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Opening real science: Authentic mathematics and science education for Australia

Final report, March 2017

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List of acronyms used

AITSL	Australian Institute for Teaching and School Leadership
ETMST	Enhancing the Training of Mathematics and Science Teachers
ICT	information and communication technology
ORS	Opening Real Science
STEM	science, technology, engineering and mathematics

Education terminology

Education terminology varies across institutions and jurisdictions. In this report, the following terms have been used:

assessment: a task or activity required by the pre-service teacher for the evaluation of the learning outcomes of a module. Synonymous with ‘assignment’.

iLearn: a student learning management system, synonymous with similar systems such as Blackboard.

module: approximately one-third of a 12-week university semester-length subject.

Moodle: a learning management system for online delivery of university units.

pedagogy: the method and practice of teaching.

pre-service teacher: synonymous with ‘initial teacher education student’ and ‘prospective teachers (of mathematics and science)’.

pre-service teacher education: synonymous with ‘initial teacher education’.

professional experience program: in-school teaching experience conducted in a pre-service program under supervision of a supervising teacher and/or university advisor. Synonymous with ‘practicum’.

program: a series of credit-bearing academic units of study leading to award of a degree. Synonymous with ‘course’ or ‘degree’.

unit: a 12-week university semester-length subject.

Executive summary

About Opening Real Science

‘Real’ science is science as it is practised, using the processes of hypothesis, experimentation, observation, interpretation and debate. Opening Real Science (ORS): Authentic Mathematics and Science Education for Australia was initiated to foster improvement in the quality of mathematics and science teaching by supporting pre-service programs to teach science as it is practised, in a way that promotes mathematics and science as authentic, dynamic, forward-looking and collaborative human endeavours.

The ORS project was one of five consortia projects undertaken through the Australian Government’s Enhancing the Training of Mathematics and Science Teachers (ETMST) Program¹. The project was led by Macquarie University, in a strategic partnership with Western Sydney University, Australian Catholic University, Charles Sturt University, Edith Cowan University, University of Canberra and The University of Notre Dame Australia. The Commonwealth Scientific and Industrial Research Organisation Astronomy and Space Science, the Australian Astronomical Observatory and Las Cumbres Observatory Global Telescope were industry partners.

Project aim and approach

The ORS project was designed to reconceptualise how mathematics and science pre-service teachers are prepared. Complementary learning resources were developed to support pre-service teachers, both in their teacher education programs and during their professional experience.

Key project outputs

The ORS project successfully provided new and effective support for engaging and empowering pre-service teachers to embrace mathematics and science through (1) development of a new specialist professional experience model, (2) delivery of a ‘real science’ learning program and (3) establishment of collaborative networks of scientists, statisticians, mathematicians, technology experts and teacher education professionals working to enhance the mathematics and science capabilities of pre-service teachers.

¹ The ETMST Program was established by the Australian Government Office for Learning and Teaching. The OLT ceased on 30 June 2016. The Australian Government Department of Education and Training continued to support the Program.

Specialist professional experience

The ORS professional experience model allowed pre-service teachers to significantly increase the quantity, quality and scope of science (and mathematics) classroom learning experiences where this would not have occurred in the regular primary school teaching program. This was achieved by enabling pre-service primary teachers to work collaboratively with school mentors and a specialist ORS primary science supervisor, and offered supervised placements within research organisations and public science education venues.

Trials involving 81 pre-service teachers working with 91 school mentors across 37 Sydney primary schools highlighted a range of challenges to increasing the focus on primary science. Unlike primary pre-service teachers, secondary pre-service teachers are being trained as specialist science or mathematics teachers. Therefore, the challenges for them do not relate so much to confidence and competence, but more to pedagogy, encouraging an inquiry-based approach and establishing authentic contexts for learning. This is an important consideration for developing an effective professional experience program.

ORS modules: a ‘real science’ learning program

The ORS modules were designed to engage pre-service teachers in ‘real science’ by linking them with case studies of cutting-edge scientific exploration and applications of mathematics, and giving them opportunities to pursue their own scientific and mathematical interests through investigative pedagogies.

The suite of 25 modules was developed by project teams comprising science, mathematics, education and design specialists, delivered through mixed and fully online modes, and trialled in a variety of contexts with tutor support. The modules cover mathematics (numeracy, statistical and financial literacy, advanced mathematics and mathematical modelling), physics, astronomy, biology, chemistry, and earth and environmental science.

There were 58 module evaluation trials across teacher education programs from seven universities involving 4226 pre-service teachers. The interdisciplinary, inquiry-based scientific approach was shown to be viable and effective in enhancing pre-service teacher knowledge and inquiry-based skills.

As a result, modules have been embedded in teacher education programs at partner universities. Components of the modules are being adapted for use in mathematics and science education programs and as teaching resources more generally. The modules are also being redeveloped for use in accredited professional learning for in-service teachers.

Collaborative networks

The development of learning modules established collaborative networks between scientists, mathematicians, and education and learning design specialists, extending across universities. The communities of practice and interest forged through the trialling, evaluation and embedding of ORS modules and aligned resources extended these networks to include schools, in-service teachers, professional associations, government agencies and other research organisations and stakeholders. The collaboration with state accrediting authorities such as the NSW Education Standards Authority has resulted in a new specialist primary mathematics and science teacher education program.

Impact

The ORS project has resulted in:

- a scalable model for offering specialist mathematics and science professional experience for pre-service teachers
- scientific method embedded in inquiry-led lessons through provision of learning materials incorporating authentic science experiences
- a professional network of ORS practising scientists, mathematicians, teacher educators and mentor teachers, and increased cooperation between schools and universities
- specialist primary and secondary mathematics and science teachers with an in-depth knowledge of science, technology, engineering and mathematics (STEM) content
- improved teacher capability, confidence and motivation in mathematics and science.

Step changes and recommendations

Seven step changes were identified through the ORS project experience, leading to the following recommendations for enhancing the mathematics and science capability of pre-service teachers.

1. Effective development of competent specialist primary mathematics and science teachers can be achieved through a collaborative ORS model.

- Implement specialist professional experience in primary mathematics and science or STEM, with a minimum of 20 hours' experience over a four-week block. Support from an expert science/mathematics advisor and a mentor teacher supportive of STEM initiatives are essential. Appendix V provides detailed recommendations for teacher education programs and schools for recruitment, planning, implementation and evaluation. A flexible and innovative approach is encouraged for tailoring specialist experience in mathematics and science, to suit pre-service teachers' backgrounds and

school contexts. The roles of the university specialist advisor and school mentors is emphasised as critical to success of the program.

- Recognise the different challenges for primary and secondary pre-service teachers in the design of education programs.

2. Capabilities and capacity of pre-service primary teachers can be significantly improved and expanded through strategic changes at higher education level.

- Prioritise within (Australian Councils of Deans of Education and Deans of Science) higher education academic programs and strategic planning the review and expansion of mathematics and science education within primary teacher education programs, coordinated with the recruitment of specialist educators with expertise in mathematics and science.
- Appoint mathematics and science tertiary education experts, recruited from science, mathematics or related fields, as ‘boundary crossers’ with effective experience in scientific pedagogy.

3. Systematic evaluation of primary and secondary (mathematics and science) pre-service teacher education programs can inform changes in scope and direction.

- Re-design mathematics and science pre-service programs from the ground up based on systematic evaluation data of the outcomes of existing programs and the potential input from science faculties (and mathematics, engineering and information and communication technology (ICT) disciplines) and collaborative networks. The groundwork has been laid, but more work is needed in academic program review and development, and strategies for effective teaching and learning.

4. Cross-faculty and cross-departmental collaboration can improve mathematics and science teacher education programs.

- Establish effective collaborative committee and program development structures within universities where science and education faculties and departments (such as a cross-faculty working group) work together in the development, implementation and evaluation of STEM programs.

5. Pre-service teachers can successfully apply mathematics and science knowledge and processes gained through academic study offered by faculties of science and mathematics.

- Develop specialist primary mathematics and science education programs that tailor mathematics and science academic units, and coordinate their delivery.

6. Authentic scientific contexts can transform and enrich pre-service training with the collaboration of scientists engaging pre-service teachers in scientific process and mathematical thinking.

- Integrate real science contexts and problems, including industry or community-based field work or contexts, into mathematics and science teacher education programs.
- Shift focus from traditional pedagogies aligned with syllabus content to engaging in contexts of authentic applications of mathematics and science.

7. Cross-institutional cooperation and collaboration can facilitate improved sharing of resources and expertise.

- Facilitate new ways of integrating content and pedagogy that reach beyond the level of individual institutions where the ETMST collaborative networks and resources can be shared, particularly where some teacher education programs do not have direct support from scientists and mathematicians.

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Chapter 1: Introduction

1.1 Project context

In July 2013, the Australian Government Office for Learning and Teaching² initiated the Enhancing the Training of Mathematics and Science Teachers (ETMST) Program. The purpose was to foster improvement in the quality of mathematics and science teachers by supporting new pre-service programs that taught mathematics and science as dynamic, forward-looking, and collaborative human endeavours.

