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Parliamentary Inquiry into Assessment Methods of Senior Maths, Chemistry and Physics in Queensland Schools

Submission from Griffith University's

Arts, Education and Law Group

and

Science, Environment, Engineering and Technology Group

Prepared on behalf of Griffith University by Professor Robyn Jorgenson, School of Education and Professional Studies and Mrs Louise Maddock, Outreach Coordinator, Griffith Science Education Alliance, with contributions from Professor Richard John, Professor Glenn Finger, Professor Donna Pendergast, in consultation with David Ghelan, Associate Professor Peter Grootenboer, Mr Harry Kanasa, Dr Kevin Larkin and staff from the Benowa Teacher Education STEM Centre of Excellence.

Key Arguments

1. There has been a trend to more appropriately align curriculum, assessment and reporting which understands the importance of deep learning and students needing to develop more skills and knowledge than were previously evident in an era of external examinations.
2. There is a need for a new narrative of the 21st Century student as scholar who actively co-constructs new knowledge and this requires changes in the relationships between student and knowledge, and between students and teachers.
3. Current educational practices need to develop students who are not only able to 'do' school science and school mathematics, but to understand and apply their knowledge to new contexts.
4. New forms of assessment are needed, and the focus should be on learning outcomes which shift from an emphasis on 'marks' to assessing and reporting the depth of student learning in science and mathematics.
5. Assessment *for* learning can complement and improves upon the restricted reliance and over emphasis on assessment *of* learning.
6. Current thinking in assessment in education requires teachers to use assessment to inform their teaching and to support deeper learning for students.
7. Social constructivist teaching approaches in science have resulted in enhanced student learning of conceptual understanding and the ability to transfer knowledge to novel problems.
8. The current Queensland Studies Authority (QSA) Senior Chemistry and Physics Syllabuses appropriately support the development of student scientific literacy as well as being a pathway for future science-based studies.
9. Suggested improvements for learning and assessing in science include innovative, student-centred, inquiry-oriented approaches that promote the development of scientific literacy and interest in science
10. Supporting teachers' professional development regarding assessment is required with a focus on developing and embedding authentic, learning-based assessment practices (alongside test-based assessment) that support inquiry-based teaching and learning practices

Supporting Commentary

1. Aligning Curriculum, Assessment and Reporting

Assessment and curriculum practices have dramatically improved over the past two decades and include more diverse approaches to enabling students to demonstrate what they know and what they can do with what they know. Specifically, this is evident in the significant shift in assessment practices with moves away from a restricted reliance, in earlier times, on external examinations. This shift reflects the need for constructive alignment between curriculum, assessment and reporting, and importantly, understandings of deep learning where students are expected to not only recount knowledge but also be able to demonstrate a much wider repertoire of skills including application, interpretation, reporting, analysing and reflecting on understandings.

This approach reflects the work of scholars such as Burton (2004) whose extensive work with research mathematicians highlighted the massive void between the work of those in the field with the knowledge, skills and dispositions fostered by the traditional approaches to teaching mathematics in schools. Furthermore, the extensive research on transfer of knowledge has highlighted the need for relevance and congruence, otherwise what students are learning in schools will fail to be transferred to new contexts. Consequently, current educational practice seeks to develop students who are able to not only 'do' school science and school mathematics but to understand and apply their knowledge to new contexts. This requires different approaches to curriculum and assessment.

2. A New Narrative of the 21st Century Student as Scholar in Co-Constructing New Knowledge

It is widely acknowledged that learners of the 21st Century are quite different from other generations (Prensky, 2001). These are the students who have grown up in a very different social space and have been heavily influenced by digital tools and media that shapes their dispositions to learning and with that comes the need for new ways of teaching and learning (Gee, 2002). New pedagogies, curriculum and assessments are needed to cater for these learners and to prepare them for the worlds that they will enter (Luke, 2003). This requires a new narrative of the 21st Century student as scholar who actively co-constructs new knowledge. This requires changes in the relationships between student and knowledge, and between students and teachers.

3. Understanding and Applying Knowledge to New Contexts

Current policies in curriculum and assessment have moved to outcomes based learning where it is expected that students are taught particular concepts, processes and skills in order to acquire particular dispositions to the fields of science and mathematics. These changes have seen a move from 'marks' which do not convey **what** students know or have learnt. Marking rubrics now operate to illustrate the depth of learning of particular concepts. This process helps to identify the key learnings of students.

