FutureSACE
Mathematics and Science Innovation Program

Research briefing:
Participation, engagement and achievement
in mathematics and science education

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Executive Summary

This research briefing summarises some of the key research findings regarding the features of Science, Technology, Engineering and Mathematics (STEM) education which contribute to enhance the teaching of the enabling subjects as well as student achievement, participation and engagement.

The need to make science education meaningful (and not just superficially relevant) is well recognised but the mechanisms through which this might be achieved are not always effectively employed. The nature of senior school science will have an effect which is propagated through the teaching of science and maths, junior science education, tertiary science education, and through to the expectations and aspirations of young people.

Scope of the briefing

In preparing new educational agendas for the future it is critical that we review and consider available research literature so that policy is informed and guided by evidence. This briefing paper addresses this requirement by providing a synthesis of key research studies that explore effective means of increasing student participation, engagement and achievement in mathematics and science, particularly in the senior school. It is structured around two sections. Firstly, we identify the features of quality teaching, assessment and school practices that support students in these subject areas. Secondly, we outline the major findings emerging from research about school programs and practices that enhance student achievement, participation, and engagement.

Contextual Background

There is much evidence available about the drop in the number of students selecting science from Year 10 into Years 11 and 12 (DEST, 2006; Fullarton et al., 2003), with less research exploring student transition between secondary and tertiary study. Importantly, the phenomenon that we are experiencing in Australia is not unique with many OECD countries facing similar difficulties in terms of student participation and engagement in the enabling sciences in the secondary years of schooling (i.e., physics, chemistry and mathematics) (Osborne & Collins, 2001; OECD Global Science Forum, 2006; Sjöberg & Schreiner, 2005).

To address the science for all agenda (Fensham, 1985) we need to allow all students to develop a designated level of scientific literacy (Goodrum et al., 2001; Osborne, 2006) by the time they complete compulsory schooling. As defined by the OECD (2006: 12) scientific literacy refers to:

An individual’s scientific knowledge and use of that knowledge to identify questions, to acquire new knowledge, to explain scientific phenomena, and to draw evidence-based conclusions about science-related issues, understanding of the characteristics of science as a form of human knowledge and inquiry, awareness of how science and technology shape our material, intellectual and cultural environments, and willingness to engage in science-related issues, and with the ideas of science, as a reflective citizen.

However, in achieving this goal it is critical that we meet the needs of all students including high-achieving students who are interested in pursuing careers in science. In catering for this diversity of students we require a differentiated curriculum to ensure that a diverse range of students can engage with meaningful content (Rennie & Goodrum, 2007) in science and mathematics for as long as possible.
Features supporting student participation, engagement and achievement

There is a plethora of educational research highlighting the impact that individual teachers have on student engagement and achievement. In a meta-analysis of 500 studies of the effects of teachers on student achievement Hattie (2003) identified that teachers account for 30% of variation, with the school accounting for 5-10%, home 5-10%, and peers 5-10%. However, accounting for 50% of the impact on student achievement are factors outside the school (e.g., socio-economic status, impact of mother on subject choices). Unfortunately, these student-related impacts are often thought to be beyond the brief of any educational system but indicate the importance of a broader educational agenda as a means of addressing and influencing these critical factors.

In considering teachers more closely, Hattie’s research indicates that they usually have a positive outcome on student achievement although some influences have a greater effect than others. For example, the factor resulting in the highest impact on student achievement is feedback with an effect size of 1.13 (Hattie, 2003: 5). Other teacher-influences gaining high to moderate effect sizes included: instructional quality (1.00), direct instruction (.82), class environment (.56), challenge of goals (.52), peer tutoring (.50), mastery learning (.50), homework (.43), teacher style (.42), and questioning (.41). A number of these factors emerge in other educational literature although different wording is used to explain essentially the same pedagogical practice.

