrostatic pressure • applications to lifting devices	• use mathematical and/or graphical methods to solve problems related to lifting devices • apply concepts of hydraulics in the solution of problems relating to types of lifting devices
Engineering Focus Module 1 (Aeronautical Engineering) → p. 42	
Aerodynamics: • forces – lift drag, weight, thrust • basic aerodynamics ○ Bernouli's principle • bending stress – airframes • propulsion systems (jet, turboprop) ***Fluid Mechanics:*** • hydrostatic and dynamic pressure • applications to aircraft components • application to aircraft instruments	• apply mathematical and graphical methods to solve flight-related problems • outline Bernouli's principle as applied to flight • investigate the nature and effect of bending stresses, applying appropriate mathematical methods • apply mathematical methods to solve hydraulics-related problems

Table 7B
"Knowledge Content" and "Expected Outcome" for Engineering Materials
Source: New South Wales Board of Studies Stage 6 Syllabus (1999)

Engineering Materials	
Students Learn About ("Knowledge Content")	**Students Learn To ("Expected Outcome")**
Engineering Application Module 1 (Household Appliances) → pp. 17-18	

• classification of materials
• properties of materials
  physical and mechanical properties
• structure of materials
  ○ atomic structure
  ○ bonding
• metals
  ○ ferrous metals including mild steel
  ○ non-ferrous metals including copper, brass and bronze
  ○ joining and cutting methods
• polymers
  thermoplastics
  thermosets
• ceramics types used
	• classify a variety of materials
	• identify the properties of materials and explain the reason for their selection
	• describe the structure and bonding of materials
	• distinguish between and explain reasons for the use of ferrous and non-ferrous metals as components in household appliances
	• compare the suitability of joining and cutting methods used on metals
	• distinguish between thermoplastics and thermosets
	• identify the types of ceramics used in household appliances

Engineering Application Module 2 (Landscape Products) → pp. 20-21	

• modification of materials
  ○ work hardening
  ○ heat treatment
  ○ nature of composites
• engineering applications of materials
• recyclability of materials
  ○ implications for recycling
  ○ recyclable materials including steel, aluminium, brass, plastics and rubber
  ○ costs and benefits of recycling materials
	• conduct simple tests aimed at improving materials' properties through work hardening, heat treatment and composites
	• analyse the properties, uses and appropriateness of materials for landscape products
	• explain the benefits of recycling materials

Table 7B (Continued).

Engineering Materials	
Students Learn About ("Knowledge Content")	**Students Learn To ("Expected Outcome")**
Engineering Application Module 3 (Braking Systems) → pp. 23-24	

• materials for braking systems
  ○ steels
  ○ cast irons
  ○ composites
  ○ manufacturing/forming processes of composites
• testing of materials
  ○ tensile and compression test
  ○ hardness test
	• describe the manufacturing processes and application of composites to friction materials

Engineering Focus Module (Bio-Engineering) → pp. 26-27	

• forming methods
  ○ forging
  ○ casting
  ○ fabrications
• structure and properties of appropriate materials
	• describe forming processes for materials used in bio-engineering
	• compare the macrostructure and properties of materials used in bio-engineering.

HSC Engineering Application Module 1 (Civil Structures) → p. 33	

• testing of materials
  ○ x-ray
  ○ specialised testing of engineering materials and/or systems
• ceramics
  ○ structure and property relationship, applications
  ○ glass
  ○ cement
• composites
  ○ timber
  ○ concrete (reinforced and pre-stressed)
  ○ asphalt
  ○ laminates
  ○ geotextiles
• corrosion
  ○ corrosive environments
  ○ dry corrosion, wet corrosion, stress corrosion
• recyclability of materials
	• describe basic testing conducted on civil structures
	• examine the properties, uses and appropriateness of materials used in civil structures
	• make appropriate choices of materials and processes for use in civil structures
	• investigate the structure and property relationships in materials
	• explain the special properties produced by composite materials
	• experiment with simple pre-tensioned and post-tensioned structures
	• evaluate the significance of corrosion problems in civil structures
	• describe methods used for recycling materials when civil structures are replaced

Table 7B (Continued).

Engineering Materials	
Students Learn About ("Knowledge Content")	**Students Learn To ("Expected Outcome")**
Engineering Application Module 2 (Personal and Public Transport) → pp. 36-37	
• testing of materials ○ x-ray ○ specialised testing of engineering materials and/or systems • Heat treatment of ferrous metals ○ heat treatment of steels ○ annealing ○ normalising ○ hardening and tempering ○ structure property relationships • structure/property relationship in the material forming processes ○ forging ○ rolling ○ casting ○ extrusion ○ powder forming • non-ferrous metals ○ aluminium and its alloys, • aluminium silicon, aluminium copper, • aluminium silicon-magnesium ○ brass, bronze ○ structure/property relationship ○ annealing, strengthening • ceramics and glasses ○ semi-conductors ○ laminating and heat treatment of glass • polymers ○ structure/property • relationships and applications ○ engineering textiles ○ manufacturing processes for polymer component	• explain the properties, uses, testing and appropriateness of materials used in transportation • identify appropriate heat treatment processes • justify appropriate choices for ferrous materials and processes used in transportation parts and systems • experiment with metals to reinforce the concepts of heat treatment • explain the method and applications of various ferrous metal forming processes • justify appropriate choices of non-ferrous materials and processes for use in transportation parts and systems based on relevant structure/property relationships • •justify appropriate choices of ceramics and glasses used in transportation parts and systems • identify the types and function of common semiconductors used in the electronics of the transport industry • justify appropriate choices of polymers and their manufacturing processes used in transportation parts and systems
Engineering Application Module 3 (Lifting Devices) → p. 39	
• testing of materials used in lifting devices ○ tension, compression ○ hardness ○ impact • structure/property relationships in heat treatment processes ○ normalising ○ hardening and tempering • structure/property relationships in forming processes ○ forging ○ casting ○ extrusion ○ rolling ○ powder forming	• describe the properties, uses and appropriateness of materials used in lifting devices • evaluate manufacturing processes for components used in lifting devices • investigate impact testing • experiment with and assess structure/property relationships, before and after heat treatment • analyse the structure/property relationship developed through forming processes

Table 7B (Continued).