4. New Forms of Assessment are Needed

Within this context, new forms of assessment are needed in the fields of school science and mathematics. Assessments that not only test knowledge but also what that knowledge means and how it can be applied in the worlds beyond school are paramount. Extended Investigations are one way of enabling students to demonstrate not only their scientific/mathematical understandings but the range of associated skills - literacy, numeracy, scientific literacy, mathematical literacy and connections to the world beyond schools. These richer scientific and mathematical investigations match the experience of scientists and mathematicians and promote motivating and contextually relevant learning experiences where students often learn much more than the content of these important discipline areas, especially when they are undertaken by experienced teachers committed to this type of assessment.

Extensive research undertaken by Boaler in the US (Jo. Boaler & Staples, 2008) and the UK (J. Boaler, 1997) has shown that reform approaches to school mathematics has enabled learners to better understand mathematics. In her studies she found that learners undertaking reform approaches (investigative, non-streamed, and open-ended) were able to perform well in high stakes testing. She reported on the case of Railside which went from the lowest performing school in California to above the mean in a few years when changing to a reform approach to teaching mathematics. Students were expected to articulate their understandings and justify their learnings and so build more robust understandings of mathematics than they had under the more traditional approaches to school mathematics.

5. Assessment for Learning and Assessment of Learning

Wiliam's (Black, Harrison, Lee, Marshall, & Wiliam, 2003; Wiliam, 2009) work on assessment *for* learning has shown the importance of complementing and improving upon the restricted reliance and over emphasis on assessment *of* learning so that there is a much more iterative approach to assessment. By using assessment to highlight the unknown and known in students' learning, assessment *for* learning, through ongoing formative assessment strategies, makes a significant shift in the purpose of assessment. Students and teachers are able to use assessment creatively to support learning rather than it being a summative.

While there are criticisms emanating from those who call for external examinations only, for example, current senior science assessment techniques in Queensland include Extended Experimental Investigations (incorporating open-ended inquiry), Supervised Assessments (generally exams/tests), and Extended Response Tasks (usually research assignments). All three have value for preparing students with the knowledge, skills, and attributes to become scientifically literate, informed citizens as well as to advance to university science. In the Physics and Chemistry syllabuses, details required of these techniques are clearly defined.

In Queensland, the assessment instruments for senior science are developed by the school to provide (QSA 2007):

- opportunities for students to demonstrate their understanding (of Physics/Chemistry)
- a level of challenge suitable for the whole range of students
- information about students' demonstration of the achievement of the general objectives
- information on which teachers may make judgments about student achievement.

Assessment instruments are accompanied by (QSA, 2007):

- statements of the conditions of assessment that apply
- a detailed description of the instrument
- a detailed criteria sheet
- details of procedures for authentication of student responses

Criteria sheets specific to each assessment instrument are developed and provided for the students prior to undertaking the assessment. These instrument-specific criteria sheets are designed to (QSA, 2007):

- be derived from the exit criteria
- describe standards congruent with the exit standards
- provide a clear specification of each of the five standards (A–E)
- inform teaching and learning practice

- be annotated to indicate student achievement
- provide the basis for teacher judgment about student achievement
- provide students with the opportunity to develop self-evaluative expertise.

These enable both assessment *for* learning and assessment *of* learning approaches.

6. Assessment to Support Deeper Learning

Current thinking in assessment in education requires teachers to use assessment to inform their teaching in order to support deeper learning. Students, by identifying what students may be struggling with, are able to develop interventions to support their mathematical and scientific learnings. This is a significant shift away from reporting percentages which did not tell anything about what students did or did not know, nor helped to remediate errors in understandings.

The national review of *The Status and Quality of Science Teaching and Learning in Australian Schools* (Goodrum et al., 2001) highlighted concerns regarding the overemphasis on assessment *of* learning and the under-utilisation of assessment to improve learning. The recommendations of this review included a reform of assessment to enhance student learning through innovative, student-centred, inquiry-oriented approaches that promote the development of scientific literacy (Goodrum et al., 2001), including assessing understanding and its application to new situations and skills of investigation, data analysis and communication; ongoing assessment and the provision of feedback that assists learning; and assessing learning outcomes that are most valued and not just easily measured. In this way, assessment is complementary to good teaching (Rennie et al., 2001, Tytler, 2007). Research demonstrates the value of ongoing formative assessment in science for the purposes of monitoring learning and providing feedback, to students to guide future learning, and to teachers to inform their teaching (eg. Donovan & Bransford, 2005; Treagust et al., 2001), approaches that are embedded in the philosophy of the new Australian Curriculum: Science (ACARA, 2013).

