“Inspire me” - High-ability students’ perceptions of school science

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ABSTRACT

A decline in the number of students opting to study science in high school is a matter of international concern, particularly in relation to students who demonstrate high academic ability in science. These high-ability students have the potential to be the innovators and leaders of the future. There is a paucity of research that provides insight into how schools address the motivational and learning needs of high-ability science students. Underpinned by a constructivist view of learning, this exploratory case study research used student questionnaires and focus group interviews to explore students’ views about their learning experiences in science. It investigated high-ability students’ perceptions of how their needs were being met. Findings indicate that these students generally experienced a wide range of teaching approaches across all science disciplines. Learning was mostly limited to science content and procedures with little evidence of students learning about how science works through Nature of Science.

KEY WORDS: High-ability students; science; learning; acceleration; choice

INTRODUCTION

Inspirational New Zealand scientist, the late Sir Paul Callaghan, spoke of his interest in science, which emerged after hearing Nobel Chemist Alan MacDiarmid speak. According to Callaghan, MacDiarmid:

> … touched audiences. I realized people were interested in science, but there was a framework in which you had to operate to make it interesting, to tell them stories, to give them a thought about where we are going in the future, what the possibilities for our country are (MacDonald, 2012, para. 38).

Countries aspiring to foster future scientific talent should consider how the needs are being met for those students who have the capability to become the scientists of the future. Arguably, these are students of high academic ability. While a range of programs and practices exist designed to meet the needs of these students (Colangelo et al., 2010; Gagné, 2015; Kaul et al., 2015; Olszewski-Kubilius et al., 2017; Wardman and Hattie, 2012), it appears that not all science students are recipients of these (Taber, 2016). For example, studies into practice across New Zealand Education Review Office (ERO, 2008) and Asia (Ibata-Arens, 2012) revealed that not all high-ability students have access to programs that provide content commensurate with these learners’ needs. ERO (2012) identified different levels of support for these learners in New Zealand schools, highlighting the importance of “challenging in-class provision” (p. 54). In this study, we investigated high-ability science students’ perceptions of the programs and practices they perceive to have encouraged and informed their learning. We discuss their responses in the light of relevant literature about the science curriculum and science learning.

The Terminology

Whereas other studies may use the term “giftedness” to addresses a range of behaviors, this study specifically focuses on perceived academic ability in science. Therefore, students in this study are identified by teachers as students of “high ability,” a phrase used to describe those who have been informally or formally identified as high achieving.

“Practical work” relates to all hands-on activities where practical work is used by students to make links between what they observe (objects and materials) and science ideas (Abrahams and Millar, 2008). Experiments are practical activities used to test theories and ideas. In the United Kingdom, Australia, and New Zealand, the term “science investigation” is used, and in the United States, “science inquiry” is more commonly used where students identify a question and use both conceptual and procedural knowledge to gather, process, and interpret data to make evidence-based conclusions (Millar, 2011).

High-ability Students

As previously stated, in this article able science students are referred to as “high ability” students rather than gifted students, as identifying giftedness requires a range of testing (e.g., Lupkowski-Shoplik and Swiatek, 1999; Swiatek, 2007) that was not part of the practice in these classrooms (Horsley and Moeed, 2017). Further description of these learners, suggests that in comparison to average ability students, high-ability students are quicker thinking, more flexible in their use of strategies, demonstrate better memory, are more knowledgeable, and prefer complexity (Scager et al., 2014). High ability may present differently in a range of contexts, assuming a role described as "social construction" (Borland, 2009. p. 237).

While it is mandatory for all state and state-integrated schools in New Zealand to demonstrate how they provide for gifted learners, an ERO (2008) report revealed that most primary and secondary schools have failed to make adequate provision for these students.

Important Understandings about School Science Education

Internationally, four goals for science education most commonly cited in literature include conceptual, procedural, nature of science (NoS) understandings, and scientific literacy. Such education would enable students to make informed decisions about socioscientific issues in their everyday lives (Hodson, 2014). The New Zealand science curriculum has a social constructivist approach to learning. This theory suggests that knowledge is personally constructed but socially mediated (Hodson and Hodson, 1998; Piaget, 1952; Posner et al., 1982; Solomon, 1987). Learning is conceptualized as linking or connecting new ideas with prior understandings and replacing any existing misconceptions. This process requires a degree of motivation as new understandings require either changing existing understandings, or abandoning misconceptions (Driver et al., 1994).

Teaching strategies for implementing a constructivist orientation in the classroom are described in detail in the literature (e.g. Appleton, 1993; Baviskar et al., 2009). In nearly all constructivist strategies, examination of pre-existing student knowledge (Naylor and Keogh, 1999; Sewell, 2002), explicitly addressing motivation to learn (Sewell, 2002), and reinforcing the new knowledge by putting it to use (Vermette and Foote, 2001) are important features.

According to The New Zealand Curriculum (NZC) (Ministry of Education, 2007), conceptual understanding means learning science content relevant to the living, physical, and material worlds, and about Planet Earth and Beyond. Procedural understanding refers to the skills and processes and how and why particular procedures are followed. The term "conceptual understanding" is used to differentiate it from conceptual knowledge, which is easily accessible and can be rote learned; understanding relies on the construction of personal meaning from the knowledge that is presented or accessed. Similarly, procedural knowledge implies a recipe approach, which appears to be the common experience of students in school science in New Zealand (Hipkins et al., 2002). NoS explains how science works and students learn about the practices that scientists use to create new knowledge.

In the NZC, the much referred to practical and hands-on science concerns itself with two sub-strands - understanding about science and investigating in science. It is expected that while investigating in science, students will engage in a variety of approaches to scientific investigation. Most international curricula suggest science inquiry or investigation is a useful pedagogical approach. Practical work is promoted and practiced in many countries; however, what students learn from practical work is a topic of much debate in the literature. Hodson (1990) argues that, at best, through practical work students discover what the teacher already knows. Abrahams and Millar (2008) assert that as practiced in school science, practical work is ineffective, though Millar (2010) advises how practical work can be made more effective. More recently, Osborne (2015) argues that "the defining feature of science is that it is a set of ideas about the material and living world. Moreover, although experimentation is an important feature of science, it is not the defining feature" (p. 16). Further discussion on the effectiveness of practical work is beyond the scope of this paper because we were investigating students' views and did not make classroom observations or collect data to be able to comment on the effectiveness of practical work.