Engineering Materials	
Students Learn About ("Knowledge Content")	**Students Learn To ("Expected Outcome")**
Engineering Focus Module 1 (Aeronautical Engineering) → pp. 42-43	
• specialised testing of aircraft materials ○ dye penetrant ○ x-ray ○ magnetic particles ○ ultrasonic • aluminium and its alloys used in aircraft ○ aluminium silicon, aluminium silicon • magnesium, aluminium copper ○ structure/property/application relationships ○ heat treatment of applicable alloys • polymers ○ structure/property relationships and applications ○ modifying materials for aircraft applications ○ engineering textiles • composites ○ types and applications in aircraft ○ structure/property relationships • corrosion ○ common corrosion mechanisms in aircraft structures ○ pit and crevice corrosion ○ stress corrosion	• describe non-destructive tests used with aircraft materials and components • analyse structure, properties, uses and appropriateness of materials in aeronautical engineering applications • investigate the effects of heat treatment on the structure and properties of aluminium alloys • select and justify materials and processes used in aeronautical engineering • outline the mechanism of corrosion common to aircraft components • produce orthogonal drawings applying appropriate Australian Standard (AS 1100) • construct quality graphical solutions • work with others and appreciate the value of collaborative working • complete an Engineering Report on the aeronautical engineering profession with reference to the following aspects: ○ current projects and innovations ○ heath and safety issues ○ relations with the community ○ career prospects
Engineering Focus Module 2 (Telecommunication) → p. 46	
• specialized testing ○ voltage, current, insulation • copper and its alloys used in telecommunications ○ structure/property relationships • ceramics as insulation materials • semiconductors ○ types and uses in telecommunications • polymers ○ insulation materials • fiber-optics ○ types and applications	• analyze structure, properties, uses and appropriateness of materials in telecommunications engineering applications • select and justify materials and processes used in telecommunications engineering

Table 7C
"Knowledge Content" and "Expected Outcome" for Engineering Electricity/Electronics
Source: New South Wales Board of Studies Stage 6 Syllabus (1999)

Engineering Electricity/Electronics	
Students Learn About ("Knowledge Content")	**Students Learn To ("Expected Outcome")**
Engineering Application Module 1 (Household Appliances) → pp. 17-18	
• basic principles ○ potential difference ○ current ○ simple circuits and components • electrical safety related Australian electrical standards • magnetic induction • fundamental AC and DC circuits • electric motors	• explain the basic electrical principles of operation appropriate to household appliances • appreciate the importance of safety when using electrical household appliances • explain the working of an induction motor
Engineering Application Module 2 (Personal and Public Transport) → p. 37	
• power generation/distribution electrical energy and power • AC/DC circuits • electric motors used in transport systems ○ principles ○ applications • control technology ○ digital technology	• identify the electrical systems used in the transport industry • investigate the principles and application of electric motors used in the transport industry • analyse the basic principles of control technology as applied to the transport industry • explain elementary digital logic
Engineering Application Module 3 (Lifting Devices) → pp. 39-40	
• applications found in appropriate lifting devices ○ motors ○ motor control • electrical safety	• describe the basic principles and applications of electrical components to lifting devices
Engineering Focus Module 2 (Telecommunication) → pp. 46-47	
• telecommunications ○ analogue and digital systems ○ modulation, demodulation ○ radio transmission (AM, FM) ○ television transmission (B/W, colour) ○ telephony – fixed and mobile ○ transmission media – cable, microwave, fibre-optics • satellite communication systems, geostations	• describe the basic concepts and applications of modulation and transmission systems in telecommunications • distinguish the communication bands in the electromagnetic spectrum • contrast the differences in transmission media • describe the basic principles of satellite communication systems

Engineering Knowledge Content Taught in Australian High Schools

The sets of engineering analytic and predictive principles and skills from the three subjects of engineering (Engineering Mechanics and Hydraulic, Engineering Materials, and Engineering Electricity/Electronics/Control System), which have been listed in the "Students Learn About/"Knowledge Content" columns (the left columns) of Table 7A, 7B and 7C, have been synthesized according to the subjects they fall under, and entered into the left columns of Tables 8A, 8B, and 8C, which are created for the above three subjects. The "Mandatory Study Topics" and "Suggested Subject Matter" listed in Queensland Studies Authority's Engineering Technology Senior Syllabus (2004), are featured in the right columns of Tables 8A, 8B, and 8C.

These Tables list the sets of engineering analytic principles and skills from various subjects that have been taught, as well as general guidelines for topic selections that have been implemented in high school engineering curriculum, in the States of New South Wales and Queensland in Australia. The Tables are based on the available information from Mr. Peter Thompson and Mr. Ruth Thompson's presentation CD.

Table 8A
Knowledge Content and Topical Guidelines for Engineering Mechanics and Hydraulics
Sources: (1) New South Wales Board of Studies *Stage 6 Syllabus* (1999); and
(2) Queensland Studies Authority *Engineering Technology Senior Syllabus* (2004)

Engineering Mechanics and Hydraulics	**Engineering Mechanics**
Specific Engineering Analytic Principles & Skills in Engineering Application or Focus Modules. From "Students Learn About" columns in Tables 7A, 7B and 7C. Source: New South Wales Board of Studies Stage 6 Syllabus (1999)	**"Mandatory Study Topics & "Suggested Subject Matter"** From Engineering Technology Senior Syllabus 2004 Source: Queensland Studies Authority (2004, pp. 17-18)
Statics	

Analysis of Force and Equilibrium Systems:
• mass and force
• forces
  ○ nature and type of forces
  ○ addition of vectors
  ○ space and freebody diagrams
  ○ resultants and equilibrants
  ○ transmissibility of forces
  ○ 3 force rule for equilibrium
  ○ moments of a force
  ○ force/couple systems
  ○ equilibrium of concurrent forces
• scalar and vector quantities
• conditions of equilibrium for non-concurrent coplanar forces
Analysis of Distributed Loads & Moments:
• uniformly distributed loads
• bending stress calculation (second moment of area given)
	1. Statics (Force and Equilibrium Systems):
	SI units in engineering
	Characteristics and components of a force - graphical and analytical solutions
	Principle of transmissibility of a force
	Resultants of two or more coplanar forces etc.
	Newton's laws
	Conditions of equilibrium for coplanar forces
	Moments and couples
	Centre of gravity of a body