7. Social Constructivist Teaching Approaches in Science

Social constructivist teaching approaches in science emphasise the importance of monitoring students' conceptions, discussing these conceptions and providing opportunities to evaluate conceptions using evidence based approaches (Hubber & Tytler, 2004). Donovan & Bransford (2005) recommend that teachers elicit and address student alternative conceptions early in the learning sequence in order to plan for conceptual change, for example, by providing students with opportunities to experience discrepant events that promote discussion; as well as supporting students in using a metacognitive 'reflective' approach in order to develop scientific understanding. These approaches have resulted in enhanced student learning of conceptual understanding and the ability to transfer knowledge to novel problems.

8. Scientific Literacy and Future Science-based Studies.

There is an international consensus that the development of scientific literacy is at the heart of all science education where "*students are able to think scientifically and to use scientific knowledge and processes to both understand the world around us and to participate in decisions that affect it*" (OECD, 2006, p. 3), a view endorsed by the new Australian Curriculum: Science (ACARA, 2013). However, one of the enduring challenges of senior science education in Australia is the 'tension' between having a focus on development of student scientific literacy as well as student preparation for university studies and science-based professions (Office of the Chief Scientist, 2012; Goodrum et al., 2012). As a result there is a belief that senior science courses across Australia have a heavy discipline-based emphasis often with large amounts of content being covered, which reinforces a transmission model of teaching and an examination system that emphasizes memorisation as compared to authentic learning (Goodrum et al., 2012). Nationally, the assessment approaches that were identified were dominated by exams and research assignments with little emphasis on investigation-based assessment methods (Goodrum et al., 2012).

Ideally, senior science teaching and learning would ensure that the curriculum is relevant to the students, centred on inquiry where students investigate, construct and test ideas/ explanations AND assessment serves the purpose of learning and is consistent with and complementary to good teaching (Goodrum et al., 2012). Tytler (2007) suggests the development of assessment approaches that support student engagement with meaningful activities, thus embedding authentic, learning-based assessment in mainstream teaching practice. Meaningful learning occurs when students engage, explore and apply science concepts in contexts that are relevant to the experiences of the students (ACARA, 2013; Goodrum et al., 2012). Hence, learning becomes intrinsically useful regardless of the career pathway, thus reducing the aforementioned 'tension' as learning experiences have the potential to provide suitable challenge and enhance personal and social decision making (Goodrum et al., 2012).

The current Queensland Studies Authority (QSA) Senior Chemistry and Physics Syllabuses appropriately support the development of student scientific literacy as well as being a pathway for future science-based studies, as evidenced in the following extract from the Chemistry Syllabus (QSA, 2007, p2)

> *'The study of Chemistry provides students with a means of enhancing their understanding of the world around them, a way of achieving useful knowledge and skills and a stepping stone for further study. It adds to and refines the development of students' scientific literacy. An understanding of Chemistry is essential for many vocations'*

These syllabuses advocate for the use of formative and summative assessment practices (with criteria and standards) as well as providing a prescriptive list of knowledge-based key concepts for teachers to design inquiry-based approaches that incorporate investigative experiences. The use of extended experimental investigations provides an authentic experience of science for students and the QSA requirements of these tasks are clearly articulated.

Whilst most educators would support the philosophy of the extended investigations, some have indicated reservations about this assessment approach. Firstly, although extended investigations work well when the teacher is strong in content/discipline knowledge and is able to focus on the science of mathematics in the investigations. There is the potential risk with inexperienced teachers or those without strong pedagogical content knowledge that the mathematics and or science is not foregrounded and made explicit and deep to the students, with the possibility that the core content may be missed and students disadvantaged in their learning (for senior studies and beyond). Secondly, the investigative tasks take considerable amount of personal time for the students outside of the classroom, and for teachers with respect to preparation and marking time. Finally, in the highly competitive environment of the Senior Years, there is considerable pressure on staff to encourage, and students to produce extensive reports of their investigations that often go beyond the requirements outlined in the syllabus. Hence, extended investigations need to be made manageable for students.

Even though the use of assessable open-ended student investigations has caused some concerns by teachers (Goodrum et al., 2012), higher order learning outcomes have been shown to result from inquiry-oriented practical work as opposed to traditional closed recipe-style laboratory exercises (Berg et al, 2003 in Hackling, 2004). Hackling (2004) advocates for the inclusion of open-ended investigations in science that allow students to plan and conduct their own investigations, are more inquiry-oriented, provide a more authentic experience of the nature of science and, as a result, actively engage students in learning and developing their critical and creative thinking skills. Recipe-style verification laboratory exercises provide limited student ownership, intellectual challenge or engagement (hands-on but not minds-on). Hackling (2004) outlines the concerns that some teachers have with the implementation of investigation-based school science (including a greater time commitment than verification practicals; difficulty in student planning; provision of equipment for each student; safety concerns) and provides suggestions for teachers including replacing several laboratory exercises with a reduced number of investigations; student experience of planning investigations using teacher modeling and coaching of explicit inquiry skills; teachers limiting students to the same investigation with different independent variables or limiting the apparatus provided initially; teacher reviews of student plans for safety issues prior to commencement. Hackling also recommends that the teacher scaffolds and facilitates the process according to the learning needs of the students, for example, breaking the task into a series of steps, providing investigation planners and modeling more specific inquiry skills.