Engaging very young students in science is recognized as an important element in generating life-long interest in this area (Organisation for Economic Co-operation and Development, 2008). Identifying topics and concepts that student *want* to learn about is also critical to engendering their interest and enjoyment in learning (Mulqueeny et al., 2015; Slavit et al., 2016). So too is creating curiosity and interest in learning, thus motivating and enthusing those students of high academic ability who may be at risk of becoming bored and underachieving (Landis and Reschly, 2013; Rubenstein et al., 2012).

REVIEW OF LITERATURE

High-ability Students in Science

Effective science education aims for all students to learn science content alongside developing an understanding of NoS with a focus on increasing the level of public scientific literacy as well as pre-professional education (Gluckman, 2011). High-ability science students, therefore, require not only high levels of content knowledge but also a strong understanding of the NoS. As Gilbert and Newberry (2007) suggest, "anybody who is in any way gifted in science must be on their way to a grasp of the philosophy of the NoS" (p. 18). Taber (2007) concurs, suggesting that teaching NoS provides an opportunity to "engage and challenge those learners who are judged to be gifted in science" (p. 94). He defines high-ability science students both specifically and pragmatically as:

> …those students who, given appropriate support, are able to either achieve exceptionally high levels of attainment in all or some aspects of the normal curriculum demands in school science….or undertake some science-related tasks at a level of demand well above that required at that curricular stage (Taber, 2007. p. 1).

Taber cites a range of characteristics to identify students showing curiosity, extracurricular scientific interest, an intense focus on a particular area of science, and those asking a lot of questions in class. High-ability science students may demonstrate a high level of cognitive ability and extensive vocabulary, they are quick at learning complex concepts and identifying patterns, and they can make complex links between theories. Showing metacognitive maturity is displayed through sustained interest and good concentration, producing work of high quality, and demonstrating a deep understanding. Taber suggests that these students may also show leadership, and there ought to be an opportunity for them to assume leadership roles.

Interest, Engagement, and Enjoyment

Motivation is considered both a pre-requisite and corequisite for learning. Interest, engagement, and enjoyment are useful indicators of motivation (Palmer, 2009), and this is particularly salient when considering first, high-ability students, and second, student motivation to continue with science when it is no longer compulsory. As Sir Paul Callaghan commented, there is a need to engage student interest in science through the provision of a sense of the important role science plays in their future (MacDonald, 2012).

Interest is an effective motivator (Pintrich and Schunk, 2002) and therefore, a key driver in retaining students' interest in science. When comparing gifted and non-gifted students' interest in science learning, Kahyaoğlu and Pesen (2013) found that gifted students were more competitive, more willing to participate, and more enthusiastic toward both dependent and independent learning. Rubenstein and Siegle (2012) highlighted the importance of teachers differentiating the learning for gifted students to ensure students remained interested and motivated. This idea aligns with multiple studies that identify the importance of motivation in relation to those students of high academic ability who may be at risk of becoming bored and underachieving (Landis and Reschly, 2013; Rubenstein et al., 2012). Palmer (2009) found that a lack of motivation prevalent amongst science students limits what they learn. He argues that learning that is personally relevant, novel, involves long-term engagement, and that offers "meaningful choice" is more enduring than situational interest. Palmer sees situational interest as short-term interest generated by a particular situation. For example, experiments that produce a "wow" factor can create short-term interest for students who might otherwise not be interested.

Internationally, science-enriched programs to target high-ability students have been found to have a positive effect on student attitude toward science. After returning to their regular schools following attendance in summer enrichment programs, participants reported positively on the "splashdown effect," citing positive gains in relation to their motivation and confidence in science (Stake and Mares, 2005). This was especially evident where the participants returned to schools with low-achieving peers. An Australian study of high-ability science students found that targeted enrichment programs transformed the students' positive attitudes toward science into a passion for the subject (Oliver and Venville, 2011).

A study of year 11 students in a New Zealand high school revealed that "engagement, variety, and novelty of task were factors that influenced student motivation to learn science investigation" (Moeed, 2015. p. 37). Students were engaged in tasks that offered variety and provided motivation by presenting opportunities to work with friends as they moved around the laboratory. Interestingly, repetition of the investigation was not motivational even when the activity had an element of fun. Moeed (2015) identified that for at least "one capable student who was almost always positive and engaged, this type of task was not motivational at all. He knew the answers and considered it a waste of time" (p. 37). This could suggest that this student's needs had not been properly assessed, his interest in learning was not ignited and; therefore, the learning was not new and held little interest for him. Potentially, this high-ability student's lack of interest in the task could lead to his underachieving. As Benny and Blonder (2018) identified, students require assistance to enable them to demonstrate excellence and this student did not appear to be the recipient of a curriculum that was commensurate with either his ability or interest.

Choice

The role of choice in motivating high-ability students to learn is documented in relation to tying student motivation and learning to differentiation, acceleration, and enrichment activities (Gentry and Springer, 2002). Choice is identified as motivating to students' learning and well-being; needing to relate to the students' interests (Katz and Assor, 2007); and both well designed and meaningful (Evans and Boucher, 2015). However, providing students with choice can impact negatively on teachers' perceptions of teaching and learning as some may feel threatened by the loss of control if they provide choices (Flowerday and Schraw, 2000). In experiments designed to measure the effect of student choice on cognitive engagement and attitude, Flowerday and Schraw (2003) found that choice had a positive effect on student attitude and effort. Furthermore, choice - as a component of differentiated learning activities - supports student interest and motivation, which assists in retaining the interest of high-academic ability students (Rubenstein and Siegle, 2012).

Meeting Needs

Two oft-debated means of meeting the needs of high-ability students are enrichment and acceleration along with motivation and relevance. Enrichment "refers to the provision of learning opportunities that give depth and breadth to the curriculum in line with students' interests, abilities, qualities, and needs" (Ministry of Education, 2012. p. 59). A seminal definition of acceleration suggests it "is progress through an educational program at rates faster or at ages younger than conventional" (Pressey, 1949. p. 2). Debate exists around the implementation of these two provisions, with research identifying teacher preference for acceleration and administrator preference for enrichment (Wardman and Hattie, 2012), support for enrichment (Kaul et al., 2015), support for using both enrichment and acceleration (Ministry of Education, 2012; Olszewski-Kubilius et al., 2017); and the promotion of planned acceleration supported by policy (Colangelo et al., 2010).