As one of five ETMST projects, Opening Real Science (ORS): Authentic Mathematics and Science Education for Australia developed a strategic partnership between leading Australian teacher educators, mathematicians and scientists across seven universities and three industry partners over a three-year period.

1.2 ORS aims

ORS supports two main priorities of the ETMST Program:

- new forms of collaboration between faculties and departments of science, mathematics and education, which will produce teachers who have a contemporary and dynamic view of science that can inspire students (priority 1)
- new curriculum arrangements in teacher education programs that give pre-service teachers of mathematics and science a new vision of how mathematical and scientific content, thinking and pedagogy can work together (priority 3).

The ORS intended project logic statement is included in Appendix B.

1.3 ORS approach

The ORS project team took up the ETMST Program challenge to reconceptualise a mathematics and science pre-service teacher education curriculum by developing complementary resources to support pre-service teachers both in their teacher education programs and through their practical experience.

The core product developed through the ORS project is a suite of learning modules, which exemplify a range of authentic scientific and mathematical contexts, aimed to develop pre-service teachers' understanding and inquiry skills.

² The Australian Government Office for Learning and Teaching ceased on 30 June 2016. The Australian Government Department of Education and Training continued to support the Enhancing the Training of Mathematics and Science Teachers Program and projects.

Recognising the critical importance of in-school experience, a unique module of professional experience was developed to support the specialist practical experience of pre-service primary science teaching, where mentor teachers collaborated with the ORS specialist university advisor.

Together, the ORS modules and the professional experience provided new and effective support for engaging and empowering pre-service teachers to embrace mathematics and science.

1.3.1 ORS modules

The ORS modules were developed to address ETMST priority 3, concerning new curriculum arrangements in teacher education programs.

The modules engage pre-service teachers in ‘real science’ by linking them with case studies of cutting-edge scientific exploration and applications of mathematics, and giving them opportunities to pursue their own scientific and mathematical investigations. This process is aimed at building the pre-service teachers’ mathematics and science competence and knowledge, so they are better equipped to inspire their school students to pose and investigate relevant questions about their world and the universe beyond.

The suite of 25 modules covers mathematics (numeracy, statistical and financial literacy, advanced mathematics and mathematical modelling), physics, astronomy, biology, chemistry, and earth and environmental science. The *Intelligent Materials* module broadened the scope to incorporate design learning and digital technologies. *Discovering Real Science through Big History* and *Frontiers of Real Science* act as ‘gateway’ and ‘capstone’ modules.

The modules were delivered to pre-service teachers through mixed and fully online modes with tutor support and trialled in a variety of teacher education contexts.

Details of module design, content, development, implementation and evaluation are provided in Chapter 2.

1.3.2 ORS professional experience model

The ORS primary science professional experience program was developed to support the teaching capabilities and authentic science pedagogy of pre-service teachers.

The professional experience model enabled pre-service primary teachers to work collaboratively with school mentors and a specialist ORS primary science advisor. As part of their professional experience, pre-service teachers were also offered supervised placements of between five and eight days within organisations such as the Sydney Observatory, the Australian Museum and the Institute of Marine Science, where scientists, educators and school students participated collaboratively.

The program was instrumental in prioritising science, in particular, as critical to science, technology, engineering and mathematics (STEM) learning within the school curriculum. A long-term goal is to increase the supply of confident primary

mathematics and science teachers capable of opening up real science to a wider, more aware and engaged generation of pre-service and practising teachers. The ORS professional experience model has been accredited for the Macquarie University primary mathematics and science specialist teacher education program (www.nswteachers.nsw.edu.au/about-us/news/stem-specialisations-for-primary-teachers/).

Details of the development, implementation and evaluation of the professional experience model are provided in Chapter 3.

1.3.3 Collaboration

Development of effective mathematics and science content and pedagogy for teacher education required input from scientists, mathematicians, statisticians and teacher education professionals. In order to accomplish this, and to address ETMST priority 1 (collaboration between mathematics, science and education departments and faculties), the ORS project team (Section 1.5) drew on expertise from across its seven partner universities and three external partner research agencies. As well as education specialists, project team members represent a range of mathematics and science disciplines.

1.4 Project goals and evaluation

The four major goals of ORS are to:

1. improve content knowledge and develop new teaching practices among pre-service and practising teachers using ‘real science’ thinking and processes
2. develop new levels of cooperation between academics, practising mathematicians, scientists and teachers
3. develop effective ‘real science’ learning modules to transform teacher education programs and professional experience
4. implement a specialised science professional experience model where mentor teachers collaborate with the ORS specialist university advisor.

There were significant achievements across all goals but most notably goal 2, exemplified by the establishment of a cross-faculty working group at Macquarie University (and in part at Western Sydney University and Charles Sturt University) (Section 4.3.4), and goal 3, with the development of the module suite and professional experience model. Over the course of the project, with increased pre-service teacher scientific knowledge and adoption of authentic scientific pedagogy, emphasis shifted to developing the professional experience model.

Evidence from a variety of sources was collected to evaluate ORS activities and outputs. Each evaluation stage – formative, summative and impact – employed a variety of activities using procedures and tools (instruments) appropriate to the scope of the evaluation task.

The ORS evaluation plan is presented in Appendix C.

1.5 ORS project team

1.5.1 Project partners

The ORS project was led by Macquarie University's Department of Educational Studies and the Faculty of Science and Engineering, in a strategic partnership with Western Sydney University (principal partnership), Australian Catholic University, Charles Sturt University, Edith Cowan University,³ University of Canberra and The University of Notre Dame Australia, Sydney.

ORS also engaged the Commonwealth Scientific and Industrial Research Organisation (CSIRO) Astronomy and Space Science, the Australian Astronomical Observatory and Las Cumbres Observatory Global Telescope as industry partners in the scoping and development of the project.

1.5.2 Project management

Four key groups were involved in ORS project management:

- The **project leadership team** was responsible for the overall decision making and progress of the project.
- A **reference committee**, comprising representatives from each partner university, the Office of the Chief Scientist, the CSIRO, the NSW Department of Education, the NSW Education Standards Authority and other stakeholders, met biannually to assess progress and offer independent advice on project direction.
- **Partner institution leaders** were responsible for the management and reporting of the project outcomes to the project leadership team and the reference committee.
- The **project support team** comprised the project manager, academic developers and designers, research assistants and the professional experience university advisors. The team was supported by Macquarie University research fellows, a PhD scholar and pre-service scholarship recipients who facilitated the development, implementation and evaluation of project outputs.

A full list and affiliations of participants constituting the four groups is provided in Appendix D.

³ Edith Cowan University, Perth joined as a partner institution in 2015 following the appointment of Professor David McKinnon, who moved from Charles Sturt University, Bathurst, NSW.

Chapter 2: ORS modules

2.1 Module themes and scope

The suite of modules developed by module writing teams – practising scientists, mathematicians and educators – involved in the initial stages of the ORS project introduced a range of concepts relevant to their collective research inquiry and projects. This resulted in a comprehensive group of modules, which were relevant to current curricula, and included new topics not previously taught in K–12 school contexts that were of interest to the target undergraduate audience.

The *Sound*, *Gateway to Numeracy* and *Smart Budgeting* modules contain fundamental mathematics and science content. More challenging topics requiring prerequisite understanding can be found in *Clocks in Rocks*, *Primary Astronomy* and *Statistical Literacy*. Feedback from pre-service teachers and practising teachers indicated that, with their growing realisation of the content requirements of the new *Australian Curriculum: Science* and *Australian Curriculum: Technologies* documents (Australian Curriculum, Assessment and Reporting Authority, 2016a, 2016b), there is an increasing need to grapple with science content – at least in an area of personal interest.

The introductory module *Discovering Real Science through Big History* builds a grand narrative upon which students can develop an informed overview of the history of the universe. Student feedback consistently emphasises their appreciation of access to the considerable resources of the [Big History Project](#) via their participation in this module. The module introduces the three foundation concepts of the ORS project: scientific questioning, fair testing and data integrity.

At the middle years and junior secondary levels, modules include *Fundamentals of Weather and Climate* and *Light*. *Statistical Literacy Secondary*, *Smart Budgeting Secondary* and *Investing & Protecting* add numeracy capability to investigative and critiquing skills to complement science modules.

The most advanced scientific content levels are in *Bioluminescence* and *Life and Death of Stars*, and the mathematics modules *Modelling the Present—Predicting the Future* and *2 Infinity and Beyond*. The former maths module engages students in mathematical modelling approaches to scientific problem solving, while *2 Infinity and Beyond* develops abstract thinking and abstraction processes.

Inquiry skills in mathematics and science are introduced to students via module design focusing on the backwards-faded scaffolding approach of Slater, Slater and Shaner (2008). Skill development begins in *Consumer Chemistry* where students engage in guided inquiry activities involving testing of materials. *Sound* provides the opportunity for students to develop an investigation that responds to a specific inquiry-based question. The activities developed for *The Living Laboratory* specifically scaffold students to develop their own investigation into their local environment.

