The Gifted Student in Science:
FULFILLING POTENTIAL

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In Australia, both the federal government and most states are committing considerable funds to enhancing science education, and in particular advocating special support for the most gifted students. These students are seen as crucial contributors to a technological society in coming generations. The provision of support for gifted students is often left to learning support teachers or gifted and talented coordinators. Rarely do teachers of science provide gifted students with opportunities for enrichment within the formal school structures. This is despite the strong interest that many gifted children have in science from a very young age. In this article, we explore the issue of why gifted students should receive special attention and highlight some of the broad strategies that can be implemented to support gifted students. The education of gifted students in science has received scant attention in the literature despite considerable advances being made in the field (e.g., Heller, Mönks, Sternberg, & Subotnik, 2000). Although, many of the strategies developed in gifted education will particularly benefit gifted students they are also of value to all students studying science.

WHY DO GIFTED AND TALENTED STUDENTS REQUIRE SPECIAL PROVISION?

Gifted children are exceptional children, each with their own innate specific capacity to excel in domains commensurate with their intellectual capability. Although most children show strengths of intellect or performance in some areas, the gifted display exceptional behaviour relative to their peers. Reasons given for supporting the gifted in the various educational policy documents stem from two concerns: economic prosperity and equity. The future well being of the nation and society is seen as an outcome of fostering productivity and creativity. There is also the affirmation that disadvantaged groups can and should be provided with opportunities for development of their potential. Despite the influence of extensive ill-informed lay opinion, gifted students can be disadvantaged by a failure to cater for their special learning needs. Inclusivity and generalisations that all students display gifts can lead to initiatives that deny the gifted a chance to discover and exhibit their full potential. By assuming all students have gifts we take a politically safe stance, which does not confront ideals of egalitarianism. However, giftedness is that characteristic that sets apart a particular group of children. Intelligence is not a fixed apportionment but grows in a nurturing environment. The gifted are not necessarily the high performers on formal tests, or those who excel at recall of information. If giftedness is seen as manifested in certain characteristics as such as extensive
knowledge recall as then those students assessed this way will be identified as gifted. Whether this characteristic is of value for life in the 21st century is questionable. What should be valued is the capacity for original thought, creativity and reasoning as outcomes not witnessed in many science classrooms. Clearly, debate is required to determine what characteristics should be valued and what strategies can be adopted to enhance the achievement of potential.

In April 1996 the Australian Association for the Education of the Gifted and Talented (AAEGT) released its Australian Future position paper (AAEGT, 1996). The paper identified three premises, which should influence the provision of support for the gifted:

- Australia’s prosperity depends on its ability to recognise and nurture its diverse gifted and talented population;
- there are students with outstanding potential and exceptional abilities in all socio-cultural groups across Australia; and
- the development of specific policies, programs and provisions and their implementation are essential in challenging and assisting these students to reach their potential.

A country’s prosperity is clearly dependent on a population that is scientifically literate but is also dependent on people who are essentially leaders in the field, who create knowledge and who can contribute to the solution of the problems that will confront us in the future. The Australian government and a number of states have acknowledged the need for enhanced science teaching to develop innovative workers (Greer, 2002). How this will be achieved for the whole population will be a challenge for teachers, policy makers and reformists. Many have advocated the teaching of science to develop scientific literacy and thus to establish a population with positive dispositions towards science. Recently, in his investigation of innovation in Australia, Batterham (2000) argued the case for scientific literacy saying:

"Australia needs to provide advanced science education so that all our children have the opportunity to better understand the rapidly changing world around them and have the option to pursue a career in science, engineering or technology. Australia’s success as a knowledge economy is dependent on a highly skilled, advanced and scientifically literate workforce who receive a strong foundation of STEM knowledge throughout their primary and secondary schooling." (p. 49)

Similarly (Goodrum, Hackling, & Rennie, 2001) suggested the purpose of science education was:

"to develop scientific literacy which is a high priority for all citizens, helping them to be interested in, and understand the world around them, to engage in the discussion of and about science, to be sceptical and questioning of claims made by others about scientific matters, to be able to identify questions and draw evidence-based conclusions, and to make informed decisions about the environmental and their own health and well being." (p. 19)