Analysis of Structures:
• truss analysis
  ○ method of joints
  ○ method of sections
Analysis of Forces in Beams:
• bending stress induced by point loads only
  ○ concept of shear force and bending moment
  ○ shear force and bending moment diagrams
	2. Statics (Frameworks):
	Articulated framework and structures
	Non-concurrent forces etc.
	Reactions at supports
	Forces acting on members and joints
	Analytical and graphical solutions
	Method of joints and sections
	Worked examples of simple structures

Analysis of Friction:
• static friction
  ○ concept of friction and its use in engineering
  ○ coefficient of friction
  ○ normal force
  ○ friction force
  ○ angle of static friction
  ○ angle of repose
	N/A

Concepts of Work, Power and Energy: work, power, energy (without calculations)	

Table 8A (Continued).

Engineering Mechanics and Hydraulics	Engineering Mechanics
Specific Engineering Analytic Principles & Skills in Engineering Application or Focus Modules. From "Students Learn About" columns in Tables 7A, 7B and 7C. Source: New South Wales Board of Studies Stage 6 Syllabus (1999)	**"Mandatory Study Topics & "Suggested Subject Matter"** From Engineering Technology Senior Syllabus 2004 Source: Queensland Studies Authority (2004, pp. 17-18)
Strength of Materials	
Analysis of Stress and Strain: • concept of neutral axis and outer fibre stress • stress and strain (tensile and compression forces) • stress and strain ○ stress (tensile and compression) ○ load/extension diagram ○ strain (tensile and compression) ○ shear stress ○ engineering and working stress ○ yield stress, proof stress, toughness, Young's modulus, Hooke's law, engineering applications ○ factor of safety ○ stress/strain diagram **Analysis of Crack and Failure:** • crack theory ○ crack formation and growth ○ failure due to cracking • repair and/or elimination of failure due to cracking	N/A
Dynamics	
• Energy ○ potential energy ○ kinetic energy • work • power	**3. Dynamics:** Linear displacement, velocity and acceleration Analytical and graphical solutions Relationship between linear and angular motion Mass, force and acceleration Work, energy and power Torque, work and power Friction and frictional forces Frictional forces on an inclined plane
Mechanical Design	
Six Simple Machines: • simple mechanisms – inclined plane, lever, screws, wheel and axle, pulley, gears • orders of levers • mechanical advantage and velocity ratio	**4. Machines:** The purpose of a machine Mechanical advantage, velocity ratio, and efficiency Examples of simple machines: levers, wheel and axle, screw-jack, worm and wheel, pulley systems
Fluid Mechanics	
Theory: • Pascal's and Archimedes' principles • hydrostatic pressure • hydrostatic and dynamic pressure **Applications:** • to lifting devices • to braking systems • to aircraft components and to aircraft instruments	N/A

Table 8A (Continued).

Engineering Mechanics and Hydraulics	Engineering Mechanics
Specific Engineering Analytic Principles & Skills in Engineering Application or Focus Modules. From "Students Learn About" columns in Tables 7A, 7B and 7C. Source: New South Wales Board of Studies Stage 6 Syllabus (1999)	**"Mandatory Study Topics & "Suggested Subject Matter"** From Engineering Technology Senior Syllabus 2004 Source: Queensland Studies Authority (2004, pp. 17-18)
Aerodynamics	
• forces – lift drag, weight, thrust • basic aerodynamics ○ Bernouli's principle • bending stress – airframes • propulsion systems (jet, turboprop)	N/A

Table 8B
Knowledge Content and Topical Guidelines for Engineering Materials
Sources: (1) New South Wales Board of Studies *Stage 6 Syllabus* (1999); and
(2) Queensland Studies Authority *Engineering Technology Senior Syllabus* (2004)

Engineering Materials	
Specific Engineering Analytic Principles & Skills in Engineering Application or Focus Modules. From "Students Learn About" columns in Tables 7A, 7B and 7C. Source: New South Wales Board of Studies Stage 6 Syllabus (1999)	**"Mandatory Study Topics & "Suggested Subject Matter"** From Engineering Technology Senior Syllabus 2004 Source: Queensland Studies Authority (2004, pp. 15-17)
Engineering Materials	
<u>Materials Classification & Properties:</u> • classification of materials • properties of materials physical and mechanical properties • structure of materials ○ atomic structure ○ bonding • modification of materials ○ work hardening ○ heat treatment ○ nature of composites • engineering applications of materials • recyclability of materials ○ implications for recycling ○ recyclable materials including steel, aluminium, brass, plastics and rubber ○ costs and benefits of recycling materials • testing of materials ○ tensile and compression test ○ hardness test ○ x-ray ○ specialised testing of engineering materials and/or systems • specialised testing of aircraft materials ○ dye penetrant ○ x-ray ○ magnetic particles ○ ultrasonic • specialised testing ○ voltage, current, insulation • testing of materials used in lifting devices ○ tension, compression ○ hardness ○ impact • corrosion ○ corrosive environments ○ dry corrosion, wet corrosion, stress corrosion ○ common corrosion mechanisms in aircraft structures ○ pit and crevice corrosion ○ stress corrosion	"Engineering Materials is intended to provide the student with an understanding of the nature of materials and their property–structure relationships. In addition, it provides an appreciation of the various mechanisms for modifying materials with respect to both properties and form, and an insight into the use of materials in the built environment and how this has changed." "The suggested subject matter should be studied within the chosen technology contexts" (Queensland Studies Authority, 2004; pp. 15-18). **<u>1. Materials Overview</u>** **<u>Classification:</u>** *Classification of engineering materials*, e.g. metals, polymers, ceramics and organics *Solid-state structure*, e.g. atomic, molecular, crystalline, macro- and micro-structure **<u>Properties:</u>** Physical properties, e.g. conductivity, colour, lustre, density Mechanical properties, e.g. tensile and compressive strength, elasticity, hardness, ductility, malleability, toughness and shear strength Properties testing, e.g. hardness — Rockwell, Vickers, Brinnell; impact — Charpy, Izod; tensile strength Properties analysis, e.g. Young's Modulus — stress and strain; stress/strain diagrams; load-extension diagrams Deformation, e.g. mechanics of deformation in crystalline and non-crystalline solids Industrial and engineering applications, e.g. the appropriate application of engineering materials (such as timber, stone, metal and composites, including concrete) to modern industrial engineering design and construction

Table 8B (Continued).