Quality teaching

This pertains to the traits, characteristics and personality of the teacher and their ability to create an engaging but challenging learning environment to stimulate students to achieve their educational optimum. In schools where students achieve outstanding educational outcomes, it is possible to identify a number of common features in regard to the teachers:

- **Qualifications**: research suggests that teachers require a minimum qualification in a discipline field to effectively teach students in the senior years regardless of the subject. In Australia for science this is a Bachelor of Science (or university equivalent) comprising a major (i.e., first, second and third-year units) in a particular field of science (Ayres et al, 2004; Harris et al., 2005; Panizzon et al., 2007).

- **Pedagogical approaches**: an important component that complements sound discipline knowledge is access to a diverse range of teaching strategies capable of maximising student engagement. For example, good questioning (ensuring open-ended and challenging questions in contrast to closed content-based items) emerges frequently in the literature as being a critical strategy for enhancing student achievement (Goodrum, 2004; Hackling, 2004).

While there is much discussion in the literature about pedagogy, it is critical to differentiate this from pedagogical content knowledge (PCK). In brief, PCK relates to a teacher’s “understanding of how topics, concepts, problems, or issues are organised, represented, and adapted to the diverse interests and abilities of learners, and presented for instruction” (Shulman, 1987: 8). Teachers with sound PCK are able to ensure that every learning opportunity is likely to enhance student understanding of the discipline. It is this deep-seated content knowledge that allows teachers to diagnose why students develop misunderstandings in a discipline area and provide various pedagogical strategies supported to generate the cognitive conflict necessary to induce conceptual changes (Loughran et al., 2006). Fundamentally, teachers with high PCK require sound discipline knowledge.

- **Emphasis on teaching and learning**: for teachers with high achieving students, a clear focus for each lesson is around supporting student learning so that ‘on task’ time is
maximised regardless of lesson length (Ayres, 2004; McPhan et al., *in press*; Panizzon et al, 2007). Keeping students on task in a manner that is engaging and not made routine requires a high level of organisation and an ability to think laterally and critically.

- **Build personal relationships with students**: highly accomplished teachers recognise that teaching involves the development of individual relationships with students with clear parameters delineated (Ayres, 2004; McPhan et al., *in press*; Patchen, 2004; Tytler, 2006). While such teachers are focused on teaching and learning, they ‘love their subject’ and are ‘motivational’ in the eyes of their students.

- **Engagement in professional development**: teachers who nurture high achieving students are usually engaged in both formal and informal (often within their own faculties) professional development opportunities (Ayres et al., 2000; Panizzon et al., 2007; Pegg et al., 2007). For example, many senior teachers recognise the importance of their experiences as senior markers for Year 12 examinations as being critical to supporting their students achieve high results. Part of this is that such experiences allow them to benchmark their assessment criteria with their peers in the same discipline area. It is this type of opportunity that many rural and regional senior teachers request because access to these marking experiences often requires many days away from the classroom and family (Lyons et al., 2006). Within the school, teachers who achieve high outcomes for their students often mentor other staff and are prepared to share their expertise and resources with new and less-experienced members.

**Assessment**

It is a truism that what is assessed and how it is assessed provides the clearest indication of what is valued about formal education (Cole, 1990; Hamilton, 2003). If we are to meet the demands of an assessment for learning agenda it is “constructive alignment” (Biggs, 1996) of the three arms of curriculum including assessment, curriculum content, and pedagogy that is essential (Hackling, 2004, Panizzon & Pegg, *in press*). It must be noted that the available literature pertaining to senior secondary students was limited although the following common features were evident in schools with high student achievement in the senior years of schooling.

- **Examination practice**: teachers of successful students tend to ‘teach for understanding’ in contrast to expecting students to ‘cram’ for examinations (Ayres, 2004). Supporting this approach is a history of practice towards examinations often beginning with students in Year 7 (Panizzon et al., 2007). This practice allows students to become familiar with the expectations and process involved with examinations (Pegg et al., 2007).