After establishing the inquiry process through investigative activity, *Statistical Literacy* directs students to sources of ‘big data’ online to conduct an investigation of their own. The secondary modules *Telescopes*, *Colour Imaging and the Cosmos* and *Tracing the Life Cycle of Stars* scaffold student involvement to build an astronomy inquiry and use the resources of the world’s radio telescopes to focus on a specific part of the sky. Students are then able to access this data to continue their inquiry.

Some modules specifically explore alternative pathways to student engagement with science. *Inspired by Plants* was developed to support science engagement through the arts, and *Science in the Community* was developed to support student engagement through actual involvement in community science events. Use of the 6Es model (Section 2.2.3) provided opportunities for student creativity in the ‘elaborate’ phase of some modules, including *Sound* and *The Living Laboratory*.

Communicating mathematics and science to other audiences is a fundamental pedagogical activity for all pre-service teachers. Activities that build student capabilities in science communication were developed across *Sound*, *Science in the Community* and *Consumer Chemistry*. Pedagogical skills in developing action-oriented teaching programs and events were the focus of *Human Impact*. Design thinking and a critical approach to its teaching is developed throughout *Intelligent Materials*.

More details on the scope and contents of each module are provided in appendices F and G, respectively.

2.2 Module design

2.2.1 Design process

Scientists, mathematicians, educators and learning designers, and other stakeholders were consulted on the content, structure and design of the ORS modules. Consensus rested on the development of stand-alone, online modules equivalent to 36 hours of learning and teaching activities, or about one-third of an undergraduate unit.

The ORS module evaluation checklist (Appendix E) was developed as a set of criteria to identify the core features of an ORS module. The checklist has been used as an internal evaluation instrument to interrogate developing modules against the intended outcomes. The checklist is organised under four big ideas, which research shows are major factors in scientific understanding and representation (Bybee, 2009; Hubber & Tytler, in press; Nichols, et al., 2016; Tytler, et al., 2013):

- learning activities with feedback
- authenticity
- representation of ideas
- conceptual correctness and clarity.

2.2.2 Scope of module content

Module content that would highlight current scientific and mathematics research and be relevant to pre-service teachers was identified in discussions with scientists from across the range of mathematics and science disciplines. The scope and sequence of the modules is illustrated in Appendix F.

The 17 science modules were clustered around biology, chemistry, earth sciences, physics and astronomy. Six of the eight mathematics modules were drawn from new mathematical topics for which pre-service primary teachers are not typically well prepared (statistical literacy, financial literacy, critical numeracy). A summary of the ORS modules is provided in Appendix G.

2.2.3 ORS module design framework

The ORS module design framework differs from other curriculum and resource design models because it integrates the authentic scientific processes practised by real scientists using real world applications. It transforms traditional science curriculum and resource design models by engaging the student in the elucidation process of scientific investigation and explanation, including modelling and use of technological tools. The ORS module design checklist (Appendix H) provides an overview of the components of the design process for the ORS modules.

The ORS design framework was built upon the 5Es instructional model (Bybee, et al., 2006): ‘engage, explore, explain, elaborate, evaluate’. This model is used in science teaching throughout Australia and promoted through the Australian Academy of Science Primary Connections program (Primary Connections, 2008). However, the ORS project has integrated an additional ‘E’, ‘elucidate’, that permeates the dynamic and interrelated processes of the model (Figure 2.1).

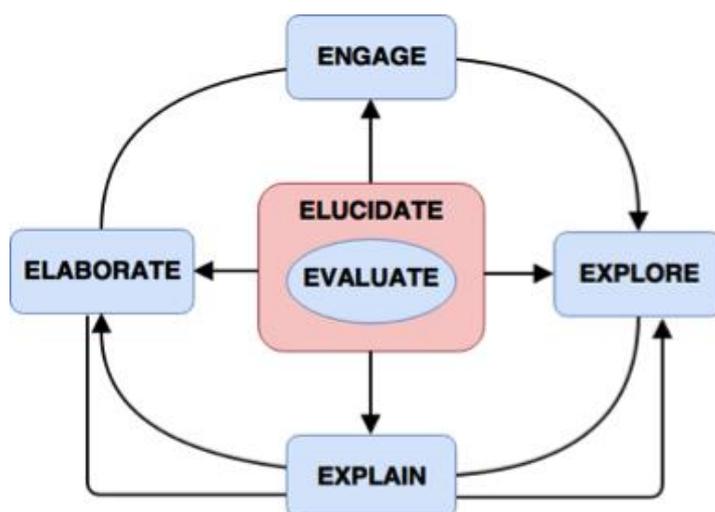


Figure 2.1: Opening Real Science 6Es teaching and learning model.

The elucidation process builds on the students’ explanations by illustrating and clarifying their reasoning through examples or cases of the authentic scientific

findings. This sixth process provides the link to real science as emphasised by the Office of the Chief Scientist: ‘the issue is that science is not taught as it is actually practised: hypothesis, experimentation, observation, interpretation and debate’ (Chubb, 2012, p. 9). The content and activities embedded in the modules emphasise explicit links with real scientists, their work and a ‘scientific’ view of the world, often through the use of video excerpts, student-led investigations and web-based resources.

2.2.4 Target audience

Modules were targeted at pre-service teachers in upper primary and transition to secondary schooling (years 4–8) and in upper secondary mathematics and science.

These modules focused on three areas: student engagement with mathematics and science content, the introduction of inquiry skills and the achievement of critical numeracy. The last of these was informed by a survey of critical numeracy skills and attitudes of several large cohorts of pre-service teachers using an adapted form of the numeracy instrument developed by Forgasz, et al. (2015).

Modules designed for secondary mathematics and science pre-service teachers acknowledged their commitment to and enthusiasm for communicating mathematics and science and provided unique opportunities to work with scientists on projects that generate real data, including possibilities for engaging their students in research.

2.3 Module development

2.3.1 Development process

The collaborative module development process – involving educators, scientists and mathematicians, and engagement with professionals – is a dynamic, iterative process, unique to the ORS model of engagement. The design process involved six phases: module development, trialling, evaluation, analysis, enhancement and revision (Figure 2.2). A full illustration of the complexities of the design, development and review process is included in Appendix I.

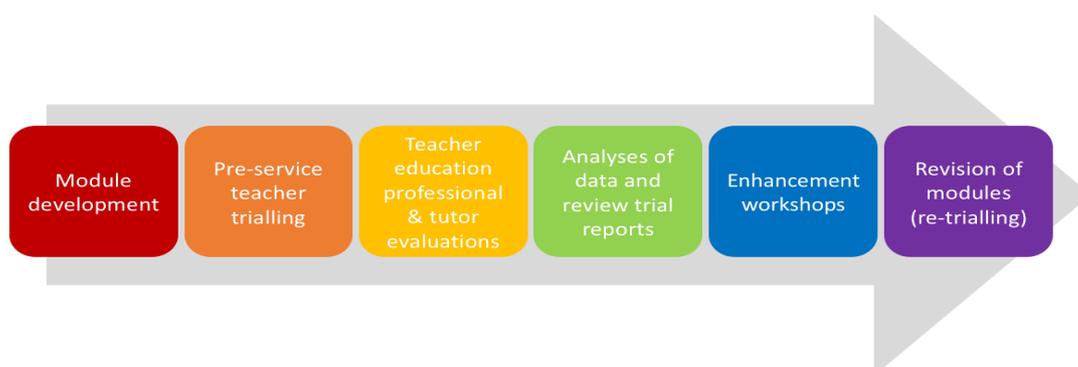


Figure 2.2: Opening Real Science module development process.

2.3.2 Learning management system and design tools

The online learning environment for the modules was created using the Moodle learning management system, which allowed for blended or online delivery. The modules use a range of Moodle tools, including discussion forums, quizzes, blogs, assignments and lessons organised in topics (Appendix J).

External resources such as YouTube clips, online collaborative tools (e.g. Google suite, Mindmeister), online applications (e.g. Money Smart), portal sites and other downloads were integrated to add variety of media and to expose students to these and other possible resources they could use.

2.4 Module trialling and evaluation

More than 70 trials were conducted across the seven partner universities between 2014 and 2016. These trials formed part of a contractual requirement of project partners to ensure module evaluation data was systematically collected from a range of teacher education programs and from varying perspectives, including scientists and mathematicians.

Trials varied in terms of the amount of module content trialled (e.g. only trialling one topic from a module consisting of five topics), level of integration into units (e.g. required 'hurdle task' or voluntary participation) and trial setting (e.g. full cohort enrolled in trial or individuals working through the module in a workshop approach). Many trials were limited by the university program approval and the state teacher accreditation requirements of the partner institution teacher education programs.

2.4.1 Data collection methods

Data was collected from three distinct sources:

- module trials with pre-service teachers (both primary and secondary)
- reviews by teacher education professionals (both in-service and teacher educators including tutors) and other education, mathematics and science academics
- module enhancement workshop reviews by stakeholders, educators and other academics, scientists, mathematicians and education designers.