Engineering Materials	
Specific Engineering Analytic Principles & Skills in Engineering Application or Focus Modules. From "Students Learn About" columns in Tables 7A, 7B and 7C. Source: New South Wales Board of Studies Stage 6 Syllabus (1999)	**"Mandatory Study Topics & "Suggested Subject Matter"** From Engineering Technology Senior Syllabus 2004 Source: Queensland Studies Authority (2004, pp. 15-17)
<u>Metals:</u> • metals ○ ferrous metals including mild steel ○ non-ferrous metals including copper, brass and bronze ○ joining and cutting methods • structure/property relationship in the material forming processes ○ forging ○ rolling ○ casting ○ extrusion ○ powder forming • heat treatment of ferrous metals ○ heat treatment of steels ○ annealing ○ normalising ○ hardening and tempering ○ structure property relationships • non-ferrous metals ○ aluminium and its alloys, • aluminium silicon, aluminium copper, • aluminium silicon-magnesium ○ brass, bronze ○ structure/property relationship ○ annealing, strengthening • structure/property relationships in heat treatment processes ○ normalising ○ hardening and tempering • aluminium and its alloys used in aircraft ○ aluminium silicon, aluminium silicon • magnesium, aluminium copper ○ structure/property/application relationships ○ heat treatment of applicable alloys • copper and its alloys used in telecommunications ○ structure/property relationships	**<u>2. Metals and related crystalline materials</u>** *Structure and properties*, e.g. crystalline structure and related physical and mechanical properties; an awareness of phase diagrams (iron-carbon), cooling curves and solubility of alloy systems *Production techniques*, e.g. metal types and related heat treatment (annealing, tempering, hardening, recrystallisation etc.), cold and hot working, casting, welding, rolling, forging, drawing, spinning, machining, powder metallurgy of metals *Industrial and engineering applications*, e.g. related to chosen contexts (manufacturing, construction etc.) *Degradation of metals*, e.g. corrosion, fatigue and work hardening
<u>Ceramics:</u> • ceramics types used • polymers • ceramics ○ structure and property relationship, applications ○ glass ○ cement • ceramics and glasses ○ semi-conductors ○ laminating and heat treatment of glass • ceramics as insulation materials • semiconductors ○ types and uses in telecommunications	**<u>3. Ceramics:</u>** Structure and properties, e.g. molecular structure and related physical and mechanical properties Production techniques, e.g. heat treatment, common forming processes, e.g. slip casting, tape casting, pressing, sintering Industrial and engineering applications, e.g. related to chosen contexts (manufacturing, construction etc.) Clay bodies, cements, concrete, glass-bonded ceramics, semiconductors, industrial ceramics Application of ceramics, e.g. insulators, semiconductors, abrasives, optics, refractories Degradation of ceramics, e.g. mechanical degradation due to low fracture toughness, wear abrasion

Table 8B (Continued).

Engineering Materials	
Specific Engineering Analytic Principles & Skills in Engineering Application or Focus Modules. From "Students Learn About" columns in Tables 7A, 7B and 7C. Source: New South Wales Board of Studies Stage 6 Syllabus (1999)	**"Mandatory Study Topics & "Suggested Subject Matter"** From Engineering Technology Senior Syllabus 2004 Source: Queensland Studies Authority (2004, pp. 15-17)
Polymers: ○ thermoplastics ○ thermosets • polymers ○ structure/property • relationships and applications ○ engineering textiles • manufacturing processes for polymer component • polymers ○ structure/property relationships and applications ○ modifying materials for aircraft applications ○ engineering textiles • polymers ○ insulation materials • fibre-optics ○ types and applications	**4. Polymers:** Structure and properties, e.g. linear and network structures of organic and inorganic polymers; related physical and mechanical properties Production techniques, e.g. injection, compression, transfer moulding, laminating and reinforcing, fabrication Industrial and engineering applications, e.g. related to chosen contexts, e.g. manufacturing, construction Degradation of polymers, e.g. fatigue, ultraviolet radiation, thermal, mechanical and chemical degradation
Composites: • composites ○ timber ○ concrete (reinforced and pre-stressed) ○ asphalt ○ laminates ○ geotextiles • composites ○ types and applications in aircraft structure/property relationships	N/A

Table 8C
Knowledge Content and Topical Guidelines for
Engineering Electricity/Electronics/ Control Systems
Sources: (1) New South Wales Board of Studies *Stage 6 Syllabus* (1999); and
(2) Queensland Studies Authority *Engineering Technology Senior Syllabus* (2004)

