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Identification of, and academic provision for high-ability science students: What does the literature say?

Matthew Burrell[1], Jenny Horsley[2] and Azra Moeed[3]
[1]Science Department, Newland's College, Wellington, New Zealand
[2]Jenny Horsley, School of Education, Victotia University of Wellington, Wellington, New Zealand
[3]Azra Moeed, School of Education, Victoria University of Wellington, Wellington, New Zealand
For correspondence: azra.moeed@vuw.ac.nz

Abstract
Over the last two decades, education inAustralia and New Zealand has focussed on improving student underachievement in schools. There is concern that this focus is having a negative impact on meeting the needs of high-ability students, including those who are potentially high-ability science students. It appearsthefreedom the national curriculum gives schools to identify and then provide for high-ability science students is problematic, and there is no clear picture emerging of how schools are identifying and providing for the learning needs of these students. This review of literature identifies toolsteachers may choose touse to identify high-ability students in science such asusinga range of characteristicscombined with evidence of students'substantive, procedural, and epistemologicalunderstandingsof science ideas.The means of meeting these students' needs is considered within the extant literature, with curriculum acceleration identifed as the preferable approach to making appropriate academic provision for high-ability sciencestudents.

Keywords: high-ability, science, gifted, identification of high-ability students, provision for high-ability science students New Zealand.

Introduction

Recent international assessments have identified a long tail of underachievement in science subjects in New Zealand. The government describes these students as 'priority learners' and the current policy focus is on targetting this group of students and raising their achievement. Although New Zealand is amongst the top ten countries in these international science tests, little is known about how the achievement of students at the top end of the spectrum is being addressed. Since the country sees its future in science and technology and high-ability science students are most likely to be the future creative and innovative scientists, we were interested to find out how the needs of the ablest students in science in New Zealand were being addressed.

Over the last two decades, education in Australasia has seen the shift towards focusing on the improvement of underachieving students through Australia's introduction of the National Assessment Program: Literacy and Numeracy (NAPLAN) and New Zealand's National Standards (Gluckman, 2011; Griffin et al., 2012; Townsend, 2011). There is some concern that high-stakes testing such as that associated with the National Assessment Program: Literacy and Numeracy and National Standards, and to some extent New Zealand's National Certificate in Educational Achievement, may be driving the need to increase the achievement of underachieving students at the expense of meeting the needs of high-achieving students (Hume & Coll, 2008; Jarvis & Henderson, 2015; Jolly, 2015).

This review of over a hundred qualitative and quantitative studies considers the definition and identification of high-ability students, in particular high-ability science students in New Zealand. Of special interest is our focus on whether or not the needs of high-ability students are being met in science education at both the primary and secondary levels in New Zealand schools.

In 2000, the New Zealand Ministry of Education published a resource aimed at supporting schools to identify and make provision for gifted and talented students. Further, the *National Administration Guidelines*(Ministry of Education, 2015) were amended to make it mandatory from 2005 for all state and state-integrated schools to demonstrate how they were providing for gifted learners. Despite this requirement, a national Education Review Office (2008) report found that 35% of primary and secondary schools did not make adequate provision for gifted students. Therefore, the needs of around 35% of the country's high-ability students were not being addressed,suggesting a disparity between policy and practicein high-ability education in New Zealand. What then are the implications of this disparity for high-ability science education in New Zealand?

Methodology

In this systematic review, we began our search by scoping the literature to find out what is known about high-ability students in science in New Zealand. We first searched for published articles and reports from the last ten years, 2005 to 2015, using the key words high-ability, gifted and science students, New Zealand. This did not produce many results other than the Ministry of Education (2000, 2007, 2012, 2015) documentationand the Education Review Office(2008) report, but led us to *Science Education for Gifted Learners* (Taber, 2007). This text devoted a chapter to science education for the gifted in New Zealand,focusing on opportunities for 'gifted science provision' for a learner-centred national curriculum. Two points of interest here – the curriculum this chapter referred to was *Science in the New Zealand Curriculum* (Ministry of Education, 1993) which was replaced by the *New Zealand Curriculum* (Ministry of Education, 2007) in the same year as the publication of Taber'sbook. This source also raised the challenge of identifying high-ability students in science in New Zealand. We broadened our search to include identification of gifted and high-ability students in science and provision for these students in New Zealand schools.