However, other evidence suggests there should be little concern. Australian students seem to perform well on measures such as the Third International Mathematics and Science Study (TIMSS) (Lokan, Greenwood, & Cresswell, 1996) and the Programme for International Student Assessment (PISA) (Lokan, Greenwood, & Cresswell, 2001). For example, in the TIMSS repeat study in 1999, 8th Grade students in Australia were ranked seventh in overall science results but with only one country (Chinese Taipei) significantly higher in performance (Martin, et al., 1999). Similarly in the PISA study, Australian students tend to be ranked more scientifically literate than students in 22 out of 30 countries that participated in the study and only outperformed by Japan and Korea. By these criteria, Australian students are among the world’s most scientifically literate.

So why should we be concerned?

Firstly, Goodrum, Hackling, & Rennie, (2001) in their extensive study found that:

Australian educational provisions have developed modern and progressive curricula frameworks for school science, however there is a considerable gap between the ideal or intended curriculum and the actual or implemented curriculum (p. 19).

Similarly, Batterham (2000) acknowledged the precarious state of science, engineering and technology emphasising the need for school curricula “to make science more exciting and be designed to foster creative, innovative approaches to problem solving” (p. 51). The concern expressed by Batterham highlights the almost desperate state of science undergraduate education especially in the enabling sciences such as mathematics, physics, and chemistry. The brightest and best minds – the gifted – are not attracted to scientific careers in part because of the poor rewards in science but also because of the experiences they endure in schools. Among the multiple issues confronting science education, one of the most
Table 1. Comparison of School Science and Genuine Science

<table>
<thead>
<tr>
<th>SCHOOL SCIENCE</th>
<th>WORLD SCIENCE</th>
</tr>
</thead>
<tbody>
<tr>
<td>Problems are well defined and devised by teachers, curriculum designers or</td>
<td>Problems are ill-defined and identified by practitioners – problem identification is as important as problem solution</td>
</tr>
<tr>
<td>publishers</td>
<td></td>
</tr>
<tr>
<td>Focus is on communicating content, facts or on testing established theories</td>
<td>Focus is on finding out the unknown or generating theory</td>
</tr>
<tr>
<td>There is assumed to be a right answer to a problem (failures are attributed to</td>
<td>Failure is important as an outcome of testing a theory – experience is the greatest teacher</td>
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<tr>
<td>methodology)</td>
<td></td>
</tr>
<tr>
<td>Science content is discrete based on technical rationality with systems being</td>
<td>Content is integrated and wholistic, Social, economic and ethical issues are significant considerations with reliance on skills of persuasion and argument</td>
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<td>considered in isolation or clustered as traditional disciplines</td>
<td></td>
</tr>
<tr>
<td>Individualistic focus, competitive, normative assessment</td>
<td>Group focus, teamwork, collaboration, authentic performance assessment</td>
</tr>
<tr>
<td>Extrinsic motivation, rewards as grades</td>
<td>Intrinsic motivation, joy of discovery, social status</td>
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important is to cultivate talent from the earliest years at school. Change in practices in schools has to occur at all levels and in all ways from identifying and programming for gifted children to reporting.

**EQUITY AND THE GIFTED**

There are further reasons why it is necessary to provide support for a group of students who some claim are already endowed with intellectual gifts and hence are naturally advantaged. Although, genetic endowment may have provided these people with an efficient and exceptional intellect, that is not sufficient. Just like identical seeds cast to the wind those that land in the soil that is rich and accommodating will prosper and grow; the others that fall on rock will perish. For those that land on the rock, deliberate relocation to more fertile soil is the necessary reaction.

The quality of experiences both in the home and in the school are essential determinants. The "brain-drain" is a manifestation of this in the context of Australian research illustrating the paucity of funding which among other reasons has led to the closure or "downsizing" of a number of physics and mathematics departments in Universities (Collins, 2001, Otmara, 1998).