Data from pre-service teacher module trials was collected using an anonymous online or paper survey, which was completed at the end of each module. Tutors provided feedback through a different survey. Both sets of data (quantitative and qualitative) are included in each of the trial reports. In all, 18 of the 25 modules were trialled by pre-service teachers.

All 25 modules were reviewed by teacher education professionals (including some Master of Education students) and/or scientists in the appropriate discipline. A module evaluation for teacher education professionals survey form (Appendix K) was used to collect this feedback. Academics reviewing newly developed modules before trialling provided an ORS module reviewer evaluation (Appendix L).

2.4.2 Pre-service teacher module trials and evaluation

Student evaluations via an online survey of the modules were collected from pre-service teachers drawn from partner university teacher education programs. From 70 trials that were commenced, 52 were completed (Table 2.1). Full trial data is provided in Appendix M.

Table 2.1: Summary of completed pre-service teacher module trials

Category	Module	Trials	Started	Completed	Evaluated
Primary maths	<i>Gateway to Numeracy</i>	5	226	121	112
	<i>Smart Budgeting Primary</i>	3	294	189	107
	<i>Statistical Literacy Primary</i>	3	323	130	73
Primary science	<i>Clocks in Rocks</i>	2	36	32	25
	<i>Consumer Chemistry</i>	6	496	340	145
	<i>Inspired by Plants</i>	2	41	31	12
	<i>Primary Astronomy</i>	4	115	92	96
	<i>Sound</i>	4	758	497	293
	<i>The Living Laboratory</i>	1	247	227	97
Secondary maths	<i>2 Infinity and Beyond</i>	1	25	22	19
	<i>Modelling the Present—Predicting the Future</i>	1	36	1	22
	<i>Smart Budgeting Secondary</i>	2	41	38	22
	<i>Statistical Literacy Secondary</i>	1	45	2	17
Secondary science	<i>Fundamentals of Weather and Climate</i>	3	698	264	395
	<i>Light</i>	3	125	30	33
K–12 science	<i>Discovering Real Science through Big History</i>	7	604	337	95
	<i>Human Impact</i>	2	80	4	29
	<i>Science in the Community</i>	2	36	31	16
Total		52	3506	2016	1468

Typically, module trials were delivered either exclusively online, or using a mixed mode where online delivery was supplemented by face-to-face tutor support. A small number of trials took place as small group workshops. Most trials took place over a three- to six-week period, or across an entire university semester. The partner institutions were mainly interested in trialling the science modules as these fulfilled a specific and prioritised need within their teacher education programs.

Participants had access to face-to-face or online support from tutors, typically from the same partner institution as the participants. Members of the ORS team also offered online and some face-to-face technical support to participants and tutors.

Most modules were received positively by pre-service teachers. However, it was found that pre-service teachers were not sufficiently prepared to work with the scientific content or the underlying inquiry-based approaches of the Australian curricula and state syllabuses. A few modules were more extensively modified following the reviews. An exemplar report of the *Consumer Chemistry* trials is provided in Appendix N.

Primary mathematics module trials focused on core critical numeracy skills, financial literacy and statistical literacy, which had not been addressed within the pre-service teachers' school preparation. Trial reports indicated that the pre-service teachers were challenged by the content and processes, such as using a spreadsheet. After working through the problems they were more confident in working with and representing numerical data.

Fewer trials were conducted for the secondary mathematics and science modules due to:

- the more advanced modules being completed later in the development cycle
- the highly sophisticated knowledge and requirements of the modules
- fewer students in the pre-service teacher education programs studying higher level mathematics and science for their degrees.

Modelling the Present—Predicting the Future and *2 Infinity and Beyond* were well received by the pre-service teachers but did require students to have specialist mathematical knowledge.

2.4.3 Teacher education professional expert reviews

In total, 110 (77 university-based and 33 school-based) teacher education professional comprehensive reviews were completed across all 25 modules, with the number of reviews per module varying from one to nine.

Teacher education professionals provided an overall rating of the modules using a six-point Likert scale (1 = 'very poor' to 6 = 'very good'). Generally, responses to the science modules were more positive than for mathematics although this varied according to the item. The module cluster with the most positive mean was the primary science cluster, which consisted of *Consumer Chemistry*, *Clocks in Rocks*, *Inspired by Plants*, *The Living Laboratory*, *Primary Astronomy* and *Sound*.

Teacher education professionals also provided qualitative responses to the question underpinning the ORS approach: 'How effective do you think the module is in improving pre-service teacher understanding of scientific/mathematical concepts?'. For each module, these responses were combined and analysed to give a 'grade' of the effectiveness of the module (Figure 2.3).

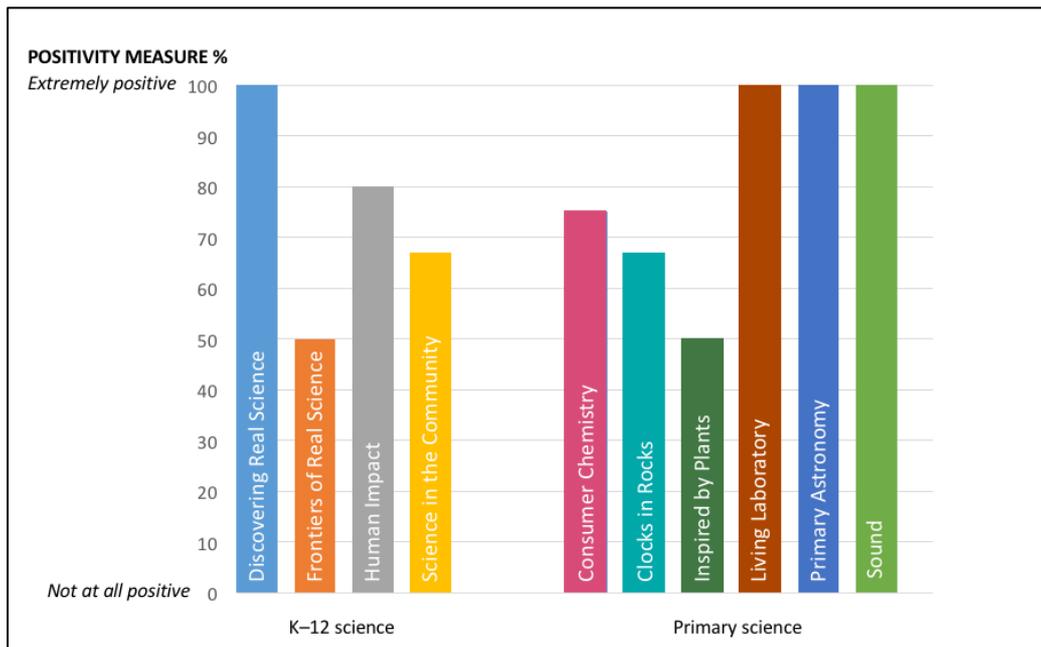


Figure 2.3: Teacher education professionals' response relating to module effectiveness.

The grade, calculated by examining the proportion of positive to negative responses for the survey, is an overall numerical gauge of the attitudes of the respondents. For example, a grade of 100 per cent indicates that all responses were positive, and a grade of 60 per cent indicates that 60 per cent of the responses were positive.

Teacher education professionals thought that many of the modules would effectively improve pre-service teacher understanding of scientific or mathematical concepts. Collectively this data (Appendix O) provided useful feedback for module enhancement from the perspective of an important group of stakeholders.

2.4.4 Module enhancement workshop reviews

Enhancement workshops were conducted to bring module development teams and other stakeholders together to review and provide feedback on the modules. Within these workshops, groups led by module developers focused collaboratively on how the modules met the ORS core concepts and design features. At least one enhancement workshop review was completed for each of the 25 modules.

During these workshops, module developers led small groups of stakeholders to review each module using a survey instrument developed for this purpose (Appendix P). Stakeholders were also invited to individually complete the same survey instrument prior to the workshop.

As a group, workshop participants responded to four items designed to gauge their perceptions of the module using a six-point Likert scale (1 = 'not at all' to 6 = 'extremely well'). Responses for each module cluster, based on stages of learning, indicate that workshop reviews were mostly very positive (Figure 2.4).