It became clear that there was a paucity of research devoted specifically to high-ability students in science in New Zealand and a decision was made to include international literature in the identified areas, the purpose being to understand how other countries were defining, identifying, and providing for their high-ability science students and, where possible, including all information on these aspects from New Zealand research. Both qualitative and quantitative literature since the year 2000 –the date of the first release of the New Zealand Ministry of Education resource on gifted and talented education – were considered, and accessed by online journal searches through ProQuest, Taylor and Francis online library, Wiley online library, EBSCO host and online search engines such as Google Scholar as well asother libraries. The research questionsfocused on both identification of,and provision for high-ability students.

Research questions:
1. Howdo schools identify high-ability science students?
2. How can the academic needs of high-ability science studentsbe met?

Key terms used in the search were: gifted, high-ability, science, and education.

An initial table of 101 papers was created of all literature that was deemed relevant, and abstracts were accessed and read. This literature pointed to key issues: identifying high-ability students in science; and determining provision by elementary and secondary schools for the learning needs of these students. From the original 101 article abstracts of interest to us, we selected 64 using the previously described criteria. First we read the abstracts and then full papers and the methodologies used in each article, and then created a table where key ideas were summarised. Finally, our findings were synthesised systematically into the two aspects of interest:the means that schools were using to define and identifyhigh-ability students, and the provisions that were being made for these students' science learning.

High-ability in the New Zealand School Context

The term high-ability is used in this review to include high academic achievers as well as those formally identified as gifted and talented. 'High-ability'is adopted to provide a focus on students' ability in science, rather than only using the label 'gifted and talented' which may suggest a range of characteristics across multiple domains, and therefore does not exclusively relateto high-academic ability in science.

Identifying high-ability students of science

New Zealand has no one definition for gifted and talented or high-abilitystudents – leaving this to individual schools – which means, there is no clear definition for identifying high-ability students of science. The Ministry of Education(2012) provides guidelines to support schools in determining a *general*definition, suggesting that a school-based, rather than a national definition allows schools to create their own culturally inclusive definition, reflecting the broad range of values in their communities. The Ministry of Education(2012) also suggest that the following range of criteria be considered in school-based definitions of high-ability: "General intellectual abilities, academic aptitude, creative abilities, leadership ability, physical abilities, and abilities in the visual and performing arts" (p. 23). However, despite the presence of criteria, there is a general paucity of research into the identification of, and provision forhigh-ability students in New Zealand, including those who may be high-ability science students.

In New Zealand and internationally, Nature of Science (NOS) is related to the epistemology of science, and is the over-arching strand in *The New Zealand Curriculum* (Ministry of Education, 2007)and is one of the three aspects that science students need to learn alongside conceptual and procedural knowledge, with the aim of increasing not only their level of scientific literacy, but also the level of pre-professional education (Gluckman, 2011). It is suggested that "anybody who is in any way gifted in science must be on their way to a grasp of the philosophy of the Nature of Science" (Gilbert & Newberry, 2007, p. 18). This sentiment is backed by evidence that an understanding about the NOS is an accurate predictor of a student's present and future assessment performance in science. Bryant et al. (2013) investigated the relationship between11-year old students' ability to control for variables and their future academic performance in science, based on school national assessment results in the United Kingdom. They found that the ability to create a test that controlled variables was accurate at predicting academic success in national examinations, both in the short and longer term (one year and three years respectively). Fair testing as a prediction of high achievement in science was also compared against intelligence quotient to predict high achievement in science and was found to be statistically more accurate at predicting success than test marks alone(Bryant et al.,2013).

It is likely then that the characteristics demonstrated by a student planning their own fair test and control variables could provide an appropriatemeans ofidentifying high-ability students in science in New Zealand schools. These characteristicscould be used to predict current and future academic success in science. However, given concerns raised about the validity and reliability of the fair testing type of investigation that is internally assessed for National Certificate in Educational Achievementgrades in New Zealand,fair testing types of investigation planned by students and not used for assessment purposes could be a better predictor of students' ability to investigate (Author, 2015; Hume & Coll, 2010).It would appear that this option has not yet been explored.