- **Shared assessment tasks**: teachers in high performing schools discuss assessment tasks as a team and apply common tasks where possible as a benchmarking process. Assessment rubrics are devised in a collaborative and critical manner within the team (where possible) to ensure greater consistency of teacher judgement (Ayres, 2004; Black & Harrison, 2000; Pegg et al., 2007).

- **Clear articulation of what and how assessment occurs**: teachers of high achieving students articulate the process of assessment to their students with clear guidelines and expectations explained. Therefore, students are engaged in the assessment process and are able to use the feedback provided by their teachers to guide their learning (Black & Wiliam, 1998; Hackling, 2004).
• **Varied assessment tasks:** in high achieving schools, students are given a range of experiences with different types of items and tasks so that they are able to apply their knowledge in alternative contexts. An important component is the opportunity for them to develop skills of problem-solving and critical thinking (McPhan, 2007; Panizzon & Pegg, *in press*; Wilson & Sloane, 2000).

• **Feedback:** Hattie (2003) identified feedback with an effect size of 1.13 as the most significant teacher factor that influences student achievement regardless of their year level. He conceptualised this as being “information provided by an agent (e.g., teacher, parent or peer) regarding aspects of one’s performance or understanding (Hattie, 2003:81). Feedback has a dual role in giving the student an idea about their progress in the learning process while informing the teacher about where teaching might best be directed.

**School practices**

Teachers and faculties cannot work in isolation but utilise the foundational support provided with the broader school context (Patchen, 2004). However, what is interesting is that recent research suggests that not all faculties ‘tap’ into the support structures offered by the school resulting in differential student success (Busher & Harris, 2000) that is quantifiable using value-added scores (Panizzon et al., 2007; Pegg et al., 2007). In schools where students achieve highly, a number of common features about school practices emerge with a particular focus on the interaction between the faculty (i.e., team of teachers in a discipline area) and the school structures.

• **Faculty focus with collaboration on teams of teachers:** teachers with high achieving secondary students often exist in discipline-specific units forming ‘teams of teachers’. These teams work collaboratively sharing expertise, resources and expectations. Subsequently, there is a high degree of mentorship within the faculty that is evident by members outside of the team (Ayres et al., 2004; Panizzon et al., 2007; Pegg et al., 2007). This faculty structure is supported by the senior executive by allowing the team to ‘do their job’ recognising that they are the content specialists.

• **High expectations shared across the faculty and school:** students achieving highly expect to do so and this is a shared expectation with their teachers. Within such schools there is evidence that students, teachers, the executive and parents are working towards the same shared goals and expectations (Ayres et al., 2004; Hattie, 2003; Panizzon et al., 2007; Pegg et al., 2007).

• **Setting up student success in junior years:** in general, schools with high achieving students in senior years establish positive and effective practices with students in the junior years of schooling (Ayres et al., 2004). Hence, an ‘enculturation’ process is evident in the schools for both students and staff (Dinham, 2007).

• **Leadership by executive:** principals do not appear to play a direct role in the high achievement of students in the senior years (Hattie, 2003). Their impact is in allowing faculties of teachers to set up their own structures that are discipline-specific while still meeting the general ethos of the school. It is often the leadership of the executive as a group (i.e., principal, deputy principals, head teachers or equivalents) that has a more direct impact on classroom practice than individual principals (Dinham, 2007; Pegg et al., 2007)
In reflecting upon these features many seem to be related to ‘good’ teaching practice with an expectation that they are evident in all schools. However, the research by Goodrum et al (2001) and more recently Rennie and Goodrum (2007) suggests that this is not the case with many secondary (and primary) schools floundering to provide the sound practices captured in the research studies cited in this section of the briefing.