Hattie's (2008) meta-analyses of more than 50,000 studies relating to education achievement identified acceleration as being more effective than enrichment in terms of students' achievement, with an acceleration effect size of 0.88 and an enrichment effect size of 0.39. Interestingly, researchers found that successful interventions for high-ability "minority students" could include both acceleration and enrichment or, solely enrichment. After experiencing both acceleration and enrichment from third to eighth-grade under-represented minority groups that included African-American and Latino students, out-performed their peers from their local school districts (Olszewski-Kubilius et al., 2017). The Kaul et al. (2015) study involving minority students in a summer enrichment program identified positive effects across a range of indicators, including social, emotional, motivational, and academic outcomes. Clearly, there are differing perspectives on which intervention is most effective with different measures identifying "success" for these students.

There is evidence to show that all schools need to provide differentiated programs for high-ability learners to experience, and these are often within the students' regular classroom (Heald, 2016). However, what is also evident from the literature is that while high-ability students require and is entitled to "real intellectual challenge," this is often overlooked (Taber, 2016. p. 10). An example of this is in one report auditing gifted and talented practices identified that only 42% of those schools reviewed used enrichment or acceleration, or a combination of both, and had "*highly* responsive and appropriate programs and provision" or "*appropriate* programmes and provision" for their gifted students (ERO, 2008. p. 77). Taber (2016) suggests that this lack of appropriate programming for our high-ability students is often absent in science classes.

METHODOLOGY

This project was situated in New Zealand where the government has mandated that each school board must identify gifted and talented students (Ministry of Education, 2015) and develop programs to meet these learners' needs (Ministry of Education, 2012). Aimed at investigating high-ability students' perceptions of science learning, the research was underpinned by the constructivist theory of learning that assumes learning will take into account the context and students' prior knowledge. In this qualitative study, data were collected through student questionnaires and focus group interviews. This exploratory case study aimed to gain an understanding of the phenomenon of science education for high-ability students in four high schools. Merriam (1998) defines a case study as an "intensive, holistic description and analysis of a single instance, phenomenon, or social unit" (p. 27). She explains that the case study is appropriate for studying educational practice with the intention of improving practice. Stake (2005) suggests that an intrinsic case study is appropriate where a researcher wants to understand a case more clearly. We took an intrinsic case study approach as we were interested in understanding how highly capable science teachers are addressing the science learning needs of their high-ability students. Four highly capable science teachers were purposefully selected from a list of teachers educated at a large New Zealand university. These teachers had received Excellence in their Teaching Certificate on graduation based on their high-grade point averages, thereby fulfilling our criterion of being highly capable teachers.

The boundary of the case was defined by the four selected teachers and students who they considered highly able in each of the classes they taught. We have offered a rich description (Geertz, 1983) of the analyzed data gathered through student interviews. The intention was for this exploratory study to be scaled up in a subsequent research project. The teachers were asked to identify students from each of their classes who demonstrated high ability in science. 96 students were offered the opportunity to participate in the questionnaire, with 56 (58%) (29 males and 27 females) ranging from year 6 to year 12 (10 from year 6, 18 year 7; 7 year 8; 18 year 9, and 3 year 12) doing so.

The questionnaire was designed following a review of the extant literature relating to both science (Gilbert and Newberry, 2007; Oliver and Venville, 2011; Taber, 2007; 2016) and high academic ability (Benny and Blonder, 2016; Hattie, 2008), and was first trialed with high-ability maths students before making it available to science students. Students were asked to provide examples of science-related activities they performed, the teaching and learning strategies their teachers used, and practical activities they had participated in, and to describe what they perceived they had learned from these practical activities, including the science content they found enjoyable and/or challenging. Further questions elicited suggestions for performing at the highest possible level, consideration of any barriers to becoming a high achieving student in science and describing any opportunities to study at a higher level than their cohort.

Group interview questions built on the questionnaire questions and enabled the researchers to follow-up responses that had emerged from the questionnaire. Each participating teacher helped to organize a group interview involving five or six high-ability students in their classes.

Following ethical approval, the questionnaire was hosted in Qualtrics, an online questionnaire tool with the capability of collecting and analyzing data using an array of tools. In this instance, data were filtered and initially grouped across subject areas (e.g. biology and physics), then student responses relating to their perceptions about their science learning were coded according to the emerging themes and concepts related to high-ability science students and their perceptions of their science learning. The coding was completed by one researcher for consistency and was member checked by a colleague, and the other researcher. Using a constant comparison approach, which occurred across questionnaire data and student interview responses, there was agreement on the codes between the two researchers. Coding was an iterative process, enabling the researchers to develop labels that were further considered on each return to the data (Charmaz and Belgrave, 2012).

Group interviews were conducted by one of the research team and were audiotaped and transcribed. These were read and re-read, identifying emerging themes. Representative quotes are those that expressed similar views by more than one participant.

We were interested in the alignment between what students were experiencing in terms of academic provision, what they perceived they were learning, and requirements of the curriculum. The research questions were:

1. What do high-ability students perceive they are experiencing and learning in science?
2. What facilitates or inhibits learning science at a high level?
3. What enrichment or acceleration opportunities are available to high-ability science students?

RESULTS OF STUDENT QUESTIONNAIRES AND INTERVIEWS

The results are presented according to the responses to the questions in the survey and interviews and later discussed as the emergent themes.

Student Experiences and Learning in Science

Science-related activities

There were a total of 100 responses from the 56 participants, as some provided more than one response. Some students named the subject in which they had done the practical activities; for example, some said Biology (n = 15), others Chemistry (n = 10), Physics (n = 10), and Astronomy (n = 5). These are represented in Figure 1 as Physics, Chemistry, Biology, and Astronomy. However, a large number of students gave specific science content within these sciences; for example, a student said nuclear physics rather than just physics. The specific responses were coded and are reported in Figure 1 as separate sub-categories. For example, within biology, there were cell processes, enzymes, and dissection of sheep hearts, and lungs and cows' eyes. Similarly, chemistry related activities included metal, acids and bases, and chemical reactions. In physics, they listed light, energy, and electricity. The examples are useful in that they provide insight into the topics covered in science. Overall, total activities for physics were nuclear physics 1, electricity 1, velocity 1, mechanics 2, energy 2, light 5, and physics 10, a total of 22 responses. Similarly, the total responses for chemistry were 25, but biology had the most responses (55). Astronomy had only five responses, and no specific areas within astronomy were identified.