Taber (2007) suggests using a range of characteristics to identify high-ability students in science that more closely reflect the diverse range of characteristics, which is in congruence with the New Zealand Ministry of Educationapproach. Suggested characteristics include showing curiosity, extracurricular scientific interests, intense focus on one area of science, andasking a lot of questions in class. Other indicators may include demonstratinghigh-level cognitive ability and extensive vocabulary, quickly learning detailed concepts, identifying patterns, and making complex links between theories. Showing metacognitive maturity is displayed through a sustained interest and good concentration, producing work of good quality, and demonstrating a deep understanding. According to Taber, the final criterion is leadership, which could include taking on leadership roles. While Taber identifies a range of criteria that can be used in the identification of high-ability students in science, he does not propose specific methods to identify students demonstrating these criteria.One means of identifying students is through teacher nomination(Kornmann et al., 2015) and it therefore seems logical that a science teacher – familiar with the characteristics and criteria such as those identified by Taber– could identify high-ability students in science.

One means of identifying high ability students is through self-nomination (Ministry of Education, 2012). However,this may not be practical for science, due to evidence that students' perceptions of science are skewed based on gender. A 2006 PISA (Programme for International Student Assessment) study in New Zealand found that boys: reported enjoying science more than girls; were more likely to participate in science related activities; and had higher self-belief in science than girls. Girls reported a higher awareness and concern for the environment and held higher expectations ofbeing in a science related career by the age of 30 (Caygill, 2008). This PISA study of fifteen year-old students is particularly important as this is often the age at which science becomes an optional subject.

It would seem that a combination of teacher identification, a broad definition of what it means to be gifted in science,the inclusion of a range of characteristics and metacognitive maturity, alongwith substantive, procedural and epistemological understandings of Science ideas, may provide useful strategies and tools with which to identify high-ability students in science. If concerns relating to validity and reliability of testing are addressed, consideration could also be given to those characteristics demonstrated by a student planning his or her own investigations, thus providing the teacher with evidenceto inform planning to meet students' needs in science.

Provision for high-ability science students

While there is a paucity of literature that specifically relates to provisions for high-ability science students, it is possible to consider the provisions that are identified for teaching and learning of high-ability science students alongside research that has identified effective evidence-based practice for working with high-ability students in general. These practices involve differentiating the learning to respond to student differences (Forster, 2010).

Taber (2007) has identified that there are specific strategies aimed at meeting the needs of high-ability students of science while at the same time acknowledging that the needs of individual students are varied and "it is important that the nature of the learning that is promoted meets the needs of the gifted learners" (p. 13). The strategies described below by both the New Zealand government and literature have been shown to support high-ability students in science (Education Review Office, 2008; Ministry of Education, 2012). A recent New Zealand study (Warmke, 2015) investigated identification and provisions for gifted and talented students in a boys' secondary school in New Zealand. This case studyincluded science amongst other subjects. Warmke asserts that the interrelationship between how giftedness is defined, gifted students are identified, the provision made for them, and evaluation of the programme are critical in understanding the full picture of gifted education. Her views are in congruence with other New Zealand literature, for example, Moltzen (2011) and the Ministry of Education (2012). The following areas of focus have been identified in the literature.

Differentiation

Differentiation is the tailoring of education to the level of the individuals in the classroom. This method of teaching requires the teacher to know the student, their current level of knowledge, their interests, and their prior learning, and to utilise this information to deliver content at the appropriate level and pace of each student (Townsend, 2011). Kronborg and Plunkett (2009) suggest that curriculum differentiation is arguably the most important response to meeting the needs of responding to giftedness.

Differentiation is being promoted as a means of meeting the needs of low-achieving students, 'closing the gap' in Australia (Griffin et al., 2012), and addressing our 'long tail of underachievement' here in New Zealand (Gluckman, 2011). Internationally and in New Zealand,teachers are being trained in curriculum differentiation. Griffin et al. (2012) found that while Australian primary teachers were easily able to volunteer strategies relating to supporting differentiation for low-achieving students, they were not able to differentiate for high-ability students.