9. Addressing the Decline in Students Studying Science and Mathematics - Suggested improvements for learning in science

Senior students of science appreciate relevant, interactive and investigation-based learning. According to surveyed senior science students, the most common reasons for studying science were an interest in the subject or the relevance of the subject to their lives (68%) and career or university intentions (38%) (Goodrum et al., 2012). In comparison, non-science students revealed the main reasons for not studying science were: students either disliked science or found it boring (61%), found it difficult or reported not being good at it (31%), or reported that studying science did not align to their career aspirations (25%) (Goodrum et al., 2012). Overall, the most common suggested improvements for learning in science made by students were making classes more interactive by including more investigations, excursions, practical lessons or class discussions (30%), improved teaching styles or better teacher resources (19%) and reducing content (10%) (Goodrum et al., 2012). Furthermore, the impact that student interest on subject choice is supported by findings of the recent Universities Australia (2012) survey where 70% of the first year university students surveyed reported that their choice of Year 12 subjects was based on their interest in those subjects.

The perceived difficulty of senior science subjects has been linked to student self-efficacy with regards to studying science (Zimmerman, 2000 as in Australian Chief Scientist, 2012) and hence subject choice. Both teachers and non-science students have indicated that the perceived difficulty of science has an influence on students choosing or not choosing senior science subjects. Essentially, students perform a cost-benefit analysis when choosing subjects, examining the anticipated difficulty of the subject against anticipated rewards or benefits. The declining proportion of students choosing senior science subjects over the last two decades suggests that the perceived utility of physics and chemistry has declined, and is 'less tangible' for students (Lyons & Quinn, 2010, as in Australian Chief Scientist, 2012). In addition to this, there has been a growth in the school-based VET courses and other non-Authority subjects over time (Queensland Department of Education, Training and the Arts, 2007) which may have impacted on enrolment numbers. Regardless, the decreasing numbers of students studying senior science would indicate that there is declining interest in science for students (Goodrum et al., 2012), which is linked to the dominant influences of science experiences at the junior secondary level as well as the future aspirations of the students (Goodrum et al., 2012).

Interestingly, even though fewer students are studying senior sciences, these students enjoy their science learning experiences and have a positive view about science, its importance in society and their expectations for the future (Goodrum et al., 2012). In addition to this, even though very few non-science students agreed that science is important, relevant or useful to their own lives, nearly 75% of these non-science students agreed that science is important to Australia's future.

10. Supporting Teacher Professional Development

Teachers are the key to educational improvement. Hattie's (Bendikson, Hattie, & Robinson, 2011) meta-analysis of and Hill and Rowe's (1998) work on school effectiveness has shown that the teacher is the most significant variable in student learning (other than social background). As such, the importance of quality teachers and quality teaching is instrumental in quality outcomes in mathematics and science learning with teachers playing a central role in inspiring and influencing students' attitudes towards and interest in the sciences (Office of the Chief Scientist, 2012). Evidence for the vital role of teachers is provided in the findings of a recent survey of first year university students in which two thirds of STEM students reported that they were encouraged by teachers to do well in science and mathematics (Universities Australia, 2012).

The recent *The Status and Quality of Year 11 and 12 Science in Australian Schools* report (Goodrum et al., 2012) indicates that, in general across Australia, the pedagogy in senior science classrooms is generally didactic with an emphasis on student memorisation of significant amounts of science information and thus recommended future provision of more professional learning opportunities for senior science teachers to support inquiry-based teaching, learning and assessment practices in the classroom. Science teachers that were surveyed suggested that professional development could be focused on using the best general pedagogical techniques, using technology in the classroom and keeping up to date with the latest scientific advances in order to integrate new learnings in to their lessons (Australian Chief Scientist, 2012).

Assessment approaches need to be developed that support embedded, learning-based practices (Tytler, 2007). Extended Experimental Investigations offer much potential (notwithstanding the concerns noted above) and a key consideration is the professional development of teachers to support them with effective and successful implementation of these valuable assessment approaches.