Furthermore, evidence emerging from the PISA 2003 (Thomson et al., 2004) and 2006 (OECD, 2006) demonstrates that student achievement in relation to mathematics and science varies depending on geographical location with students in rural areas achieving significantly lower scores than their metropolitan peers. A study by Lyons et al (2006) indicates that the features discussed in this section are either missing or severely limited in schools located in rural and regional areas. Consequently, there appears to be a lack of equity of educational opportunity for many students in Australia based on geographical location.

**Effective programs to extend students’ participation, engagement and achievement**

The Longitudinal Surveys of Australian Youth studies indicate that 75% of the majority of students enrolled in advanced mathematics courses are derived from the top two quartiles of achievement (Lamb & Ball, 1999; Fullarton & Ainley, 2000; Fullarton et al., 2003). This same pattern of choice based on student achievement in earlier years of schooling emerged for the enabling sciences in the ACER’s Study of Subject Choice (Ainley et al., 1990). Interestingly, it is numeracy achievement that has the strongest link with tertiary entrance performance (Marks et al, 2001).

The most recent synthesis of educational research in science education by Tytler (2006) highlights a number of issues around student participation and engagement in the enabling sciences. However, the majority of this work relates to the junior years and primary science with few strategies regarding how change could be implemented on the scale needed to make an impact in a short space of time. Similarly, the mapping exercise undertaken by Rennie and Goodrum (2007) provides a sound overview of research and programs relevant to student engagement in the enabling sciences. While they outline a national action plan for change, their recommendations are at a macro-scale and require very clear articulation in order to inform implementation at a State level.

These studies provide clear evidence about particular aspects of student participation and engagement without necessarily providing proven strategies for ‘turning the tide’. A review of the literature in science and mathematics education identifies that there are in fact few programs based on research evidence that highlight specific strategies for increasing student achievement, participation and engagement in the enabling sciences in senior secondary schools. Studies directly relevant to the scope of this research paper are synthesised in this section of the briefing.

1. **High achievement of students for the Higher School Certificate (HSC) in NSW**

The research by Paul Ayres, Wayne Sawyer and Steve Dinham (2000, 2004) explored the practices and characteristics of HSC teachers achieving outstanding educational outcomes for their Year 12 students. During their interviews and lesson observations of nineteen HSC teachers, the researchers were able to identify a series of factors demonstrated by these teachers across a range of disciplines. The study is extremely pertinent to the scope of this paper with the majority of findings emerging from the study discussed in the earlier section of this paper.

Overall the researchers identify eight categories or themes in the data. These categories along with examples of the items coded into each is summarised in Table 1.
### Table 1: Examples of common factors contributing towards successful teaching of the HSC

<table>
<thead>
<tr>
<th>Category</th>
<th>Item description</th>
<th>Frequency in data (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>School background and students</td>
<td>Students seen as having positive attitudes</td>
<td>60</td>
</tr>
<tr>
<td></td>
<td>Good atmosphere in the school</td>
<td>32</td>
</tr>
<tr>
<td>Subject faculty</td>
<td>Share ideas and resources</td>
<td>80</td>
</tr>
<tr>
<td></td>
<td>Our faculty is the dominant school culture</td>
<td>56</td>
</tr>
<tr>
<td></td>
<td>Success starts in Years 7-10</td>
<td>48</td>
</tr>
<tr>
<td>Personal qualities</td>
<td>Strong content knowledge</td>
<td>60</td>
</tr>
<tr>
<td></td>
<td>Hardworking and committed</td>
<td>60</td>
</tr>
<tr>
<td></td>
<td>Love of subject</td>
<td>44</td>
</tr>
<tr>
<td>Relationship with students</td>
<td>Student relationships seen as important</td>
<td>88</td>
</tr>
<tr>
<td></td>
<td>Sees raising student confidence as important</td>
<td>40</td>
</tr>
<tr>
<td></td>
<td>Relationship built upon mutual respect</td>
<td>36</td>
</tr>
<tr>
<td>Professional development</td>
<td>Learnt through experience</td>
<td>56</td>
</tr>
<tr>
<td></td>
<td>Main source of inservice within the faculty</td>
<td>40</td>
</tr>
<tr>
<td></td>
<td>Determines own PD needs and priorities</td>
<td>20</td>
</tr>
<tr>
<td>Resources and planning</td>
<td>Planning important</td>
<td>80</td>
</tr>
<tr>
<td></td>
<td>Develops own workbooks and resources</td>
<td>28</td>
</tr>
<tr>
<td>Classroom climate</td>
<td>Non-threatening environment</td>
<td>100</td>
</tr>
<tr>
<td></td>
<td>High level of student involvement</td>
<td>42</td>
</tr>
<tr>
<td>Teaching strategies</td>
<td>Building understanding</td>
<td>63</td>
</tr>
<tr>
<td></td>
<td>Questioning (whole class)</td>
<td>100</td>
</tr>
<tr>
<td></td>
<td>Frequent use of questions</td>
<td>58</td>
</tr>
</tbody>
</table>