Research in America has shown that pre-service teachers who have received training in differentiation in order to meet student needs across a range of domains, shows that high-achieving student teachers have spent more time working with high-ability students than their counterparts who have not received the training (Megay-Nsepoli, 2001). The high-ability differentiation group also reported being more "confident in identifying, assessing, adapting and individualising instruction for academically talented learners" and this led to instances of successful differentiation in the classroom (p. 181). By focusing so much on our long tail of underachievement, we may be overlooking the needs of our high-ability students. However, in New Zealand, Warmke (2015) reports some evidence of successful differentiation in academic subjects. Teaching the strategies to differentiate learning for high-ability students has been shown to be effective at changing teacher practice in the classroom in New Zealand (Tunmer et al.,2015).Perhaps with adequate training and professional development, differentiation could be used to meet the needs of high-ability science students in New Zealand.

Enrichment

"Enrichment, refers to learning activities that provide breadth and depth to regular instruction according to the abilities and needs of the child" (Townsend, 2011, p. 257). In New Zealand, enrichment usually involves in-class work but can also include pull-out programmes (Townsend, 2011; Warmke, 2015). Examples of New Zealand enrichment programmes for science include science fairs, BP technology challenge, Creativity in Science and Technology and Hands-on Science at Otago University, and science competitions (Authors, 2016; Warmke, 2015).

Literature supports the use of after-school programmes and summer schools as ways of meeting the academic and social needs of high-ability students. A review of summer school enrichment programmes run by the National Academy for Gifted and Talented Youth and the Centre for Talented Youth, English and American respectively, found both programmes reported improved student self-direction and increased confidence,with parents reporting increased academic performance (Frost, 2006). This is further supported by research showing after-school homework programmes with qualified staff increase motivation and student achievement (Huang & Cho, 2009).Huang and Cho'sstudy also found both parents and programme instructors reporting positive attitudinal and social changes in the students as well as improved teacher-student relationships.

Able Scientists Collectively Experiencing New Demands is an English after-school enrichment programme, specifically for science students. This enrichment programme is based around the NOS and metacognition, and invites a range of schools to send their most able science pupils to participate during the school term. The programme uses group work and a challenging curriculum to meet the needs of the students with the students reporting positive feedback on what they enjoyed and what they found of benefit in the course (Taber & Riga, 2007).

Hattie's (2009) analysis of teacher interventions showed that almost every strategy a teacher attempts has some improvement in student achievement, and he argues that a small increase in improvement is not enough to justify the promotion of a strategy. This sentiment reflects Townsend's (2011) argument that while there is evidence that after-school and summer school enrichment programmes are effective in meeting the needs of high-ability students when compared to no intervention, they are not as effective as acceleration or the use of both acceleration and enrichment together. Townsend asserts that the "use of enrichment at the expense of acceleration disadvantages students" (p. 252).

Acceleration

Acceleration covers a wide range of strategies that can be broken up into two categories: content based and grade based. Content based allows students to remain with their own age but receive content at a higher grade level (Colangelo, et al., 2010). Grade-based acceleration allows high-ability students to move through the education system faster than peers of a similar age (Southern & Jones, 2004).

At the summation of a case study, Watts (2006) suggests that the use of grade skipping and subject acceleration would be the most relevant types of acceleration to use in the New Zealand school that he studied. Subject acceleration is when students are placed in "classes with older peers for part of the day (or with materials from higher placements) in one or more content areas" whereas grade skipping is when a student is placed in a class which is at a higher grade than their peers of the same age (Southern & Jones, 2004, p. 5). Not only can acceleration such as grade skipping be a more economic option compared to enrichment or differentiation as it avoids the need for the development of expensive pull-out programmes, extra specialised teachers, and fewer years in school, but it has also been shown to increase socio-emotional development and promote academic success (Anthony et al., 2002).

According to Colangelo, et al. (2010), the research on acceleration consistently demonstrates the academic benefits to students.Acceleration may involve a student being placed a full year or more ahead of their peers, the idea being they are learning at their ability level, which may not necessarily be their age level. Benefits of thisincludethe opportunity to socialise with ability peers, rather than age peers.

Importantly, acceleration meets the specific needs of high-ability students in science education at both the primary and secondary levels (Robinson et al., 2014; Venville & Oliver, 2015). Acceleration is veryrarely used in New Zealand; however, there are some documented cases (Riley et al., 2004). While not referring specifically tohigh-ability*science* students, Wardman and Hattie (2012) report that other forms of acceleration used in New Zealand include:"curriculum compacting/telescoping (e.g., two years are covered in 18 months); dual enrolment with tertiary; and early entry to tertiary"(p. 25). These strategies are uncommon and generally schools consider some sort of enrichment to bea better option, and often these classes are incorrectly called 'accelerate' classes. Another example is Watts' (2006) study where both grade skipping and subject acceleration were present in the school that he researched. Subject acceleration was also taking place in some secondary schools in New Zealandin the late 1990s (Authors, 2016; Warmke, 2015).