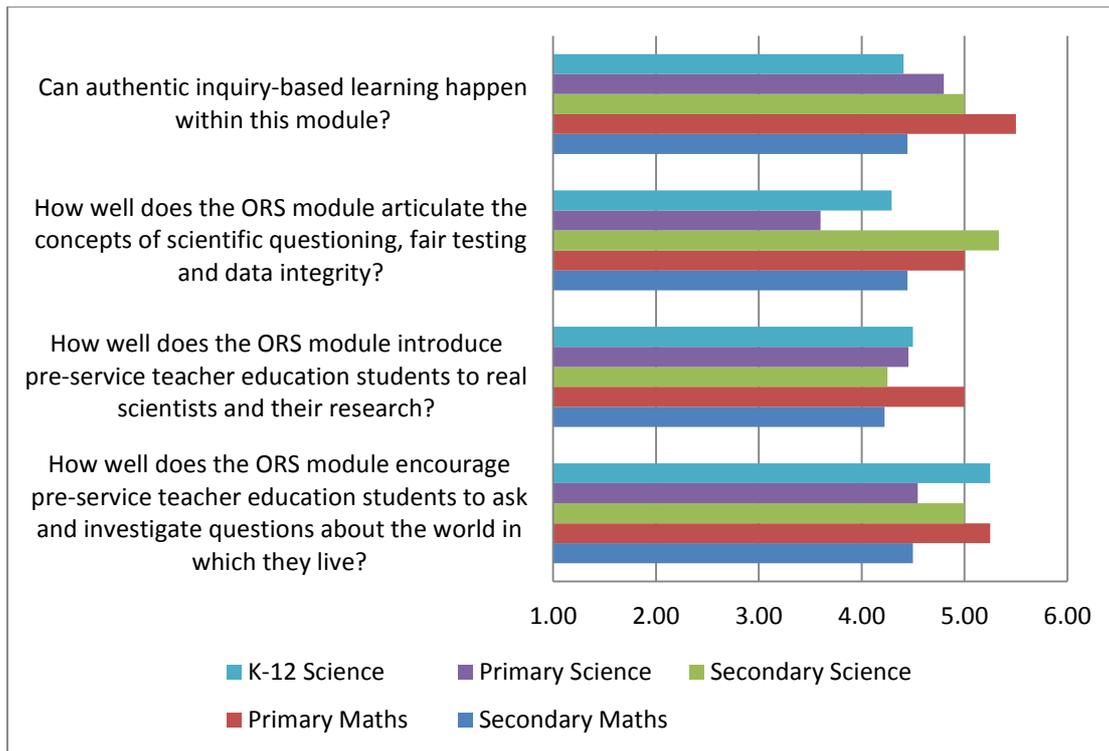


Figure 2.4: Workshop participants' perceptions of module clusters (mean values).

2.5 Module enhancement

The module review process described in Section 2.4 informed module enhancement, which involved three processes:

- mapping the module against the ORS design and framework, to ensure the final module design fulfilled the original design brief (based on design criteria) and met the project goals
- reviewing learning designs to ensure the modules achieved intended learning outcomes and met the needs of the intended audience
- quality assurance, to ensure the resulting set of modules were consistent in presentation and function, fulfilled the ORS design brief and were free from scientific errors at the point of testing before release.

The review process led to important enhancements. For example, initial reviews of some primary science modules indicated that the tutors needed more support to effectively implement the modules as part of the pre-service primary program. In response, tutor guides and learning strategy support were provided for modules trialled after the initial group. Work undertaken by the ORS module development teams after the initial trials also addressed the background and required knowledge of the pre-service teachers such that they were more able to complete high levels of conceptual understanding and engagement in later trials.

2.6 Implications and recommendations

Analysis of the data indicates that the ORS modules were successful in developing pre-service teachers' knowledge and understanding of mathematical and scientific concepts and engaging them in authentic problem-solving contexts.

It is clear that the trialling context affected the pre-service teachers' experiences and perceptions of the modules. The modules were implemented most effectively when they were integrated into existing teacher education units and when completion of the module was acknowledged for credit as part of the pre-service teacher's grade. Pre-service teachers reported that they enjoyed the practical nature of the learning experiences. Tutors and teacher education professionals also recommended that the modules align with primary and secondary curricula, enabling clear connections to be made between the modules and classroom applications.

Chapter 3: Specialist professional experience

A unique feature of the ORS project was the development and evaluation of a specialist professional experience model to enable pre-service teachers to focus on science and/or mathematics with support from a school mentor teacher and an ORS specialist advisor.

This was a direct response to previous findings that pre-service teachers in primary schools rarely observed or taught science during their professional experiences, and that most of the teaching of maths/science they observed or practised was traditional and teacher-centred (Campbell & Chittleborough, 2014).

3.1 Key features of the ORS professional experience model

The ORS specialist professional experience model included several unique elements:

- selection of pre-service teachers who expressed a particular interest in completing a science/mathematics-focused professional experience
- selection of mentor teachers who agreed to support the pre-service teachers in teaching of science/mathematics
- support from an ORS specialist science/mathematics advisor
- focus on the 6Es inquiry-based approach, and access to ORS modules.

3.2 Implementation, trials and refinement

3.2.1 Implementation procedures

Implementation varied between trials but generally included the following:

- Pre-service teachers were invited to submit expressions of interest.
- Schools known to ORS project staff to have a particular interest or expertise in teaching science and/or mathematics were approached to participate in the program and to nominate appropriate mentor teachers.
- Pre-service teachers and mentor teachers were selected, matched and advised about the ORS project aims and requirements.
- The specialist ORS advisor provided support for pre-service teachers during the professional experience and visited pre-service teachers on site.
- Mentor teachers completed a specific one-page report (Appendix Q) focusing explicitly on their pre-service teachers' competencies.
- Mentor teachers, pre-service teachers and the specialist university advisors were interviewed at the conclusion of their professional experience period.

A report of implementation issues is provided in Appendix R.

3.2.2 Trials

From 2014 to 2016 five specialist professional experience trials were conducted: four in primary schools and one small-scale trial in secondary schools (Table 3.1).

Table 3.1: Participant numbers in professional experience trials

	Primary				Secondary
	Trial 1 Sem 2 2014	Trial 2 Sem 1 2015	Trial 3 Sem 2 2015	Trial 4 Sem 1 2016	Trial 5 Sem 1 2016
Pre-service teachers	29	22	12	14	4
Mentor teachers	37	24	12	14	4
Schools	9	10	6	9	3

3.2.3 Trial refinement

As trials progressed, smaller numbers of pre-service teachers and schools were included.

Not all mentor teachers and schools could commit to involvement in multiple professional experience trials within a year due to the structure of alternating semesters of science and history/geography in school programs. In later professional experiences the criteria widened from seeking ‘expert’ science mentor teachers to recruiting those committed to supporting a pre-service teacher who wanted to focus on teaching science or mathematics.

Clarity about expectations was enhanced by provision of an after-school ORS orientation meeting. The goals and expectations of the specialist professional experience regarding a focus on science and/or mathematics were explicitly outlined, and mentor teachers and pre-service teachers were able to meet their professional experience partner if available. The modules were introduced and their place in the project was clarified.

3.2.4 Evaluation of the trials

A pre-program survey of the pre-service teachers’ competence and confidence in science, using the Science Teaching Efficacy Belief Instrument (Riggs & Knochs, 1990) and a post-program written survey, provided in-depth evidence of the change process. Two different formal assessments were provided by mentor teachers and the university advisors. Pre-service teachers’ learning plans/units of work, student learning data, and reflections provided supporting evidence of the impact of the program. Semi-structured interviews with pre-service teachers, mentor teachers and the ORS specialist university advisor also contributed to the evaluation process. Interview questions are included in Appendix S.

Mentor teachers reported on pre-service teacher competencies at the end of the 20-day professional experience, making an overall assessment using a specific ORS mentor teacher professional experience evaluation report (Appendix Q). This ranked pre-service teachers on 15 competencies as 'yet to be demonstrated', 'working towards', 'demonstrated' or 'exceeds expectations'. Mentor teacher assessments of pre-service teachers on three key science competencies are reported.

The ORS specialist university advisor completed a report after visiting the classroom and observing at least one lesson. A standard university pre-service teacher report based on the Australian Professional Standards for Teachers (issued by the Australian Institute for Teaching and School Leadership (AITSL)) at similar levels was completed. Four relevant elements of the Standard 2 section are reported.

3.3 Professional experience trial results

3.3.1 Primary professional experience trials

An important result from the professional experience trials was the increase from 2015 to 2016 in the percentage of pre-service teachers who were assessed as 'exceeded expectations' in science teaching competencies and subject and teaching knowledge (Table 3.2).

Table 3.2: Comparison of two professional experience trial cohorts – as assessed by mentor teachers and specialist university advisor in semester 1, 2015 and 2016

Year	Mentor teacher reports			Specialist university advisor reports		
	Competency	Pre-service teacher (n)	% exceeding expectations	Element	Pre-service teacher (n)	% exceeding expectations
2015	1	11	54	1	22	14
	2	11	54	2	22	32
	3	11	9	3	22	9
				4	22	40
2016	1	8	75	1	14	85
	2	8	75	2	14	92
	3	8	37	3	14	35
				4	14	50
	Science teaching competencies assessed by mentor teachers Competency 1: Uses scientific methodology and higher order tasks (e.g. hypothesising, predicting, observing, fair testing, data collection) Competency 2: Develops ‘rich’ science tasks Competency 3: Assesses science concepts and processes			Elements of AITSL professional standard 2 assessed by ORS advisor Element 1: Demonstrate knowledge and understanding of the concepts, substance and structure of the content and teaching strategies of the teaching area Element 2: Organise content into an effective learning and teaching sequence Element 3: Use curriculum, assessment and reporting knowledge to design learning sequences Element 4: Implement strategies for ICT to expand learning opportunities for students		

The results summarised in Table 3.2 suggest that the skills and competencies of students have generally been raised and demonstrate that pre-service teachers did use a ‘real’ science approach and engaged in higher order thinking and rich tasks.