From birth, we see in many children signs of giftedness, but any correlation between infant precociousness and adult achievement is yet to be established. Tannenbaum (1989) emphasises the need to distinguish between early promise and fulfilment. He argues that a person's intelligence or mental structures determine the existence of high potential, and that society and the environment provides the direction and pathway towards fulfilment. He suggests that five factors are important: superior innate intelligence (IQ), exception-
affirmatively. Therefore, because the development of potential may not occur spontaneously, deliberate and individually planned intervention practices are essential. Thus, equity, excellence and the environment are inextricably linked. Unjustly, the gifted in a hedonistic Australian society are marginalised and disregarded. Pedagogical and curriculum practices do not cater for their specific needs and indeed may even exacerbate failure.

SO HOW IS SCIENCE USEFUL TO GIFTED STUDENTS?

The teaching of science is frequently justified in school because through the skills and knowledge developed in this discipline area students are better prepared as citizens in a technological society. However, science is also way of understanding the world and our interactions with it in a broader cultural sense (Coburn, 1993). Indeed, Fensham (1994) argues that empowerment from science rather than induction into science is a more important way of thinking about the purpose of school science. Science should contribute to the establishment of a scientifically literate society whose members can confront social and technological problems. Effective problem solving, particularly novel problem solving, would seem to depend on the breadth of experience in problem solving tasks and the effectiveness of this may depend on the level of intelligence of that person (Gardner & Sternberg, 1994). Regrettably, school science is rarely implemented in ways that typify genuine science (Table 1). Furthermore, assessment of students’ performances in science for the most part is still norm referenced, group oriented and focussed on reproduction of knowledge.

THE DECLINE OF INTEREST IN SCIENCE

If one laments the status of science in primary school, one should also be despondent about the teaching of science in secondary school. The compulsive orientation towards content, epistemological beliefs of teachers and discipline-based rote learning that characterises the majority of secondary science teaching has the impact of generating highly negative attitudes towards science in many students. Much of what is taught, if they remember it longer than the next examination, is unlikely to be ever used by students when they become adults. “Learning less – better” is a cliché that is perhaps well worth considering. Curricula have been under revision throughout Australia, but perhaps the best improvement of all would be to encourage students to pursue their own curiosity about the natural world. Almost ten years after the introduction of outcomes based education, which in its transformative manifestation should enable the individual to demonstrate genuine learning outcomes, there still exists practices that assume all children will achieve the same outcomes at the same time. Contemporary views of learning suggest that students need to personally, and in a social context, make sense of new experiences through active engagement with ideas and phenomena. However, these constructivist principles of learning appear to have made little impact on the majority of classroom practices (Tobin & McRobbie, 1996). Where constructivist ideas have been implemented, students have come to enjoy and engage in science rather than becoming totally alienated from science (e.g. Moscovici, 2000). As long as the focus is on quantity of learning and not quality, negative attitudes to science will persist for many students.

Indeed, students are being turned off science at all levels. The lack of exposure at primary school and an overemphasis on content, abstract ideas in upper primary and secondary are limiting the attractiveness of science as a career for many students. For most students, science will not become a career. However students need an understanding of science that becomes a grounding for “life functional literacy” – the term the Australian Science and Technology Council (ASTEC) [1997] has used to describe the skills required to live in a complex modern society. However, gifted students are often intrinsically interested in science and it will be to them we turn for solutions to world problems in the 21st Century. Unfortunately, dull routine, recall-based assessment and the lack of meaningful experiences can turn these students away from science. If the gifted are to be given the opportunity to impact on Australia’s scientific, technological and social future, our school systems needs to provide them with more challenging and meaningful learning experiences.

Thus from two perspectives, gifted students deserve opportunities to engage in meaningful and worthwhile experiences in science. As individuals, gifted students have much to gain from the challenge of abstract thinking, creative problem solving, and intellectual self-actualisation that can be achieved through the scientific enterprise. Society also desperately needs the most gifted minds to face the enormous problems that will confront humanity in the next decades.

DIFFERENTIATED CURRICULUM DESIGNS

The provision of enrichment for students
with exceptional intellectual abilities is an affirmative action initiative that attempts to ensure equality of opportunity by meeting the needs of all students. However, enrichment practices need to be carefully and deliberately implemented with planning, monitoring and evaluation. Indeed the administration of effective enrichment may be a source of consternation and resistance to action. More of the same type of work, the quick puzzle, the set of lateral thinking problems that in the short term may be entertaining and satisfying represent a quick fix without permanent intervention. Many programs for gifted students are based on the provision of the next grade level of work or moving the student into more advanced content. Gifted students can assimilate knowledge rapidly but they need opportunities to use that knowledge productively.