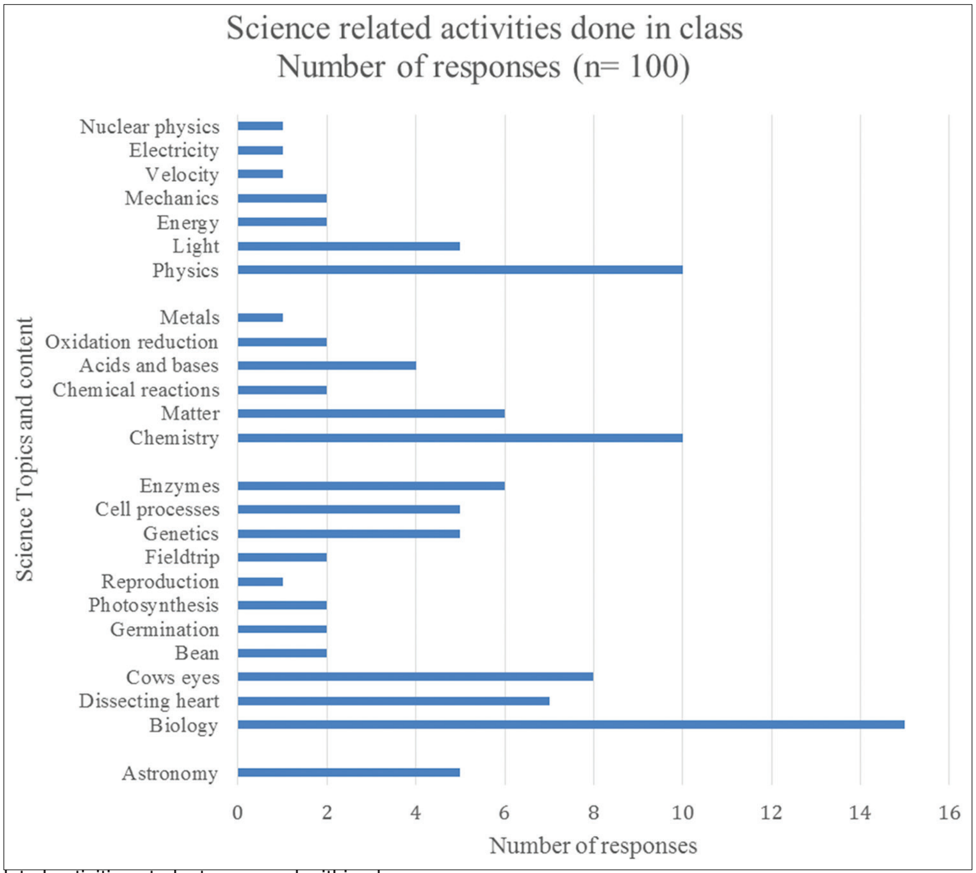

Figure 1: Science-related activities students engaged within class

The following quotes are representative of a number of responses and describe the science activities students experienced:

> We use the brain in a variety of ways, with practicals involving sheep brains to demonstrate vulnerability of the brain, which was interesting and exciting. We dissected a sheep's heart, which enabled us to visualize the real-life appearance and proportions.

Students described the range of activities including:

> Performing experiments with alkali metals in water, dissecting a heart, looking at the structure and function of neurons, looking at the vulnerability of the brain without its layers of protection.

Further comments about what students had experienced included using Play-Doh to make models of cells, games for gene expressions and genetic variation, quizzes, and hands-on activities. It was evident that students recalled a wide range of activities that encompassed numerous pedagogical approaches to learning content.

Science Learning Strategies that High-ability Student Experienced

Analysis of student responses also showed that they experienced a range of learning approaches in their science lessons. They gave more examples of practical work they carried out (n = 19) than of other strategies such as online activities (n = 5). These findings are presented in Figure 2.

Science content that students found enjoyable

Students offered many specific examples of science activities they enjoyed. These have been coded under specific subjects (Figure 3). Separate coding was used to show where students chose to only write the word practicals rather than provide an explanation of what the practical sessions involved.

Enjoyment of practical work

Many students said they enjoyed dissecting; they also enjoyed chemistry and physics practicals and being allowed to work at their own pace:

> I really enjoyed dissecting the heart, as it was not only interesting but also very educational, and made my passion for science even greater.
>
> I enjoyed learning about the eye and how it works. We are halfway through our "Matter Matters" topic, and I'm really liking it.
>
> Practicals and working through the textbook at my own pace and given pages to complete.

Completing chemistry and physics practicals

Most students recalled a science experiment they had enjoyed. Responses indicated a range of practical activities, including dissections, identifying starch in food, sliding an object downhill to test velocity, and mixing a range of chemicals. However, there were also students who commented that they experienced little practical work. For example, one student explained that practical work at his school comprised worksheets and another suggested that science was not a big thing at their school.

When asked why they enjoyed experimentation, student responses included:

> We were learning something, which was not in lecture format. It was practical. After the necessary safety briefs, we were straight into science! I believe enjoyment cannot be attempted to be generated from a "boring" lecture but will automatically fill the classroom if it is genuinely fun.

What Students Said they Learned from Doing Practical Work

When asked what students learned from their practical work, a large number of responses (n = 49) indicated particular science content (Figure 4), most (n = 37) relating to the conceptual