(Source: Ayres et al., 2000; 2003)

2. **An exceptional schoolings outcomes project (AESOP)**

This study complements the work of Ayres, Sawyer and Dinham through an investigation of science, mathematics and English faculties (Panizzon et al., 2007; Pegg et al., 2007; Sawyer et al., 2007) achieving high value-added results for students in Years 7-10 in NSW Department of Education and Training schools. The calculation of value-added includes baseline data from Year 5 students compared with their achievement in the School Certificate examinations conducted at the end of Year 10. Plots are derived for faculties so that it is possible to identify faculties in schools that appear to be ‘adding value’ to the learning of experiences of their students. In addition to this criteria, faculty inclusion in the AESOP study required that they had demonstrated outstanding student success in the HSC. The research involved intensive case studies in schools over the period of one-week including interviews with teachers, principals, students, parents, lesson observation, and documentary analysis.

Results from the study for science faculties identified seven broad themes (Panizzon et al., 2007) with five demonstrated for mathematics (Pegg et al., 2007). The categories for science along with descriptions of each are provided in Table 2 while those for mathematics are summarised in Table 3.
Table 2: Major AESOP themes for science along with item descriptions

<table>
<thead>
<tr>
<th>Major categories</th>
<th>Item descriptions</th>
</tr>
</thead>
</table>
| Distributed leadership                                | • Senior executive provided direction through policy and procedures that faculties built upon  
|                                                       | • Recognition of the important role of the head teacher of science                                           |
| Commitment to the faculty group and the school        | • Staff worked cohesively and were committed to a shared view of the faculty goals  
|                                                       | • Focus around working as a team                                                                             |
| Experienced thoughtful and reflective teachers        | • Qualified teachers who reflected on their practice at an individual and team scale  
|                                                       | • Teachers created and engaged in their own informal professional development                               |
| High standards and expectations of self and students  | • Teachers were demanding of themselves, one another and their students  
|                                                       | • Students, staff and parents shared these high expectations                                               |
| Interest in and enthusiasm for science                | • Teachers ‘loved’ science and enjoyed teaching it and this was recognised by their students                |
| Quality pedagogy                                      | • Range of sound teaching practices evident in classroom practice and in the way teachers related to their students |
| Commitment to maximising learning outcomes for all students | • Clear focus to teach for understanding and engage students in the learning process  
|                                                       | • Education perceived as a ‘life long quest’                                                                  |