A differentiated curriculum can provide the basis for discovering, serving and nurturing academic giftedness. Differentiation provides tools to vary the curriculum so that students who have already mastered given material can progress or whose potential giftedness is not cultivated by the standard curriculum can pursue an area in greater depth. Differentiation can occur at the classroom level or at the school level. In exploring the differentiated curriculum we will examine how content, teaching processes and the environment can be differentiated.

**Modifying content**

A goal of education should be to develop thinking citizens. Students need to be challenged to think, to reason and to be able to explain and justify their thoughts. Higher-level thinking can be developed in classrooms through programs that draw upon Bloom’s Taxonomy (Bloom, 1956) or deBono’s (1985; 1996) techniques. Whilst these strategies may be useful as heuristics to encourage creative or critical thinking, they are often devoid of context. Learning in science requires students to be engaged in making sense of the environment and become scientifically literate. Content is important.

Gifted students are proficient at learning new content or facts and should be encouraged to pursue the learning of information at their own pace. If they master a particular concept, they need to be provided with more advanced or qualitatively more complex material. Their learning characteristics are best served by thematic, broad-based, and integrative content, rather than just single-subject material (Watters & Diezmann, 2000). Gifted students have a high sense of social responsibility and frequently have an interest in solving meaningful, significant world or local problems, seeing beyond the discipline areas. In lower primary this is not all that different from normal curriculum practices but it needs to be appreciated that gifted students are likely to be faster, more intensely involved and more abstract in their approach and solutions to problems. By high school, they have the maturity and insight to devise their own projects in which they can explore problems of interest to them. Problem based learning through inquiry may be implemented individually with students undertaking projects for entry into the numerous competitions that exist or may be implemented through enrichment programmes. Even in regular classes, a community of inquiry can be established. The open-ended nature of such problems...
solving allows all students to explore issues to the extent and depth that they can be challenged. The more able students can be encouraged, guided and expected to produce outcomes at a much higher level.

Modifying process

The role of teaching and teachers in the learning process is under challenge as an outcome of contemporary understanding of how students come to acquire knowledge and our changing beliefs about the nature of scientific knowledge. Knowledge is an individual and socially facilitated construction. It is a representation of personal experiences. Knowledge cannot be acquired or concepts understood by the transmissive approach often seen in classrooms where students copy copious notes into workbooks. Understanding requires active engagement by the learner in making sense of new experiences. However, teachers play a vital role as guides, collaborators and learners in this same process. Teachers are models and catalysts for learning.

Problem solving skills can be developed through cognitive apprenticeship and the mediation of learning experiences as described in Table 2. These approaches are dependent on teachers helping students assimilate new experiences into existing knowledge structures through modelling and scaffolding. Research on interactions between very young children and parents has shown the importance of adults who demonstrate a learning orientation rather than a performance goal and hence emphasise problem solving and metacognition rather than merely knowledge accumulation (Moss & Strayer, 1991; Renshaw & Gardner, 1990). Cognitive apprenticeship implies responsibilities for both students and teachers. The teachers through modelling, coaching and scaffold-

Modifying the environment

Gifted students learn best in a receptive, non-judgemental, risk-free environment that encourages scholarship and a central purpose as a community of learners (Brown & Campione, 1990). They often have difficulty communicating with their chronological peers about academic matters and prefer to associate with older children or adults. Often peer pressure and a desire to conform suppresses their enthusiasm for learning with the subsequent danger of under-achievement and behavioural disturbances. It is essential to provide gifted students with an environment where risk-taking is tolerated, where ideas are cherished and encouraged (irrespective of conformity) and where independence, creativity and autonomy are the norm. Such learning environments should also be tolerant of learning styles, strengths and idiosyncratic behaviours that in a normal classroom may be disruptive. For example, gifted students often like to work undisturbed for lengthy periods but when the task is sufficiently challenging, they will seek capable peers to exchange ideas and pool resources (Diezmann & Watters, 2001).