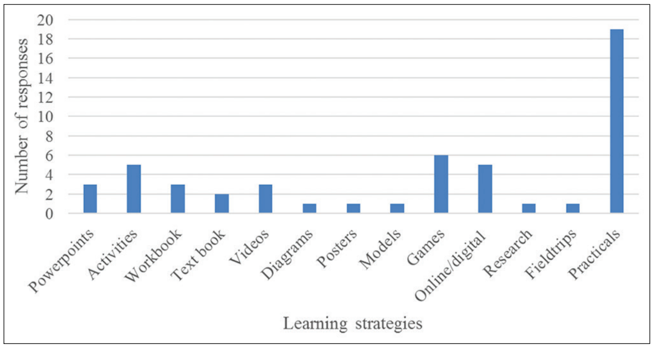

Figure 2: Variety of learning strategies experienced by students

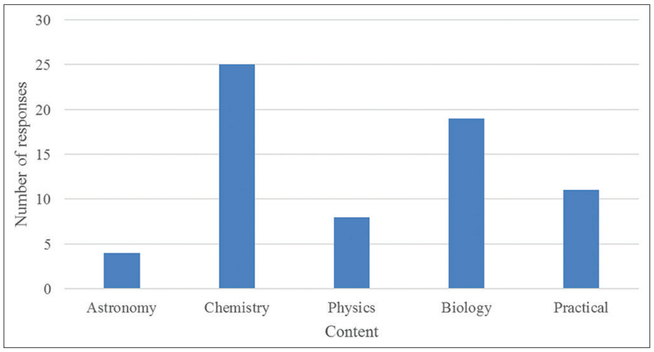

Figure 3: Students' responses about the science content they enjoyed

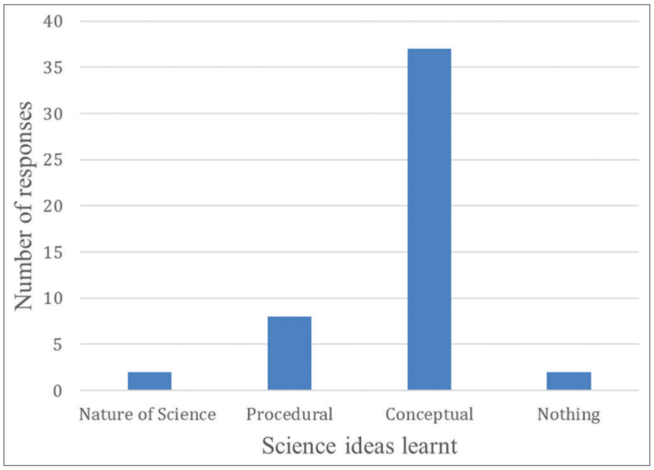

Figure 4: What students said they learned from practical work

understanding of science content. Eight specified learning of a procedure; for example, how to light a Bunsen burner. Two responses showed some understanding of the NoS, and the following response shows that the student had carried out an investigation, made observations, and offered an explanation:

> I learned that you do not need light to grow a seed, because the process of germination happens underground with no light.

Other students explained the science ideas they had learned:

> I learned how electricity behaves when passing through your body, and it cannot get to the ground. I also learned about friction being used to separate electrons.
>
> As the concentration of hydrogen peroxide increases, so does the rate of enzyme activity, up until enzyme activity starts to plateau, as the amount of hydrogen peroxide particles is more than the amount of enzyme active sites, so the rate of reaction can no longer increase.

Although some students wrote responses that indicated they understood what they were talking about, it was unclear what it was that they had learned:

> This experiment made it a lot easier to picture how the different organs in a creature relate to one another. It highlighted how each organ fits with the next and showed how every animal and creature differs from others as well.

A couple of students said they did not learn much from doing the practical and it appears there was another kind of learning for at least one student:

> I learned that patience will go a long way in any science class, especially Chemistry. And that higher-level science experiments can be both educational and entertaining in the right context.

In response to other questions, students suggested that they were not only doing science but also learning science ideas as well:

> I enjoyed dissecting the cow's eyeball for the light and sight topic. Although it was disturbing, I got to not only learn the different parts of the eye, and where they are and how they work, I also got to feel what they feel like and see how it looks in a real-life object.
>
> We used enzymes from potatoes to watch peroxidase break down into water and oxygen.

Science content students said they found challenging

In the questionnaire, 50 students identified areas of science they found challenging. Most students said they found physics ideas more challenging to understand (n = 23) than chemistry (n = 14) or biology (n = 6), which appeared to be the least challenging (Figure 5).

Similarly, during the focus group interviews students talked about what they found challenging in science, for example:

> I found the light and sight topic most challenging because we did not have much time on it before the test meaning I did not understand it as much as I could have.
>
> I do not really find any parts of science particularly challenging; however, I find it hard to be concise when answering questions.
>
> While I did like physics, I also found it was my most challenging subject this year. Physics, as some of the principles are hard to get your head around.

Facilitators and Barriers to Achieving in Science

Students' views about high-level achievement

When asked what they could do to achieve at the highest possible level, students offered over 60 responses. Some of these were general, for example, studying (n = 9), listening (n = 8), and working hard (n = 5). Other things that would help to achieve at the highest possible level included practicing, revising, getting involved, doing practicals, and using assorted learning strategies. More specifically, the following quotes are insightful:

> Do not just think about it in class and do not think it has to be applied to questions only; the possibilities are endless.
>
> I think doing all of the work set in class as well and making sure you do some work outside of school as well is extremely important when wanting to achieve highly. In science, it's especially important to make sure you fully understand the concepts and so memorizing definitions and understanding them is key as well.
>
> Go to extra science classes after school, complete everything in class to a higher standard than asked. I would like extra classes that specify in different units not in class because I think that would help too. Teachers could spend extra time with those striving for higher grades after class or giving them extra work with the same level of interest.

This student had advice for the teachers:

> Actually, give a damn and remember that they are there to learn, not there to mess around. At the highest possible level, likely it would be best to allow students to partake of their own investigations, limitedly, so they find something that interests THEM, so they will put more effort into it.

And perhaps advice for the school:

> Have a teacher that inspires the students to learn and someone that has a passion for the topic and the job.

Barriers to becoming a high-achieving student

Students provided their views about possible barriers that prevented them from achieving to a high level. These are broadly grouped as high-achieving student related, peer-related, and teacher related. Some students suggested that they

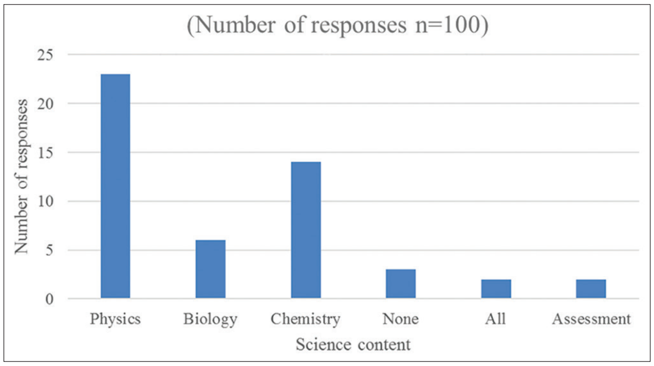

Figure 5: Science content students reported as challenging

were inattentive in class, did not have a personal interest in the topic, did not find the content engaging, or did not give their studies the time required.

> Time, listening, and personal topic interest/mind frame/boredom.

Some acknowledged social barriers like:

> Being too self-conscious or shy to ask for help, as some students find it hard to ask in front of their peers.

The most common reason offered (n = 13) was the negative influence of peers in the form of distraction. For example:

> The class being disruptive and not communicating well with the teacher (my classroom is exactly like this, and it's very challenging to learn).

Some perceived not getting enough support from the teacher, the teacher not having enough content knowledge, not being able to manage the disruptive students, and not following up on set homework as barriers for students wishing to achieve at a high level:

> …not having a science teacher that is good enough. The only thing setting me back is that there is a limit to how hard your questions and education can be each year.