Engineering Electricity/Electronics	**Control Systems**
Specific Engineering Analytic Principles & Skills in Engineering Application or Focus Modules. From "Students Learn About" columns in Tables 7A, 7B and 7C. Source: New South Wales Board of Studies Stage 6 Syllabus (1999)	**"Mandatory Study Topics & "Suggested Subject Matter"** From Engineering Technology Senior Syllabus 2004 Source: Queensland Studies Authority (2004, pp. 18-21)
Engineering Application Module 1 (Household Appliances) • basic principles ○ potential difference ○ current ○ simple circuits and components • electrical safety related Australian electrical standards • magnetic induction • fundamental AC and DC circuits • electric motors **Engineering application module 2 (Personal and Public Transport)** • power generation/distribution electrical energy and power • AC/DC circuits • electric motors used in transport systems ○ principles ○ applications • control technology • digital technology **Engineering application module 3 (Lifting Devices)** • applications found in appropriate lifting devices ○ motors ○ motor control ○ electrical safety **Engineering Focus Module 2 (Telecommunication)** • telecommunications ○ analogue and digital systems ○ modulation, demodulation ○ radio transmission (AM, FM) ○ television transmission (B/W, colour) ○ telephony – fixed and mobile ○ transmission media – cable, microwave, fibre-optics ○ satellite communication systems, geostations	"The study of control systems and the associated software and hardware will enable students to appreciate the application of automated technologies in industry and society. Frequently these systems are so taken for granted as to become invisible. In reality they are at the heart of many mechanical devices ranging from washing machines and photocopiers through to power stations and oil refineries. This area of study enables students to analyze the operation of basic automatically controlled industrial devices, define the operating sequences and develop the control logic necessary to achieve basic operational outcomes. It will also enable students to present findings in a logical format capable of being interpreted. The programming and operation of industrial automation control systems is expected to be an integral part of this area of study." "The suggested subject matter should be studied within the chosen technology contexts" (Queensland Studies Authority, 2004; pp. 18-21). **1. Overview of control systems:** Domestic, commercial, industrial applications Implications of control systems on society **2. Fundamentals of control systems:** Control elements — input, process, output; control loop; feedback; sequential logic Theory relating to control system elements, for example, electronics, electricity, electromagnetism, pneumatics, hydraulics, mechanics

Table 8C (Continued).

Engineering Electricity/Electronics	**Control Systems**
Specific Engineering Analytic Principles & Skills in Engineering Application or Focus Modules. From "Students Learn About" columns in Tables 7A, 7B and 7C. Source: New South Wales Board of Studies Stage 6 Syllabus (1999)	**"Mandatory Study Topics & "Suggested Subject Matter"** From Engineering Technology Senior Syllabus 2004 Source: Queensland Studies Authority (2004, pp. 18-21)
↑ **(Previous pages)**	**3. Components:** • **input** • **processors** • **output** Some possible systems may include: • Electrics • analogue and digital sensors, for example, light, sound, heat, proximity • switches, for example, momentary, push-button, toggle, limit • electric motors, starters, solenoid actuation of contactors • Pneumatic and electro-pneumatic — compressors, motors, cylinders, pressure regulators, valves (three- and five-port, solenoid-operated, flow-control, check, quick-exhaust) • Hydraulic - pumps, motors, cylinders, valves (three- and four-port, solenoid-operated, pressure-relief, check, speed-control) • Mechanical - clutches, brakes, gearboxes, power screws, racks and pinions, shock absorbers • Processors - microprocessors, programmable logic controllers **4. Process:** Flow charts and event-timing diagrams Safety considerations Functional block diagrams Industrial programming techniques, for example, ladder logic, statement list, basic, compilers, or any other suitable method **5. Applying control systems:** Simulation of integrated systems using modelling techniques Safe handling of equipment and systems Practical application of control systems using input/output devices connected to a control device, for example, microprocessors, PLCs, CNC machines, robots, electronics etc. Examples include household appliances, manufacturing plant, traffic-light system, robotics, numeric-control machines, conveyor systems, sorting devices, loading systems, security systems

Statics Topics Taught at Australian High Schools as an Estimated Percentage of All

How much has been taught in Australia's high schools? In the left column of Table 9, all statics topics covered throughout all 10 chapters of *Vector Mechanics for Engineers Statics 7th Edition*, a popular undergraduate engineering textbook by Ferdinand P. Beer, E. Russell Johnston, Jr., and Elliot R. Eisenberg (2004), and published by

McGraw Higher Education, are listed. On the middle and right columns, corresponding data from Table 8A are listed so as to indicate the approximate amount of statics topics that have been tried in Australian high schools, based on information available from Mr. Peter Thompson and Mr. Ruth Thompson's presentation CD. A rough estimate of 15-20% of all knowledge content has been tried in Australian high schools; this knowledge content is concentrated on two areas of statics: (1) analysis of system of forces and equilibrium; and (2) analysis and design of trusses.

Table 9
Statics Topics Taught at Australian High Schools as an Estimated Percentage of All

Possible Grade to Start the Topic		**Engineering Analytic Topics & Typical Formulas**	**Statics Topics Tried in Australia**	
Ch	**Sec**		**Specific Engineering Analytic Principles & Skills** in Engineering Application or Focus Modules From "Students Learn About" columns in Tables 7A, 7B and 7C.	**"Mandatory Study Topics" & "Suggested Subject Matter"** From Engineering Technology Senior Syllabus 2004 (Queensland Studies Authority, 2004) From Tables 8A, 8B and 8C
Chapter 1: Introduction			**Analysis of Force and Equilibrium Systems**	**1. Statics (Force and Equilibrium Systems)**
9th	9th	**1.1: What Is Mechanics?**	• mass and force • forces ○ nature and type of forces ○ addition of vectors ○ space and freebody diagrams ○ resultants and equilibrants ○ transmissibility of forces ○ 3 force rule for equilibrium ○ moments of a force ○ force/couple systems ○ equilibrium of concurrent forces • scalar and vector quantities	SI units in engineering Resultants of two or more coplanar forces etc. Characteristics and components of a force - graphical and analytical solutions Newton's laws Conditions of equilibrium for coplanar forces
		1.2: Fundamental Concepts and Principles		
	6th	**1.3: Systems of Units**		
		1.4: Conversion from One System of Units to Another		
	3rd	**1.5: Method of Problem Solution**		
	5th	**1.6: Numerical Accuracy**		
Chapter 2: Statics of Particles				
9th	4th	**2.1: Introduction**		
		Forces in a Plane **2.2: Force on a Particle. Resultant of Two Forces**		
	9th	**2.3: Vectors**		
		2.4: Addition of Vectors		
		2.5: Resultant of Several Concurrent Forces		
	9th	**2.6: Resolution of a Force into Components**		
		2.7: Rectangular Components of a Force. Unit Vectors		
	8th	**2.8: Addition of Forces by Summing *x* and *y* Components**		
	9th	**2.9: Equilibrium of a Particle**		
	9th	**2.10: Newton's First Law of Motion**		
		2.11: Problems Involving the Equilibrium of a Particle. Free-Body Diagrams		
	9th	**Forces in Space** **2.12: Rectangular Components of a Force in Space**		
	9th	**2.13: Force Defined by Its Magnitude and Two Points on Its Line of Action**		
	9th	**2.14: Addition of Concurrent Forces in Space**		
	9th	**2.15: Equilibrium of a Particle in Space**		

Substantial number of statics analysis principles and skill already taught in Australian high schools.