Such environments can be instigated within a regular classroom but also by the establishment of special "pullout" classes for gifted students. Pullout classes involve students attending a class timetabled either within the normal class time or after school. Gifted students need opportunities to interact with peers of similar interest and abilities to overcome feelings of isolation and low self-esteem. The pull-out option is of particular value in the high school where students with high ability or motivation towards science can come together as a group in a special class for the purpose of undertaking school-based science research. Such initiatives have proven to be very successful but there is the need for a highly dedicated teacher with considerable energy to provide logistical and pedagogical support. Students undertaking independent studies, either individually or as groups require sensitive and skilled mentors, support for obtaining resources and considerable guidance during their project. Mentors, such as retired engineers or university academics, also need to be aware of the capability and experiences of students to avoid overwhelming them with information or setting too high expectations. The establishment of enrichment or extension classes also requires the strong support of other teachers, the administration and parents. Many gifted students, if they have persisted with science, are concerned about grades and acquiring basic "knowledge" and may not value the opportunity to develop independent problem solving skills as behaviours not always valued in traditional science classes.

A summary of some of the strategies in developing a school-based programme are presented in Table 3 (over page).

CONCLUSIONS

Providing for the gifted student offers a number of challenges. Firstly, are we willing to confront social and cultural pressures that do not support enrichment for gifted students? Secondly, are we prepared to take the gamble, recognise the plurality of giftedness, and confront our preconceptions about giftedness?
Table 3. Strategies for catering for exceptional students

CLASSROOM STRATEGIES
1. Learning contracts
2. Individual timetables
3. Ability pairing
4. Grouping according to ability, learning style, interests, mutual support
5. Older tutor, adult mentor
6. Use of self-teaching instructional materials, multimedia, self-pacing
7. Interest centres
8. Involvement in extra-class competitions etc
9. Open-ended projects

SCHOOL STRATEGIES
1. Co-operative or team teaching—share expertise
2. Special clustering—removal of students from one or more classes to meet special needs
3. Cross-setting—ability grouping of students across year levels
4. Heterogeneous groups - composite groups — multi-age
5. Homogeneous groups - same age and ability
6. Cross age tutoring — older students working with younger ones
7. Specialist teacher
8. Electives program—non-graded opportunities to pursue individual interests
9. Acceleration — introduction of advanced concepts
10. Resource centre—place where students can pursue advanced interests.
11. Concurrent education—attending high school or advanced learning institute
12. Cluster groups—co-operation between schools in a region to provide a central facility and specialist
13. Field trips—excursions to work with mentors
14. Project classes — school based science research and extension classes

COMMUNITY STRATEGIES
1. Weekend or evening classes—school parents, university Enrichment programs, gifted and talented associations, industry extension programmes, CSIRO Double Halix Club
2. Camps
3. Community clubs

Thirdly, can we recognise the role content, teaching processes and the environment in facilitating the development of gifts? The final challenge is to have the confidence to allow gifted students to explore life in ways that may be quite different to those we would consider normal and within the dictates of regular classroom practice.

Science is the human endeavour through which we try to make sense of our environment. In contrast to religion or other belief systems, science is a worldview that is built around practices that purport to guide the individual towards a personal understanding. The problems of the world are real problems that influence all of us striving to cope with a technologically society. These problems are of intrinsic interest to gifted students. Although not all gifted students will exhibit aptitudes and interest in science, an attribute that may be very much environmentally determined, they have the passion to want to understand and contribute to solving the world’s problems. Thus, science practised as authentic problem solving can meet the intellectual needs of gifted students. In turn, the investment in these individuals will yield high returns for all humanity through their leadership in science, their contributions to knowledge development, and their engagement in the unknown problems of the new century.

References
Invitation to tender for the consultancy to produce the ASTA National Science Week Resource Book 2004: Out of this World: Investigating Space

Tenders are invited from applicants to produce the 2004 National Science Week Resource book on behalf of the Australian Science Teachers Association (ASTA).

Interested parties should contact the ASTA Secretariat as detailed below to obtain a copy of the tender documents.

Applications to produce the book will close COB Monday 27 October 2003

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