Students' Views about Acceleration and Enrichment

Students were asked if they were aware of their teachers providing enrichment or acceleration opportunities, for example, accessing content ahead of their peers or doing out-of-class science-related activities. 16 students said they were being given these opportunities; of these, eight said they were being accelerated, and eight said they had experienced enrichment. However, the students did not show an understanding of what enrichment was:

> In our science class, if we do really well in class, then we get small rewards such as chocolate and fossils.

One student acknowledged support from the teacher and saw this as enrichment:

> The teachers at our college will give those who want to do well in class the opportunities they need to do so. They will even give up their free time to help someone achieve the best they can.

Those students who talked about acceleration said they were offered the opportunity to work with a higher cohort in particular subjects:

> …making higher level classes (e.g., Year 13 subjects while in Year 12).

> High achieving students can do upper years' work out of class.
> Year 12 students are able to take year 13 scholarships, some talented year 11 students end up in year 12 calculus classes.

It was evident from student comments that those who identified that they had received either enrichment or acceleration were unable to describe enrichment activities but could identify where acceleration had occurred. In these instances, students referred to accessing content a year ahead of their peers.

DISCUSSIONS

The study aimed to elicit high-ability students' perceptions of their experiences in science classes. Our findings are discussed using indicators from literature that identify key components of a program designed to meet the needs of high-ability science students.

First, these high-ability students identified the science activities they enjoyed, those activities they found challenging, and what they learned. Practical and hands-on activities were more enjoyable than those that required reading from a textbook; for example, opportunities to dissect were popular, as was the chance to mix chemicals to observe reactions. However, while most students identified opportunities to engage in practical work, there were a few who did not, citing little opportunity to experience practical work and the provision of worksheets.

Second, students described experimentation as a "fun" activity. Palmer (2009), Moeed (2016), and Burrell et al. (2017) identified the role of motivation in learning science, with Moeed (2016) reporting that engaging in novel tasks and the variety of experiences were factors that influenced students' motivation in science. Student engagement in and enjoyment of tasks are essential components in programs designed for high-ability students. Without motivation, these students become bored and are at risk of underachievement (Landis and Reschly, 2013; Rubenstein et al., 2012).

Third, students' practical work involved mostly exploration and observation. Although they enjoyed practical work, there is little evidence of their learning a variety of approaches to scientific investigation as required by the curriculum (Ministry of Education, 2007). Enjoyment of science learning is an important part of motivating high-ability students, but these students also require experiences that enable them to demonstrate high-level cognitive ability (Taber, 2007).

Fourth, these students learned ideas related to science content, but their responses showed little evidence of learning about the NoS ideas. As students gifted in science require a strong understanding of NoS (Gilbert and Newberry, 2007), this is concerning as NoS is the overarching strand of the NZC (Ministry of Education, 2007). As Taber (2007) identified, high-ability students require opportunities to be engaged and challenged through the NoS to achieve exceptionally high levels of attainment. That said, there is little evidence that NoS is understood by science students internationally.

Fifth - and in contrast to the literature (Abrahams and Millar, 2008; Hodson, 1990; Osborne, 2015) - some of these students learned science content through engaging in practical work and provided evidence of long-term retention of their learning. Data suggest that students experienced a broad range of topics across all science disciplines, although more experiences were cited in Biology and Chemistry (Figure 1). Further, the interviews revealed that learning was limited to conceptual knowledge (facts) rather than understanding.

Sixth - there was little evidence of students gaining procedural understanding although they followed instructions to carry out the practical activity. Engaging in a single practical activity is unlikely to lead to the learning of science ideas (Millar, 2004). High-ability science students need opportunities to develop procedural understanding and to design and carry out their own investigations. There was no evidence of students designing and carrying out their own investigation, and at least one student stated that they were looking for such an opportunity.

Seventh, whereas choice - in the form of differentiated learning - is advocated for high-ability students, it did not appear as a feature of the students' learning in this study. As already noted, at least one student suggested it would be great to carry out investigations where they had the choice to decide what they wanted to investigate. Differentiated learning is a key component of effective teaching and learning for high-ability students, with acceleration identified as more effective than enrichment (Hattie, 2008). The provision of choice through differentiated learning opportunities is motivational for high-ability students as it can provide them with learning experiences that align with their interests (Katz and Assor, 2007). Differentiation may be offered through enrichment and/or acceleration practices. However, most of the students in this study who were identified by their teachers as students of high academic ability in science were unaware of receiving either acceleration or enrichment. Some students referred to acceleration, identifying that it was possible to take classes the year ahead. Enrichment activities were less clearly understood, with the suggestion that these related to edible rewards for doing well or to support from a teacher. Evidently, there was some confusion amongst those who indicated they had participated in acceleration or enrichment classes. Without differentiation, there is concern that students of high academic ability may not receive curricula commensurate with their ability and they are at risk of not receiving a real intellectual challenge (Taber, 2016) and of underachieving (Rubenstein et al., 2012).

Eighth, student advice to those aiming to achieve at the highest level in science included awareness of the negative influence of some peers and of the need to work to the highest standard and make sure concepts are fully understood. Students suggested that teachers have a role to play, recommending that teachers of high-ability science students need to be willing to offer time outside of class to help students achieve higher grades. There was also a suggestion that those teachers working with high-ability students need to be inspirational and passionate about teaching. This idea aligns with findings from successful high-ability scholarship students who also identified the need for teachers to be passionate and knowledgeable about the subject they were teaching (Horsley, 2012).

Finally, most high-ability students in this study enjoyed many aspects of their science classes, particularly those classes that involved practical work. While enjoyment is a component of motivation, there are additional essential components of science education for high-ability learners that student did not identify. High-ability science students require strong intellectual challenge and a deep understanding of how scientific knowledge is created, validated, and disseminated. There was little evidence that students had the opportunity to be creative in designing investigations, gather reliable data, engage in critiquing the evidence, or in the design of their investigations.

CONCLUSIONS

This study identified aspects of high-ability science students' learning that will require further research. These aspects included the link between the science curriculum and high-ability students, and specifically, how NoS can be taught to support high-ability students to become creative and critical. While exploring the perceptions of only a small group of students, these findings suggest that further research is needed by curriculum developers, policy makers, and those charged with the implementation of these policies. In sum, these high-ability students engaged in a broad range of practical activities that they enjoyed. They have stated that these practical experiences were one of their preferred pedagogical strategies. Evidence suggests that while some students' motivational needs were being met, it is less clear whether they were learning what literature suggests high-achieving students ought to learn.