When implementing reform pedagogy and assessment, such as the extended investigations, it is crucial to the success of rollout of change that adequate professional learning is made available and accessible to teachers. As a result of this professional learning, teachers become more confident and more able to engage, challenge and inspire their science students. This is a vital key to building our mathematically and scientifically literate citizens, mathematicians and scientists of the future.

References

ACARA (2013) *Australian Curriculum: Science V4.2*. Australian Curriculum, Assessment and Reporting Authority

Bendikson, L., Hattie, J., & Robinson, V. (2011). Identifying the comparative academic performance of secondary schools. *Journal of Educational Administration, 49*(4), 433 - 449.

Black, P., Harrison, C., Lee, C., Marshall, B., & Wiliam, D. (2003). *Assessment for learning: Putting it into practice*. Maidenhead, UK: Open University Press.

Boaler, J. (1997). *Experiencing school mathematics: Teaching styles, sex and setting*. Buckingham: Open University Press.

Boaler, J., & Staples, M. (2008). Creating Mathematical Futures through an Equitable Teaching Approach: The Case of Railside School. *Teachers College Record, 110*(3), 608-645.

Burton, L. (2004). *Mathematicians as enquirers*. Dordrecht: Springer.

Donovan, M. S. & Bransford, J. D. (Ed) (2005). *How students learn: Science in the Classroom*. National Research Council. Washington DC: National Academic Press

Gee, J. P. (2002). New Times and new literacies: Themes for a changing world. In B. Cope & M. Kalantzis (Eds.), *Learning for the future: Proceedings of the learning conference* (pp. 3-20). Spetses, Greece: Common Ground Publishers.

Goodrum, D., Druhan, A., and Abbs, J. (2012). *The Status and Quality of Year 11 and 12 Science in Australian Schools Report.* Prepared for the Office of the Chief Scientist. Australian Academy of Science.

Goodrum, D., Hackling, M., & Rennie, L. (2001) *The status and quality of teaching and learning of science in Australian schools: A research report.* Canberra: Department of Education, Training and Youth Affairs

Hackling, M. in Venville, G. and Dawson, V. (2004). 'Assessment in Science' & 'Investigating in Science' in *'The Art of Teaching Science'*, Crows Nest, Australian: Allen & Unwin

Hill, P. W., & Rowe, K. J. (1998). Multilevel modelling in school effectiveness research. *School Effectiveness and School Improvement, 7*, 1-34.

Hubber & Tytler, R. in Venville, G. and Dawson, V. (2004) 'Conceptual Change Models of Teaching and Learning' in *'The Art of Teaching Science'*, Crows Nest, Australian: Allen & Unwin.

Luke, A. (2003). Making literacy policy and practice with a difference. *Australian Journal of Language and Literacy, 26*(3), 58-82.

OECD. (2006). *Assessing scientific, reading and mathematical literacy*. Paris: OECD

Office of the Chief Scientist (2012). *Health of Australian Science.* Australian Government, Canberra

Queensland Department of Education, Training and the Arts (2007). *Towards a 10 year plan for Science, Technology, Engineering and Mathematics (STEM) Education and Skills in Queensland* Discussion Paper

Prensky, M. (2001). Digital natives, digital immigrants, part II: Do they really think differently? *On the Horizon, 6*, 2-10.

QSA, (2007). Chemistry Senior Syllabus. Queensland Studies Authority

Rennie, L., Goodrum, D. and Hackling, M. (2001). Science Teaching and Learning in Australian Schools: Results of a National Survey. *Research in Science Education,* 31, 455-498.

Treagust, D., Jacobowitz, R. , Glallagher, J . and Parker, J. (2001). Using assessment as a guide in teaching for understanding: A casestudy of a middle school science class learning about sound. Science Education, 85 (2), 137-157.

Tytler, R. (2007). *Re-imagining Science Education: Engaging students in Science for Australia's future.* Australian Coucil for Educational Research

Universities Australia (2012). *STEM and Non-STEM First Year Students.* Report prepared for the Office of the Chief Scientist, Canberra

Wiliam, D. (2009). *Assessment for learning.* London, UK: Insitute of Education Press.

Education and Innovation Committee

From: [redacted] on behalf of Ian O'Connor [redacted]
Sent: Monday, 13 May 2013 1:45 PM
To: Carolyn Heffernan
Subject: Re: Inquiry into assessment methods for senior maths, chemistry and physics
Attachments: Parliamentary Inquiry into Assessment Methods_Griffith University.docx

Categories: Blue Category

Dear Ms Menkens

Thank you for your letter of 8 March.

I am pleased to attach Griffith University's submission in response to the Inquiry into assessment methods for senior maths, chemistry and physics.

We appreciate the opportunity to comment.

Regards
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