Table 9. (Continued).

Possible Grade to Start the Topic		Engineering Analytic Topics & Typical Formulas	Statics Topics Tried in Australia	
			Specific Engineering Analytic Principles & Skills in Engineering Application or Focus Modules From "Students Learn About" columns in Tables 7A, 7B and 7C.	**"Mandatory Study Topics" & "Suggested Subject Matter"** From Engineering Technology Senior Syllabus 2004 (Queensland Studies Authority, 2004) From Tables 8A, 8B and 8C
Ch	**Sec**			
Chapter 3: Rigid Bodies - Equivalent Systems of Forces				**1. Statics (Force and Equilibrium Systems)**
9th	6th	**3.1: Introduction**		Principle of transmissibility of a force
		3.2: External and Internal Forces		
		3.3: Principle of Transmissibility. Equivalent Forces		
	9th	**3.4: Vector Product of Two Vectors**		
	9th	**3.5: Vector Products Expressed in Terms of Rectangular Components**		
	9th	**3.6: Moment of a Force about a Point**		
	9th	**3.7: Varignon's Theorem**		
	9th	**3.8: Rectangular Components of the Moment of a Force**		
	9th	**3.9: Scalar Product of Two Vectors**		
	9th	**3.10: Mixed Triple Product of Three Vectors**		
	9th	**3.11: Moment of a Force about a Given Axis**		
	9th	**3.12: Moment of a Couple**		
	6th	**3.13: Equivalent Couples**		
	9th	**3.14: Addition of Couples**		
	9th	**3.15: Couples Can Be Represented by Vectors**		
	9th	**3.16: Resolution of a Given Force Into a Force at *O* and a Couple**		
	9th	**3.17: Reduction of a System of Forces to One Force and One Couple**		
	8th	**3.18: Equivalent Systems of Forces**		
	9th	**3.19: Equipollent Systems of Vectors**		
	8th	**3.20: Further Reduction of a System of Forces**		
	9th	**3.21: Reduction of a System of Forces to a Wrench**		

<u>How much could be taught at high school 9th Grade</u>? The "9th" code on the leftmost portion of the left column in Table 9 indicates that corresponding Section (under the "Sec" sub-column) or Chapter (under the "Ch" sub-column) could be taught at Grade 9 in Georgia's high schools, based on Georgia Performance Standards' mandated satisfaction of mathematics and physics pre-requisites at previous grade levels. The determination of grade level suitability is based on careful analysis of all mathematics skills and physics concepts and principles involved in the formulas used in each Section and Chapter. Details of such determination are available in my Research Paper for which

this report constitutes the Appendix 2, which is titled *High School Appropriate Engineering Content Knowledge in the Infusion of Engineering Design Into K-12 Curriculum: Statics* (pp. 58-102). As shown in Table 9, approximately 50% of all knowledge content has been determined as suitable to instruction at Grade 9 in Georgia's high schools, based on the fulfillment of prerequisite mathematics and physics prior to 9th Grade as mandated by Georgia Performance Standards. Thus, there is still room for infusing additional statics topics into high school curriculum.

Table 9. (Continued).

Possible Grade to Start the Topic		Engineering Analytic Topics & Typical Formulas	Statics Topics Tried in Australia	
			Specific Engineering Analytic Principles & Skills in Engineering Application or Focus Modules From "Students Learn About" columns in Tables 7A, 7B and 7C.	**"Mandatory Study Topics" & "Suggested Subject Matter"** From Engineering Technology Senior Syllabus 2004 (Queensland Studies Authority, 2004) From Tables 8A, 8B and 8C
Ch	**Sec**			
Chapter 4: Equilibrium of Rigid Bodies			**Analysis of Force and Equilibrium Systems**	**2. Statics (Frameworks):**
9th	9th	**4.1: Introduction**	• conditions of equilibrium for non-concurrent coplanar forces	Reactions at supports
	9th	**4.2: Free-Body Diagram**		
	9th	**<u>Equilibrium in Two Dimensions</u>** **4.3: Reactions at Supports and Connections for a Two-Dimensional Structure**		
	9th	**4.4: Equilibrium of a Rigid Body in Two Dimensions**		
	9th	**4.5: Statically Indeterminate Reactions. Partial Constraints**		
	9th	**4.6: Equilibrium of a Two-Force Body**		
	9th	**4.7: Equilibrium of a Three-Force Body**		
	9th	**<u>Equilibrium in Three Dimensions</u>** **4.8: Equilibrium of a Rigid Body in Three Dimensions**		
	9th	**4.9: Reactions at Supports and Connections for a Three-Dimensional Structure**		
Chapter 5: Distributed Forces: Centroids and Centers of Gravity				**1. Statics (Force and Equilibrium Systems)**
PS	PS	**5.1: Introduction**		Centre of gravity of a body
	PS	**<u>Areas and Lines</u>** **5.2: Center of Gravity of a Two-Dimensional Body**		
	PS	**5.3: Centroids of Areas and Lines**		
	PS	**5.4: First Moments of Areas and Lines**		
	PS	**5.5: Composite Plates and Wires**		
	PS	**5.6: Determination of Centroids by Integration**		
	PS	**5.7: Theorems of Pappus-Guldinus**		
	PS	**5.8: Distributed Loads on Beams**		
	PS	**5.9: Forces on Submerged Surfaces**		
	PS	**<u>Volumes</u>** **5.10: Center of Gravity of a Three-Dimensional Body. Centroid of a Volume**		
	PS	**5.11: Composite Bodies**		
	PS	**5.12: Determination of Centroids of Volumes by Integration**		

Substantial number of statics analysis principles and skill already taught in Australian high

Table 9. (Continued).