As Taber (2007) identified, these high-ability students require appropriate support to fulfill their promise to become students from whom we can expect exceptional levels of attainment. Without opportunities to engage with NoS, students are potentially missing the academic challenges with which high-ability students ought to be presented. If these students are destined to become the scientists and leaders of the future, we need to ensure they receive an education abundant in opportunities for extending and enriching their knowledge of science.

REFERENCES

Abrahams, I., & Millar, R. (2008). Does practical work really work? A study of the effectiveness of practical work as a teaching and learning method in school science. *International Journal of Science Education*, 30(14), 1945-1969.

Appleton, K. (1993). Using theory to guide practice: Teaching science from a constructivist perspective. *School Science and Mathematics*, 93(5), 269-274.

Baviskar, S., Hartle, R.T., & Whitney, T. (2009). Essential criteria to characterize constructivist teaching: Derived from a review of the literature and applied to five constructivist-teaching method articles. *International Journal of Science Education*, 31(4), 541-550.

Benny, N., & Blonder, R. (2018). Interactions of chemistry teachers with gifted students in a regular high-school chemistry classroom. *Chemistry Education Research and Practice*, 19(1), 122-134.

Borland, J.H. (2009). Myth 2: The gifted constitute 3% to 5% of the population. Moreover, giftedness equals high IQ, which is a stable measure of aptitude: Spinal tap psychometrics in gifted education. *Gifted Child Quarterly*, 53(4), 236-238.

Burrell, M., Horsley, J., & Moeed, A. (2017). Identification of, and academic provision for high-ability science students: What does the literature say? *European Journal of Science and Mathematics Education,* 5(2), 110-118.

Charmaz, K., & Belgrave, L.L. (2012). Qualitative interviewing and grounded theory analysis. In: Gubrium, J.F., (Ed.), *The SAGE Handbook* *of Interview Research: The Complexity of the Craft.* London: Sage. pp. 347-366.

Colangelo, N., Assouline, S.G., Marron, M.A., Castellano, J.A., Clinkenbeard, P.R., Rogers, K., & Smith, D. (2010). Guidelines for developing an academic acceleration policy: National work group on acceleration. *Journal of Advanced Academics*, 21(2), 180-203.

Driver, R., Asoko, H., Leach, J., Scott, P., & Mortimer, E. (1994). Constructing scientific knowledge in the classroom. *Educational Researcher*, 23(7), 5-12.

Education Review Office. (2008). *Schools' Provision for Gifted and Talented Students.* Available from: http://www.ero.govt.nz/publications/schools-provision-for-gifted-and-talented-students/findings/#schools-programmes-and-provision-for-gifted-and-talented-students. [Last accessed on 2018 Aug 13].

Evans, M., & Boucher, A.R. (2015). Optimizing the power of choice: Supporting student autonomy to foster motivation and engagement in learning. *Mind, Brain, and Education*, 9(2), 87-91.

Flowerday, T., & Schraw, G. (2000). Teacher beliefs about instructional choice: A phenomenological study. *Journal of Educational Psychology*, 92(4), 634-645.

Flowerday, T., & Schraw, G. (2003). Effect of choice on cognitive and affective engagement. *The Journal of Educational Research*, *96*(4), 207-215.

Gagné, F. (2015). Academic talent development programs: A best practices model. *Asia Pacific Education Review*, 16(2), 281-295.

Geertz, C. (Ed.). (1983). Thick description: Towards an interpretive theory of culture. *The Interpretation of Cultures*. New York: Basic Books. pp. 3-30.

Gentry, M., & Springer, P.M. (2002). Secondary student perceptions of their class activities regarding meaningfulness, challenge, choice, and appeal: An initial validation study. *Journal of Secondary Gifted Education*, 13(4), 192-204.

Gilbert, J.K., & Newberry, M. (2007). The characteristics of the gifted and exceptionally able in science. In: Taber, K., (Ed.), *Science Education for Gifted Learners.* Oxfordshire: Routledge. pp. 15-31.

Gluckman, P. (2011). *Looking Ahead: Science Education for the Twenty-first Century (A Report to the Prime Minister from the Prime Minister's Chief Science Advisor)*. Auckland: Office of the Prime Minister's Science Advisory Committee.

Hattie, J. (2008). *Visible Learning: A Synthesis of Over 800 Meta-Analyses Relating to Achievement*. New York: Routledge.

Heald, S.B. (2016). *Curriculum Differentiation for Gifted Learners using Instructional Technology: A Multiple-case Study.* (Doctoral Dissertation, Georgia, Northcentral University). Available from ProQuest Dissertations Publishing, (UM. No. 10105310).

Hipkins, R., Bolstad, R., Baker, R., Jones, A., Barker, M., Bell, M., Coll, R., Cooper, B., Forret, M., Harlow, A., Talyor, I., France, B., & Haigh, M. (2002). *Curriculum, Learning and Effective Pedagogy: A Literature Review in Science Education.* Auckland, NZ: Ministry of Education.

Hodson, D. (1990). A critical look at practical work in school science. *School Science Review,* 70*,* 33-40.

Hodson, D. (2014). Learning science, learning about science, doing science: Different goals demand different learning methods. *International Journal of Science Education*, 36(15), 2534-2553.

Hodson, D., & Hodson, J. (1998). From constructivism to social constructivism: A Vygotskian perspective on teaching and learning science. *School Science Review*, 79(289), 33-41.

Horsley, J. (2012). Teacher catalysts: Characteristics of teachers who facilitate high academic success. *The Australian Journal of Gifted Education,* 21(1), 23-31.

Horsley, J., & Moeed, A. (2017). If only I had time. *New Zealand Science Review,* 74(2), 36-44.

Ibata-Arens, K.C. (2012). Race to the future: Innovations in gifted and enrichment education in Asia, and implications for the United States. *Administrative Sciences*, 2(1), 1-25.

Kahyaoğlu, M., & Pesen, A. (2013). The relationship between gifted students' attitudes towards science and technology and their learning and motivation styles. *Turkish Journal of Giftedness and Education*, 3(1), 38-49.

Katz, I., & Assor, A. (2007). When choice motivates and when it does not. *Educational Psychology Review*, 19(4), 429-442.

Kaul, C.R., Johnsen, S.K., Witte, M.M., & Saxon, T.F. (2015). Critical components of a summer enrichment program for urban low-income gifted students. *Gifted Child Today*, 38(1), 32-40.