In meeting the AITSL standards (elements) pre-service teachers demonstrated a substantial improvement in demonstrating knowledge, and understanding of the concepts, substance and structure of the content and teaching strategies (element 1) and organising content into an effective learning and teaching sequence (element 2). These data were supported by observation notes, pre-service teachers’ reflections and student work samples.

Participant comments supported the quantitative review. The following are indicative of comments received:

From pre-service teachers:

I got to teach science, because in all my other pracs, they actually didn't do science at all during the time I was at the school. I never saw a science lesson. They never taught a science lesson. So that was good that I actually got to see a teacher actually focusing on science. – Pre-service teacher, 2015

In my first prac last year I was just absolutely terrified after teaching maths and science because I just didn't know what I was doing ... [in this prac] I felt like I was more confident and I felt more excited to teach maths and science and I want to teach it just 24/7 now. – Pre-service teacher, 2016

From mentor teachers:

Primarily because of this Opening Real Science prac that we've had over the last few years it's changed my outlook in science and therefore we in Year 6 this year ... that's been our main focus for the last six months. So that's Year 6, but the rest of the school was just – get a unit, most probably don't finish it; would barely touch it. – Mentor teacher, 2015 and 2016

A major positive was the support from the university advisor ... he spoke to the class and worked closely with us. He gave us ideas ... I asked him about changing how we teach science here and he spent time with me ... He has been a wonderful advisor and a major part of the program. – Mentor teacher, 2015 and 2016

Absolutely. I learned a lot from her. Not only her energy and engagement with children, the way she explained things, she was very collaborative, the way she set key inquiry questions for children. My teaching practice has changed – I ask more questions the way she modelled ... I am doing more of that. – Mentor teacher, 2014–2016

The big positive advantage was the focus on science. I found it challenging as I lacked confidence and also found it hard to fit into the crowded week, so being forced to do it helped over time. We tried different ways and I got to try ways that were not teacher-directed. – Mentor teacher, 2015

Mentor teacher and university advisor comments are provided in Appendix T.

3.3.2 Secondary professional experience trial

The small-scale secondary mathematics and science trial identified issues and pressures on implementation different to those of the primary specialist professional experience.

Secondary pre-service teachers are being trained as specialist science or mathematics teachers, unlike the primary pre-service teachers. Therefore, the challenges for them do not relate so much to confidence and competence, but more to pedagogy, encouraging an inquiry-based approach and establishing authentic contexts for learning.

Evaluation data suggest that the ORS professional experience was successful in meeting these needs. One mentor teacher saw the focus on 'hands-on' science (with demonstrations and experiments) as a major benefit, assisting pre-service teachers to 'support theory with practice', an element seen to be missing in previous professional experience periods. ORS pre-service teachers were judged to have connected lessons more to real life (i.e. 'real science'), planned together more collaboratively than in the past, and successfully engaged some quite challenging students through a more active inquiry approach to lessons. It was noted that other in-service science teachers also joined in the discussions.

The input of the specialist ORS university advisor, who provided support by email and visited each student several times, was seen as a particular advantage, as was the self-nomination of pre-service teachers for the program.

Chapter 4: Project outcomes and impact

The ORS project outcomes and impact are described in terms of three main outputs:

- developing and evaluating a new model of specialist primary science professional experience (ETMST priority 3)
- developing and embedding a new pre-service teacher education curriculum through 25 learning modules (ETMST priority 3)
- developing a collaborative network (ETMST priority 1)

4.1 A new model of specialist professional experience

The ORS professional experience model was well received, with clear benefits for pre-service teachers, mentor teachers and schools. Appendix V provides further detail of the recommendations for planning, implementation, and evaluation process. The roles of the university specialist advisors and the school-based mentors are described as critical to effectiveness of the program.

Pre-service teacher participants cited greater confidence, commitment to science teaching and an inquiry-based approach, and excitement about teaching generally. Participants took up opportunities for broader engagement in science networks set up by the ORS program and university advisor (e.g. volunteering at the Australian Museum), promoting their broader knowledge and ongoing interest in science. Both the quality and quantity of science learning was significantly increased. The focus of lessons extended beyond regular topics embedded in school plans to units of work on relevant scientific investigations, often linked to collecting and analysing data.

Mentor teachers valued the focus on science (in particular) and some learned new scientific knowledge or pedagogical strategies. Those mentor teachers not claiming to be science experts noted greater student engagement and participation in science lessons, and thought that their students were learning 'real' scientific concepts. Several very experienced mentor teachers thought that they had learned a great deal from working with their pre-service teacher, while mentor teachers without particular expertise often gained significantly from participation. The resulting establishment of networks between pre-service teachers, ORS schools and university staff has been a positive outcome that will continue beyond the project.

4.2 A new pre-service teacher education curriculum

The role of the ORS modules collectively in promoting and engaging pre-service teachers in authentic mathematics and science is still being articulated, and in particular an evaluation of the explicit role of quantitative skills within scientific inquiry is needed (Matthews, et al., 2012).

Broadly, the ORS trialling has indicated that modules are viable, and effective for enhancing pre-service teacher knowledge and inquiry-based skills. However, finely articulated aims concerning approaches to pre-service teacher engagement in

authentic scientific problems are essential as modules become embedded in teacher education programs.

4.2.1 Embedding ORS modules across teacher education programs

Five of the seven ORS university partners embedded the modules in varying ways to accommodate their teacher education program requirements and resource limitations (summarised in Table 4.1).

Table 4.1: Embedded Opening Real Science material at partner institutions

Institution	How ORS modules have been embedded	ORS modules
Macquarie University	ORS material embedded into a range of newly designed units approved for teacher education programs. Activities from some of the ORS modules embedded into tutorials for primary pre-service teachers in the compulsory science and technology methodology units. Activities from other ORS modules have been adapted for the compulsory secondary pedagogical units.	<i>Consumer Chemistry: Gateway to Numeracy; Smart Budgeting Primary; Statistical Literacy Primary; Discovering Real Science through Big History; Frontiers of Real Science; Clocks in Rocks; Fundamentals of Climate and Weather; Sound</i>
Charles Sturt University	ORS material used in science literacy unit for pre-service teachers.	<i>Discovering Real Science through Big History; Consumer Chemistry; The Living Laboratory</i>
Australian Catholic University	ORS material incorporated into two science education units.	<i>Sound; The Living Laboratory; Consumer Chemistry</i>
Western Sydney University	ORS material embedded into new and existing undergraduate pathways to teaching units.	
The University of Notre Dame Australia	ORS material is the basis for a science education unit.	<i>Discovering Real Science through Big History; The Living Laboratory</i>

4.2.2 Redevelopment of ORS modules for accredited professional learning

The plan for the adoption of ORS modules for professional learning for in-service teachers within the school sector has been developed in collaboration with the NSW Education Standards Authority from the early stages of ORS.

To date, some professional learning workshops using ORS modules have been given 'proficient' level accreditation by the NSW Education Standards Authority. The proposal for professional learning accreditation of selected and adapted ORS modules in the Macquarie University teacher education program is under review by the NSW Education Standards Authority.

In-service teacher professional learning workshops based on ORS have already provided welcome opportunities for developing professional networks between students, teachers, education researchers and scientists. Pre- and in-service teachers have reported their enthusiasm for engaging with professional scientists: effective relationships have been forged and follow-up workshops are planned. The upscaling of the ORS professional learning strategies has been planned within the scope of the ORS dissemination plan for ORS partners and with regulatory authorities.

4.3 Collaborative networks

Networks are about people. This project has been very successful in connecting scientists, mathematicians, statisticians and teacher education professionals, both within the project team and with external parties. The extent of collaboration within ORS has grown substantially over the project lifetime, both organically and through concerted and directed effort. This collaboration exists at many levels and in diverse forms: the project leadership team sought to bring together university and external partner scientists, mathematicians and educators, pre-service and in-service teachers, and representatives of the various stakeholder groups.

4.3.1 Collaboration between scientists, mathematicians and educators

Each of the universities has reported improved communication between disciplines through this project. The intermingling of people involved in scientific research with the teacher education professionals has led to curriculum changes and more interplay between departments, which will improve the teaching in the science faculties as well as influence teacher education to engage with real science.

Collaboration between scientists, mathematicians and educators is most clearly evident in module development, and is showcased in the module *Modelling the Present—Predicting the Future*. This module involved distinct contributions from mathematicians, scientists and educators, and featured real interdisciplinary problems and contexts (Appendix U).