Possible Grade to Start the Topic		Engineering Analytic Topics & Typical Formulas	Statics Topics Tried in Australia	
			Specific Engineering Analytic Principles & Skills in Engineering Application or Focus Modules From "Students Learn About" columns in Tables 7A, 7B and 7C.	**"Mandatory Study Topics" & "Suggested Subject Matter"** From Engineering Technology Senior Syllabus 2004 (Queensland Studies Authority, 2004) From Tables 8A, 8B and 8C
Ch	**Sec**			
Chapter 6: Analysis of Structures			**Analysis of Structures**	**2. Statics (Frameworks):**
9th	9th	**6.1: Introduction**	• truss analysis ○ method of joints ○ method of sections	Articulated framework and structures Non-concurrent forces etc. Forces acting on members and joints Analytical and graphical solutions Method of joints and sections Worked examples of simple structures
	9th	**<u>Trusses</u>** **6.2: Definition of a Truss**		
	9th	**6.3: Simple Trusses**		
	9th	**6.4: Analysis of Trusses by the Method of Joints**		
	9th	**6.5: Joints under Special Loading Conditions**		
	9th	**6.6: Space Trusses**		
	9th	**6.7: Analysis of Trusses by the Method of Sections**		
	9th	**6.8: Trusses Made of Several Simple Trusses**		
	9th	**<u>Frames and Machines</u>** **6.9: Structures Containing Multiforce Members**		
	9th	**6.10: Analysis of a Frame**		
	9th	**6.11: Frames Which Cease to Be Rigid When Detached from Their Supports**		
	9th	**6.12: Machines**		
Chapter 7: Forces in Beams and Cables			**Analysis of Forces in Beams**	
PS	PS	**7.1: Introduction**	• bending stress induced by point loads only ○ concept of shear force and bending moment ○ shear force and bending moment diagrams	
	PS	**7.2: Internal Forces in Members**		
	PS	**<u>Beams</u>** **7.3: Various Types of Loading and Support**		
	PS	**7.4: Shear and Bending Moment in a Beam**		
	PS	**7.5: Shear and Bending-Moment Diagrams**		
	PS	**7.6: Relations among Load, Shear, and Bending Moment**		
	8th	**<u>Cables</u>** **7.7: Cables with Concentrated Loads**		
		7.8: Cables with Distributed Loads		
		7.9: Parabolic Cable		
	PS	**7.10: Catenary**		

Some statics analysis principles and skill already taught in Australian high schools.

Table 9. (Continued).

Possible Grade to Start the Topic		**Engineering Analytic Topics & Typical Formulas**	**Statics Topics Tried in Australia**	
			Specific Engineering Analytic Principles & Skills in Engineering Application or Focus Modules From "Students Learn About" columns in Tables 7A, 7B and 7C.	**"Mandatory Study Topics" & "Suggested Subject Matter"** From Engineering Technology Senior Syllabus 2004 (Queensland Studies Authority, 2004) From Tables 8A, 8B and 8C
Ch	**Sec**			
Chapter 8: Friction			**Analysis of Friction:**	
PS	9th	**8.1: Introduction**	• static friction ○ concept of friction and its use in engineering ○ coefficient of friction ○ normal force ○ friction force ○ angle of static friction ○ angle of repose	
		8.2: The Laws of Dry Friction. Coefficients of Friction		
		8.3: Angles of Friction		
		8.4: Problems Involving Dry Friction		
		8.5: Wedges		
		8.6: Square-Threaded Screws		
		8.7: Journal Bearings. Axle Friction		
	PS	**8.8: Thrust Bearings. Disk Friction**		
	8th	**8.9: Wheel Friction. Rolling Resistance**		
	PS	**8.10: Belt Friction**		
Chapter 9: Distributed Forces: Moments of Inertia			**Analysis of Distributed Loads & Moments**	**1. Statics (Force and Equilibrium Systems)**
PS	PS	**9.1: Introduction**	• uniformly distributed loads ○ bending stress calculation (second moment of area given)	Moments and couples
	PS	**<u>Moments of Inertia of Areas</u>** **9.2: Second Moment, or Moment of Inertia, of an Area**		
	PS	**9.3: Determination of the Moment of Inertia of an Area by Integration**		
	PS	**9.4: Polar Moment of Inertia**		
	PS	**9.5: Radius of Gyration of an Area**		
	PS	**9.6: Parallel-Axis Theorem**		
	PS	**9.7: Moments of Inertia of Composite Areas**		
	PS	**9.8: Product of Inertia**		
	PS	**9.9: Principal Axes and Principal Moments of Inertia**		
	PS	**9.10: Mohr's Circle for Moments and Products of Inertia**		
	PS	**<u>Moments of Inertia of Masses</u>** **9.11: Moment of Inertia of a Mass**		
	PS	**9.12: Parallel-Axis Theorem**		
	PS	**9.13: Moments of Inertia of Thin Plates**		
	PS	**9.14: Determination of the Moment of Inertia of a Three-Dimensional Body by Integration**		
	PS	**9.15: Moments of Inertia of Composite Bodies**		
	PS	**9.16: Moment of Inertia of a Body with Respect to an Arbitrary Axis through *O*. Mass Products of Inertia**		
	PS	**9.17: Ellipsoid of Inertia. Principal Axes of Inertia**		
	PS	**9.18: Principal Axes and Moments of Inertia of a Body of Arbitrary Shape**		

Some pre-calculus statics analysis principles and skill already taught in Australian high schools.

Table 9. (Continued).