Internationally there is resistance to acceleration from both parents and teachers (Bain et al., 2007). This resistance often stems from the fear that it comes at the cost of students' social adjustment, it will put stress on the student, or there are concerns that it will not work (Colangelo et al., 2004). However, literature provides evidence that properly considered and evaluated acceleration leads to better social and emotional development (Colangelo, et al., 2010; Townsend, 2011). In New Zealand, Wardman (2009) researched in-service and pre-service teacher attitude towards acceleration and found that contrary to claims made earlier, the participants had positive attitudes towards full year acceleration in secondary schools.

Wardman and Hattie (2012) argue that the able students have little in common with their agepeers. Additionally, a lack of acceleration for highly gifted students can result in social and emotional problems (Feldhusen, 2005). Research in New Zealand suggests that students who are accelerated experienced healthy socio-emotional development, with accelerated students reporting positive self-perceptions, relief from boredom in mainstream classes and increased enjoyment, and confidence and self-worth (Anthony et al., 2002). Evidence also supports the use of acceleration based on academic success in primary school, high school, and university (Colangelo et al., 2004; Kulik, 2004).

Research evidence shows that although acceleration has a positive effect for high-ability students, in New Zealand and elsewhere, enrichment is the choice of uninformed practice(Wardman & Hattie, 2012). In New Zealand, enrichment has been more commonly used and is often dropped when there is pressure on resources (Wardman & Hattie, 2012). Findings suggest that the majority of New Zealand schools prefer to use a combination of acceleration and enrichment (Riley & Bicknell, 2013; Riley et al., 2004; Warmke, 2015).

Finally, whilst conducting this review, it was evident that identification and programming for high-ability science students requires a means of gauging the success of both processes withliterature suggesting thatsuccess can be defined in many ways. Internationally, different programmes aimed at meeting the needs of high-ability students measure their own success by considering student outcomes,for example, academic success (Bryant et al., 2013), and the number of students who select a future career in their specialist area (Feldhusen, 2005) or selecting science-based papers at school or university (Ackerman et al., 2013; Mephie & Mark, 2014). At this time, there appears to be very little evaluation ofoutcomes that are evidence of success, either from schools' definitions of highability or of the resulting provision for high-ability students in New Zealand (Riley & Moltzen, 2011).

Conclusion

This review is restricted by the paucity of New Zealand literature relating to high-ability science students, and as such relies on the use of international literature, limiting the conclusions that can be drawn in the New Zealand context. New Zealand's learner-centred national curriculum and mandatory identification of gifted students is not currently translating to addressing the needs of high-ability science students (Coll, 2007). The New Zealand government has identified a range of strategies supported by evidence as well as inclusive definitions for student identification, yet these do not often translate to best practice in the classroom (Education Review Office, 2008; Ministry of Education, 2012). There is not enough research into the provision of science in New Zealand for high-ability students to draw any valid conclusions; however, if provision for high-ability students in science is consistent with the provision of education for high-ability students in general, then the majority of these students are not having their needs met. Research suggests that educating teachers on how to meet the needs of high-ability students is effective, and teacher professional development and teacher training in this area may have a desirable impact on both its provision for high-ability science students and changing teacher attitudes regarding the most effective strategies (Megay-Nsepoli, 2001).

This review aimed both to determinehow schools identify high-ability science students and to consider the range of provisions for these students in the New Zealand context.What is clear is that in order to gain a fuller picture of the still emerging provisions for high-ability science students in New Zealand, it is important to consider both national and international literature that describes evidence-based practices to first identify, and second to support these learners. With the well-documented importance of ensuring that high-ability students receive a curriculum that is commensurate with their capabilities, and government policy requiring mandatory reporting of provisions for gifted and talented students,it seems obvious that all schools have a responsibility for being wellinformed about their options in relation to identifying and meeting the needs of their high-ability science students.

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