Beyond the modules are many examples in which ORS project scientists have delivered (science) content to pre-service teachers during tutorials, laboratory sessions and customised workshops. As notable examples, ORS Research Fellow Dr Cormac Purcell designed and delivered hands-on workshops to 40 pre-service teachers and 26 in-service teachers, while Professor Pask (ORS physics) educated pre-service teachers on the topic of light during a Science behind the Art workshop at the Macquarie Art Gallery. There have also been ongoing joint dissemination activities such as collaborative conference and seminar presentations and publications (Appendix X).

The strong links forged during the project will continue, and will enable sustainability strategies and outcomes to be communicated beyond the life of the ORS project.

4.3.2 Collaboration with industry organisations

ORS engaged three non-academic industry partner organisations, each of which made important contributions to the project:

- Las Cumbres Observatory Global Telescope made their remote telescope network available to pre-service teachers undertaking ORS modules.
- The Australian Astronomical Observatory provided videos and other materials that were incorporated into several modules. This allowed the ORS to capitalise on the work of Dr Amanda Bauer and colleagues, which resulted in authentic and engaging content. In addition, Dr Fred Watson and Mr Rob Hollow served on the ORS Reference Committee.
- CSIRO Astronomy and Space Science contributions included participation in workshops, critiquing of astronomy modules, and sharing of initiatives to support training of pre-service and in-service teachers.

Other organisations and agencies that have been involved in the project collectively span science, astronomy, the arts, museums, professional associations and government. From the outset, collaborative partnerships were seen as pivotal to the success of ORS, and indeed to the long-term prospects for ETMST. In particular the collaboration with the CSIRO provided access to certain resources, which would have not been possible without their input in the ORS module development and other activities.

4.3.3 The ORS Fellowship: ‘boundary crossing’ between science and education

A cross-faculty ORS Fellowship in Science (Physics and Astronomy) and Education funded by Macquarie University was created at Macquarie University, with the purpose of melding scientific and educational expertise to support module development and engage with pre-service teachers. The leadership of two ‘real scientists’, Dr Heath Jones and Dr Cormac Purcell, was critical in designing module content as relevant to scientific practice: hypothesis, experiment, observation, interpretation and debate.

4.3.4 Cross-faculty (Science and Education) working group

A legacy of ORS at Macquarie University has been the formation of a cross-faculty working group. Chaired by the Head of Mathematics, the group will continue to review the role of mathematics and science in the primary and secondary teacher education programs. This collaboration will provide students with STEM-focused options for primary mathematics and science specialisations and an improved integrated Bachelor of Science/Bachelor of Education (BSc/BEd) double degree.

The model can be adapted at universities where education students can access units of study from established science faculties, and similar groups have been partially developed at Western Sydney University and Charles Sturt University.

Developing and embedding effective cross-faculty relationships relies on executive-level support from deans and Teaching and Learning Program directors, and the engagement of committed representatives from science departments and education departments. It is then important to establish terms of reference and processes for reporting the activities for program review. Ongoing success relies on revising program scope and delivery as required in response to cross-faculty review and evaluation of student engagement.

Chapter 5: Lessons, recommendations and dissemination

5.1 Lessons learned

Over the course of the project, a number of lessons were learned that will inform future initiatives to support the development of mathematics and science capabilities in pre-service teachers:

- **Allow sufficient lead time for approval and accreditation.** Reconceptualising mathematics and science teacher education curricula for a range of degree structures is a complex process that takes planning and substantial lead time for approval through education faculties and universities. Approval processes for university programs vary widely, as do their strategic directions for teaching and learning. The various requirements of teacher education accreditation authorities need to be taken into account.
- **Teacher educators and tutors collaborated well with the project team,** although some required additional support with the integration into their education programs. A further challenge will be the ongoing evaluation to demonstrate impact at pre-service and in-service level and in turn on student learning in schools.
- **Online learning opportunities can engage students provided that they are given appropriate support at program level.** Another challenge focused on the online delivery, which raised some questions about the implementation of practical experiences utilising scientific (and mathematical inquiry) approaches. The challenge was to design the ORS modules in a way that would require pre-service teachers to engage in their own scientific explorations with an expanded view of what constitutes real mathematics and science. The use of real cases through videos and active experimentation and articulation of scientific and mathematical concepts gave impetus for pre-service teachers to develop new knowledge and more relevant scientific approaches in their teaching.

5.2 Step changes and recommendations

Seven step changes were identified through the ORS project experience, leading to the following recommendations for enhancing the mathematics and science capability of pre-service teachers.

1. Effective development of specialist competent primary mathematics and science teachers can be achieved through a collaborative ORS model.
 - Implement specialist professional experience in primary mathematics and science or STEM, with a minimum of 20 hours' experience over a four-week block (e.g. a science lesson each day). Support from an expert science/mathematics advisor (seconded from school systems or part of a

university program) and a mentor teacher supportive of STEM initiatives are essential.

- Recognise the different challenges for primary and secondary pre-service teachers in the design of teacher education programs.

2. Capabilities and capacity of pre-service primary teachers can be significantly improved and expanded through strategic changes at higher education level.

- Prioritise within (Australian Council of Deans of Education and Deans of Science) higher education academic programs and strategic planning the review and expansion of mathematics and science education within primary teacher education programs, coordinated with the recruitment of specialist educators with expertise in mathematics and science.
- Train and appoint mathematics and science tertiary education experts, recruited from science or mathematics or related fields, as ‘boundary crossers’ with effective experience in scientific pedagogy.

3. Systematic evaluation of primary and secondary (mathematics and science) pre-service teacher education programs can inform the scope and direction of much needed change.

- Redesign mathematics and science pre-service programs from the ground up based on systematic evaluation data of the outcomes of existing programs and the potential input from science faculties (and mathematics, engineering and ICT disciplines) and collaborative networks. The groundwork has been laid, but more work is needed in academic program review and development, and strategies for effective teaching and learning.
- Monitor the progress of specialist primary science teacher education graduates from their early career stage with a priority to review their impact on teaching and learning and their potential leadership role in school systems.

4. Cross-faculty and cross-departmental collaboration can improve mathematics and science teacher education programs.

- Establish effective collaborative committee and program development structures within universities where science and education faculties and departments (such as a cross-faculty working group) work together in the development, implementation (and possibly joint teaching) and evaluation of STEM programs.

5. Pre-service teachers can successfully apply mathematics and science knowledge and processes gained through academic study offered by faculties and departments of mathematics and science.

- Develop specialist primary mathematics and science education programs that tailor mathematics and science academic units and coordinate their delivery.

6. Authentic scientific contexts can transform and enrich pre-service programs with the collaboration of scientists engaging pre-service teachers in scientific process and mathematical thinking.

- Integrate real science contexts and problems, including industry or community-based field work or contexts, into mathematics and science teacher education programs.
- Shift focus from traditional pedagogies aligned with syllabus content to engaging in contexts of authentic and practical applications of mathematics and science.

7. Cross-institutional cooperation and collaboration can facilitate improved sharing of resources and expertise.

- Facilitate new ways of integrating of content and pedagogy that reach beyond the level of individual institutions where the ETMST collaborative networks and resources can be shared, particularly where some teacher education programs do not have direct support from scientists and mathematicians.

5.3 Dissemination of project outputs and knowledge

ORS project outputs and knowledge have been disseminated to different audiences including the higher education sector, school systems, teacher educators, primary and secondary mathematics and science professionals, professional associations and other stakeholder groups via a range of publications and activities.

Two key tools in this regard have been the [ORS project website](#), which provides an overview of project activities, news, events and outputs, and the ORS brochure (Appendix W), which served as the primary source of marketing for the project.

The project produced 11 articles, published in both peer-reviewed and professional (education) publications. In addition, 14 conference papers were produced, with some reported at international meetings and forums.

Particular attention was paid to dissemination at meetings of Australian Conferences in Science and Mathematics Education, and the Australian Council of Deans of Education. An ORS submission to the Teacher Education Ministerial Advisory Group was contributed in 2015.

A comprehensive list of key dissemination outputs is contained in Appendix X ('Summary of ORS project dissemination activities'), Appendix Y ('Publications and conferences'), and Appendix Z ('Other resources').

The ORS project activities will be sustained throughout 2017 and beyond. Activities include dissemination to other ETMST consortia. The ORS modules will be accessible to all Australian teacher education programs in 2017 with ORS university partners embedding in programs. An MQ specialist primary science professional experience program will be implemented in July-August period. A series of

publications about the implementation and evaluation of pre-service teachers' learning gleaned from the module trial data is planned for the period 2017-2019 with each of the module teams. Other activities include widespread dissemination at local, state and national Australian conferences for professionals from university and educational systems; impact will also be extended to a paper to the Psychology of Mathematics Education group, Singapore July 2017. Further activities centre on adaptation of the ORS modules for professional learning and the NSW Education Standards Authority accreditation of the ORS professional experience model for mentor teachers.

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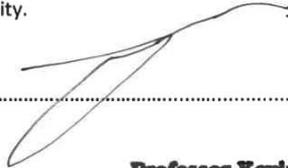
Appendices

Appendix A: Certification by Deputy Vice-Chancellor (Research)

Certification by Deputy Vice-Chancellor, Macquarie University, Sydney

I certify that all parts of the final report for this *Enhancing the Training of Mathematics and Science Teachers* project provides an accurate representation of the implementation, impact and findings of the project, and that the report is of publishable quality.