Table 3: Major AESOP themes for mathematics along with item descriptions

<table>
<thead>
<tr>
<th>Major categories</th>
<th>Item descriptions</th>
</tr>
</thead>
</table>
| About the school                                      | • Established policies and procedures  
|                                                       | • Leadership of the executive  
|                                                       | • Shared expectations of high achievement                                                           |
| About the faculty                                     | • Strong sense of team  
|                                                       | • High degree of professionalism  
|                                                       | • Assessment as catalyst for teacher cohesion                                                        |
| About teachers                                        | • Passionate and enthusiastic about their subject  
|                                                       | • Well qualified in the subject                                                                     |
| About teachers and teaching                           | • Solid teaching evident  
|                                                       | • Effective classroom management  
|                                                       | • Care for students and their learning                                                               |
| About parents and students                            | • Strong parental support and involvement  
|                                                       | • Parental encouragement of learning thereby supporting teachers  
|                                                       | • Students related well to the mathematics teachers  
|                                                       | • Students enjoyed teacher appreciation of their efforts                                              |
3. Maths? Why not?
The focus of this survey of mathematics teachers and career professionals was to explore the question: Why is it that capable students are not choosing to take higher-level mathematics in the senior years of schooling? Of four major groupings of questions about the perceived influences contained in surveys, the Individual Influences group was considered as having the greatest impact on students’ decision making. Specific areas contributing to this were students’:

- Self-perception of ability
- Interest and liking for higher-level mathematics
- Perception of the difficulty of higher-level mathematics subjects
- Previous achievement in mathematics, and
- Perception of the usefulness of higher-level mathematics (McPhan et al., in press).

Further analyses of these data to identify significant item effects and interactions produced the following items:

- Students’ experience of junior secondary mathematics
- A greater appeal of less demanding subjects
- Advice of mathematics teachers
- Students’ perception of how good they are at mathematics
- Parental expectations and aspirations, and
- Students’ understanding of career paths associated with higher-level mathematics (McPhan et al., in press).

Unfortunately, further details about these findings are not possible at this stage given that the Draft Report has not been approved by the Department of Science, Education and Training. Once it has approval it will be available from the DEST (or equivalent) website.

Queensland are currently involved in a review of their senior schooling credentials. In light of this agenda, the Smart State Council on Education and Skills in Queensland developed a discussion paper to explore issues around ensuring a future generation with the necessary skills in science, engineering and technology. Termed Education and Skills for the Smart State (2006), the document focuses on teachers, curriculum, and career awareness and engagement. While it outlines some of the key ideas about what might comprise a curriculum that provides both the depth and breadth of study for all students (i.e., greater flexibility, increased pathways in the senior school), little research evidence is incorporated to substantiate the suggestions.

Supplementing this paper is the Towards a 10-year plan for science, technology, engineering and mathematics (STEM) education and skills in Queensland (DETA, 2007) document. Again, although the paper attempts to provide an overview of the issues likely to be confronted in the near future in STEM in Queensland, it overlooks a number of established inadequacies already identified in the research literature. According to Emeritus Prof. Peter Fensham (pers. comm. 9th November 2007) some of these oversights include: the lack of relevance of secondary science to many students; the negative experiences students have of secondary science classes; issues associated with STEM in rural and remote areas; the failure of many previous government programs to initiate reforms in science teaching in secondary schools; and the likelihood of losing high achieving science students at Year 12 during the transition into universities as they enrol in non-STEM courses. Given that these oversights are already evident in the literature (Goodrum et al., 2001; Lyons et al., 2006; Rennie & Goodrum, 2007; Tytler, 2006) they are worthy of a more careful consideration in any review of Year 12 accreditation.
Conclusions

This review of research literature demonstrates that there are a number of features of quality teaching, assessment, and school practices that impact student achievement, and engagement in science and mathematics. Importantly, these commonalities emerge from a number of different data sources and studies suggesting a degree of validity. More evidence to substantiate structured programs that increase student engagement and participation in the enabling sciences is required internationally.

The commonalities that do exist generally point to the development of a culture of value of both the STEM enabling subjects and teaching and learning. This cultural value and meaning of STEM is exhibited in a number of ways across a range of constituents including students, teachers, leaders in education and parents.

When considering the future nature of secondary school science, the research findings summarised in this briefing point to features of the system which can ensure that learning science and mathematics and developing a sophisticated understanding means something to students of all abilities.
References