Possible Grade to Start the Topic: Ch	Possible Grade to Start the Topic: Sec	Engineering Analytic Topics & Typical Formulas	Statics Topics Tried in Australia: Specific Engineering Analytic Principles & Skills in Engineering Application or Focus Modules From "Students Learn About" columns in Tables 7A, 7B and 7C.	Statics Topics Tried in Australia: "Mandatory Study Topics" & "Suggested Subject Matter" From Engineering Technology Senior Syllabus 2004 (Queensland Studies Authority, 2004) From Tables 8A, 8B and 8C
Chapter 10: Method of Virtual Work			**Concepts of Work, Power and Energy**	
PS	PS	**10.1: Introduction**	• work, power, energy (without calculations)	
	PS	**10.2: Work of a Force**		
	PS	**10.3: Principle of Virtual Work**		
	PS	**10.4: Applications of the Principle of Virtual Work**		
	PS	**10.5: Real Machines. Mechanical Efficiency**		
	PS	**10.6: Work of a Force during a Finite Displacement**		
	PS	**10.7: Potential Energy**		
	PS	**10.8: Potential Energy and Equilibrium**		
	PS	**10.9: Stability of Equilibrium**		
THE END				

PART SIX
CONCLUSIONS AND RECOMMENDATIONS

The previous parts of this report have presented and analyzed the infusion of engineering design in some of Australia's high schools; compared Australia's K-10 education with the American system; and evaluated the potential referential values of Australia's experience and achievement.

This part of the report will present overall conclusions and recommendations for improving K-12 engineering curriculum in the United States.

Conclusions

The relative strengths of academic performance standards for mathematics, science, engineering and technology education at pre-collegiate level (K-10) in Victoria, Australia, and in Georgia, the United States could be summarized in Table 10.

Table 10
Comparison of Academic Performance Standards for Mathematics, Science and Engineering Education in Victoria (Australia) and in Georgia (United States)

Academic Performance Standards	Victoria (Australia)	Georgia (United States)
Mathematics	More practical and flexible	More "traditional" and vigorous
Science	Adequate for average students	Stronger, deeper and more specialized
Engineering & Technology	More balanced between engineering and technology	More technology-savvy
○ **Engineering Analytic Principles and Skills**	More structured and cohesive infusion (with clearly-defined standards)	Fewer standards defined, except for electronics and a few other subjects
○ **Design Process**	Practically no difference	
○ **Engineering-related Technology**	Practically no difference	
○ **Exit Credential Testing**	Yes! For both engineering and technology (high school level)	For technology only

Table 10
Comparison of Academic Performance Standards for Mathematics, Science and Engineering Education in Victoria (Australia) and in Georgia (United States)

Academic Performance Standards	**Victoria (Australia)**	**Georgia (United States)**
○ **Outcome (Products)**	Real-world and professional quality products design and prototyping	To be studied
Overall Education Goal	More “controlled” and “specialist”	More “generalist”

Recommendations

Based on information on Table 10, the following could be recommended for improving K-12 engineering and technology education in the United States:

- Further study of Australian achievements in pre-collegiate engineering education, as well as those from other advanced Western Industrialized Democracies, such as Great Britain, Canada, Ireland, Germany, Sweden and Japan. Let foreign experience serve American needs!

- More systematic and cohesive infusion of engineering analytic principles and skills into a potentially viable K-12 engineering curriculum in the United States, with (1) a solid foundation in engineering analytic principles and skills; (2) well designed national and state guidelines (lists of topics to be included, learning focus, standards, etc.), which could be used by various existing stakeholders such as Project Lead The Way for further development of high school engineering curriculum. In the pyramid of knowledge, mathematics and science per se are on the top level; engineering is applied mathematics and science in the middle; and technology is applied engineering at the base. The Georgia Performance Standards for K-12 schools are very strong on mathematics and science as well as on technology (the top and the base); what we need might be to strengthen the middle (engineering) so as to strengthen the linkage between mathematics on the top and technology at the base. This pyramidal relation is shown on *Figure 8*.

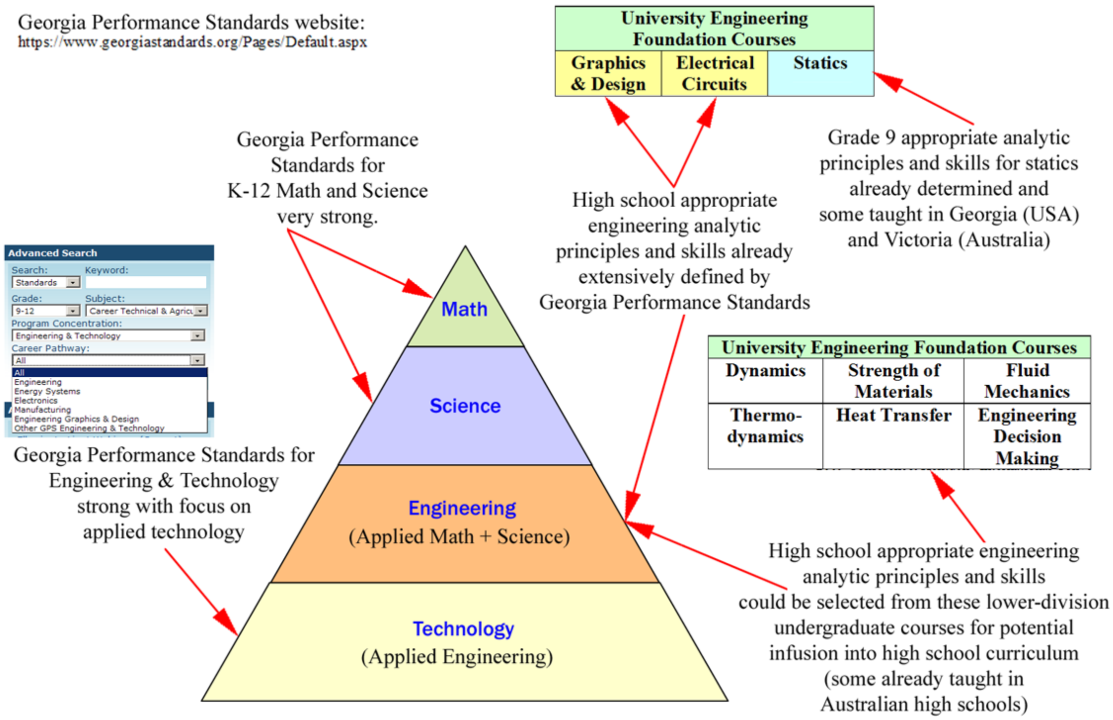


Figure 8. Pyramidal relations of academic performance standards for mathematic, science, engineering and technology.

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