Landis, R.N., & Reschly, A.L. (2013). Reexamining gifted underachievement and dropout through the lens of student engagement. *Journal for the Education of the Gifted*, 36(2), 220-249.

Lupkowski-Shoplik, A., & Swiatek, M.A. (1999). Elementary student talent searches: Establishing appropriate guidelines for qualifying test scores. *Gifted Child Quarterly,* 43, 265-272.

MacDonald, N. (2012). Sir Paul Callaghan: Kiwi Visionary Looks Back on Life. *The Dominion Post*. Available from: http://www.stuff.co.nz/dominion-post/news/6636553/Sir-Paul-Callaghan-Kiwi-visionary-looks-back-on-life. [Last accessed on 2018 Aug 13].

Merriam, S.B. (1998). *Qualitative Research and Case Study Applications in Education.* San Francisco: Jossey-Bass.

Millar, R. (2004). *The role of Practical Work in the Teaching and Learning of Science. Paper Presented at the Meeting of High School Science Laboratories: Role and Vision.* Washington, DC: National Academy of Sciences.

Millar, R. (2010). *Analysing Practical Science Activities to Assess and Improve their Effectiveness*. Hatfield: Association for Science Education.

Millar, R. (2011). Practical work. In: Osborne, J., & Dillon, J., (Eds.), *Good Practice in Science Teaching: What Research has to Say.* 2nd ed. Maidenhead: Open University Press. pp. 108-134.

Ministry of Education. (2007). *The New Zealand Curriculum*. Wellington, NZ: Learning Media.

Ministry of Education. (2012). *Gifted and Talented Students: Meeting their Needs in New Zealand Schools*. Wellington, NZ: Learning Media.

Ministry of Education. (2015). *The National Administration Guidelines.* Available from: http://www.education.govt.nz/ministry-of-education/legislation/nags/. [Last accessed on 2018 Aug 13].

Moeed, A. (2015). *Science Investigation: Students views about Learning, Motivation, and Assessmen*t. Singapore: Springer.

Moeed, A. (2016). Novelty, variety, relevance, challenge and assessment: How science investigations influence the motivation of year 11 students in New Zealand. *School Science Review,* 97(361), 75-81.

Mulqueeny, K., Kostyuk, V., Baker, R.S., & Ocumpaugh, J. (2015). Incorporating effective e-learning principles to improve student engagement in middle-school mathematics. *International Journal of STEM Education*, 2(1), 1.

Naylor, S., & Keogh, B. (1999). Constructivism in classroom: Theory into practice. *Journal of Science Teacher Education*, 10(2), 93-106.

Oliver, M., & Venville, G. (2011). An exploratory case study of Olympiad students' attitudes towards and passion for science. *International Journal of Science Education*, 33(16), 2295-2322.

Olszewski-Kubilius, P., Steenbergen-Hu, S., Thomson, D., & Rosen, R. (2017). Minority achievement gaps in STEM: Findings of a longitudinal study of Project Excite. *Gifted Child Quarterly*, 61(1), 20-39.

Organisation for Economic Co-operation and Development. (2008). *Encouraging Student Interest in Science and Technology Studies*. Available from: http://www.oecd.org/sti/sci-tech/encouragingstudentinterestinscienceandtechnologystudies.htm. [Last accessed on 2018 Aug 13].

Osborne, J. (2015). Practical work in science: Misunderstood and badly used? *School Science Review*, 96, 357.

Palmer, D.H. (2009). Students' interest generated during an inquiry skills lesson. *Journal of Research in Science Teaching,* 46(2), 147-165.

Piaget, J. (1952). *The Origins of Intelligence in Children*. (M. Cook, Trans.). New York, NY: W. W. Norton.

Pintrich, P.R., & Schunk, D.H. (2002). *Motivation in Education: Theory, Research and Applications*. 2nd ed. Columbus, OH: Merrill Prentice Hall.

Posner, G.J., Strike, K.A., Hewson, P.W., & Gertzog, W.A. (1982). Accommodation of a scientific conception: Toward a theory of conceptual change. *Science Education,* 66(2), 211-227.

Pressey, S.L. (1949). *Educational Acceleration: Appraisals and Basic Problems (No. 31)*. Columbus, OH: Columbus, Ohio State University.

Rubenstein, L.D., & Siegle, D. (2012). Introduction to the special issue: Understanding and promoting motivation in gifted students. *Psychology* *in the Schools,* 49(7), 619-621.

Rubenstein, L.D., Siegle, D., Reis, S.M., Mccoach, D.B., & Burton, M.G. (2012). A complex quest: The development and research of underachievement interventions for gifted students. *Psychology in the Schools*, 49(7), 678-694.

Scager, K., Akkerman, S.F., Pilot, A., & Wubbels, T. (2014). Challenging high-ability students. *Studies in Higher Education*, 39(4), 659-679.

Sewell, A. (2002). Constructivism and student misconceptions: Why every teacher needs to know about them. *Australian Science Teachers Journal*, 48(4), 24.

Slavit, D., Nelson, T.H., & Lesseig, K. (2016). The teachers' role in developing, opening, and nurturing an inclusive STEM-focused school. *International Journal of STEM Education*, 3(1), 1.

Solomon, J. (1987). Social influences on the construction of pupils' understanding of science. *Studies in Science Education*, 14, 63-82.

Stake, J.E., & Mares, K.R. (2005). Evaluating the impact of science-enrichment programmes of adolescents' science motivation and confidence: The splashdown effect. *Journal of Research in Science Teaching,* 44(4), 359-375.

Stake, R.E. (2005). Case studies. In: Denzin, N.K., & Lincoln, Y.S., (Eds.), *Handbook of Qualitative Research*. Thousand Oaks, CA: Sage. pp. 435-454.

Swiatek, M.A. (2007). The talent search model: Past, present, and future. *Gifted Child Quarterly,* 51, 320-329.

Taber, K.S. (2007). *Science Education for Gifted Learners*. Oxford Shire: Routledge.

Taber, K.S. (2016). Giftedness, intelligence, creativity, and the construction of knowledge in the science classroom. In: Taber, K., & Sumida, M., (Eds.), *International Perspectives on Science Education for the Gifted*. Oxford: Routledge. pp. 2-11.

Vermette, P., & Foote, C. (2001). Constructivist philosophy and cooperative learning practice: Toward integration and reconciliation in secondary classrooms. *American Secondary Education*, 30(1), 26-37.

Wardman, J., & Hattie, J. (2012). Administrators' perceptions of full-year acceleration at high school. *Australasian Journal of Gifted Education*, 21(1), 32-41.