Name: Date:



22.4.17

**Professor Kevin Jameson
Interim Deputy
Vice-Chancellor
(Academic)**

Appendix B: ORS intended project logic statement

'Real' science is practised science using the processes of hypothesis, experimentation, observation, interpretation and debate.

1 Opening Real Science (ORS) is a collaborative partnership between Macquarie University, University of Western Sydney, Charles Sturt University, Australian Catholic University, Canberra University, The University of Notre Dame Australia, Australian Astronomical Observatory, CSIRO Astronomy and Space Science and Las Cumbres Observatory Global Telescopes, supported by funding from the Australian Government Office for Learning and Teaching (OLT) Enhancing the Training of Mathematics and Science Teachers (ETMST) grant scheme.

2 Opening Real Science will:

- Improve content knowledge and develop new teaching practices among graduating teachers.
- Develop new levels of cooperation between academics, practising mathematicians, scientists and teachers.
- Develop innovative curricula and pedagogies in pre-service and in-service primary and secondary teacher education.
- Support a specialised mathematics and science practicum involving teams of pre-service student and school-based mentors.

3 Inputs

- The module development team will align resources with AITSL and ACARA standards in collaboration with other key stakeholders – practising teachers, mathematicians and scientists.
- The partner universities will trial and evaluate the ORS program and train ORS school-based mentors.
- School-based mentors and practising scientists will support pre-service teachers in primary and secondary Initial Teacher Education programs.
- Partner institutions provide facilities for flexible delivery of the ORS program.

4 Actions

- Authentic science will be embedded in the design of the ORS task-based resources.
- Newly-developed ORS modules will be integrated into existing teacher education programs.
- School-based mentors will trial and evaluate the ORS modules at varying levels.
- AITSL will accredit the ORS modules for pre-service and in-service primary and secondary teacher levels.

5 Outputs

- The ORS program and resources for pre-service and in-service teacher education.
- Specialist primary and secondary mathematics and science teachers.
- A network of ORS practising mathematicians and scientists.
- A network of ORS accredited school-based mentors in both primary and secondary schools.
- An ORS website with links to other educational resources.
- An ORS teacher educator network.

6 Outcomes

- Increased cooperation within and between universities, schools, practising mathematicians and scientists, and stakeholders.
- A 'real science' approach to pre-service and in-service teaching.
- New pre-service mathematics and science teacher education program.
- Improved teacher capability in mathematics and science.
- Increased capacity of mathematics and science teachers at primary and secondary levels.

7 The *Opening Real Science* legacy

- Open access to the ORS program and authentic science.
- Sustained cooperation between educators and practising scientists and mathematicians.
- Valuing mathematics and science in Australian society.
- Task and inquiry-based resources that promote authentic science.

Appendix C: ORS evaluation plan

Office for Learning and Teaching

Enhancing the Training of Mathematics and Science Teachers Program

Evaluation Plan – 28 February 2014

MS13-3169: Opening Real Science: Authentic Mathematics and Science Education for Australia

Macquarie University

Project Partners: University of Western Sydney, Charles Sturt University, Australian Catholic University, Canberra University, The University of Notre Dame Australia, Australian Astronomical Observatory, CSIRO Astronomy and Space Science, Las Cumbres Observatory Global Telescopes.

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Evaluation of Opening Real Science

The evaluation of *Opening Real Science* will take a design research process approach. It will employ mixed methods so that the early designs for the rich tasks will be trialled and evidence for the design decisions collected. It is expected that as more of the modules are trialled with more of the partners less intensive data collection methods will be undertaken. Each evaluation function formative, summative and impact will employ a variety of activities using procedures and tools (instruments) that are appropriate to the size of the evaluation task. The tools have been used in previous projects of the team leaders such the ARC project entitled *Space to Grow* which focussed on the development of interest in Astronomy with senior students years 10 to 12. The tools will include measures of efficacy, as major changes will be required in the pre-service and in-service participants.

Project goals

The major goals of the project and evidence of achievement of these goals are to:

1. Improve content knowledge and develop new teaching practices among graduating and in-service teachers using 'real science' thinking and processes.
Teachers demonstrate content knowledge of mathematics and science to ensure they can competently design and implement real science learning programs. The ORS modules will cover a range of pertinent content areas (topics) and model well designed learning experiences in mathematics and science.
2. Develop new levels of cooperation between academics, practising mathematicians, scientists and teachers.
As each module content and teaching strategies will be derived from academics and professional scientists, the final modules, designed in conjunction with the National Curriculum, will also show evidence of effective collaboration for their success.
3. Develop innovative curricula and pedagogies in pre-service and in-service primary and secondary teacher education in mathematics and science and inspire their students through embedding mathematics and science practices in the developed resource modules.
Innovative curricula and pedagogies are evaluated through various instruments in terms of pre-service and in-service teaching learning, and quality of learning experiences demonstrated in classrooms.
4. Support a specialised mathematics and science practicum involving teams of pre-service student and school-based mentors.
Attracting pre-service and practising teachers to engage in specialist studies and programs in mathematics and science to participate in, and disseminate, applied science practices for improved uptake of these subjects in secondary school.

These already-endorsed goals form the purposes of the evaluation of the *Opening Real Science* project.

Evaluation audiences

The evidence to be collected will be used to report on project progress to the Office of the Chief Scientist, Office for Learning and Teaching, the project Reference Committee, the project evaluators, and stakeholder partners. Reports will also be made to the University Executive, the participating mentor teachers, pre-service teachers, in-service teachers, state Departments of Education, other participating systems, community-based organisations, and the collaborating scientists. Secondary audiences will include: national and international professional associations and specialist STEM conferences.

Formative evaluation plan

These questions and strategies will inform the monthly project team evaluation team and Reference Committee meetings (biannual) of the project's progress. The data will be collected continuously and reported as each module is released for trial.

Outcomes (from IPL)	Formative questions	Evidence sources	Action/strategies
Increased cooperation within and between universities, schools, practising mathematicians and scientists and stakeholders.	<p>What cooperation has been achieved at each review point?</p> <p>Is the ORS program module development on time and track?</p> <p>What support is needed to achieve effective collaboration between the partners?</p>	<p>An ORS network of contributing scientists and mathematicians.</p> <p>A network of ORS accredited school-based mentors actively providing teacher guidance and 'working' feedback.</p> <p>Survey and interview data to monitor from the mathematicians, scientists & academics on pedagogical 'lessons' and changes.</p> <p>Survey and interview educators on mathematical and scientific changes in knowledge and practices while developing, trialling and implementing modules.</p> <p>Survey and interview major stakeholders on the effectiveness of the partnership and cooperation overall.</p>	<p>Review plan will be presented to the Reference Committee and progress assessed.</p> <p>Monthly review and summary of what has been achieved and composition of groups working on modules by the Project Leaders.</p> <p>Regular formal and informal discussions and input on the basic design framework, pedagogies, and scientific processes between stakeholders.</p> <p>Ongoing OLT reporting</p> <p>Scoping Workshops</p>
A 'real science' approach to pre-service and in-service teaching.	<p>Does each module employ an authentic approach to the topic and enable the learners to undertake a scientific approach to the module topic?</p> <p>How are the design principles realised in the approach?</p>	<p>Authentic science will be embedded in the design of the ORS task-based resources with input by practising mathematicians and scientists.</p> <p>ORS website with links to other educational, mathematics and science resources.</p> <p>Rich task-based learning experiences where 'real' methods are documented for assessment by the ORS team and teachers.</p>	<p>Each module will be reviewed by the project team and trialled in module-development universities (MQ, WSU, CSU) and trialling universities (ACU, UC, UND).</p> <p>Provide links to examples of science methodology and thinking that relate to the topic for both ORS module presenters and audience.</p> <p>School-based mentors will use and evaluate</p>

Outcomes (from IPL)	Formative questions	Evidence sources	Action/strategies
			each module.
New pre-service mathematics and science teacher education program.	How are the newly-developed ORS modules integrated into existing teacher education programs? How would the modules be relevant to more than one 'discipline' and curriculum area?	Pre-service teachers will be actively encouraged to enrol in 'mainstream' mathematics and science courses and learn alongside students who have a natural interest for the topic. Specialised practicum for mathematics and science for primary	Curriculum-mapping to ensure modules align to relevant discipline/s of the Australian Curriculum. Accrediting authorities will accredit the ORS modules for pre-service and online professional learning. NSW Education Standards Authority (or the equivalent in different jurisdictions) will accredit the professional learning.
Improved teacher capability in mathematics and science.	Do the ORS modules contribute to increasing knowledge and improved teaching practice of the pre-service and in-service teachers?	Interviews of existing, basic misconceptions of the topic content, and where these may have originated. Specialist primary mathematics and science teachers. Classroom practice: evidence of teaching (video data). Assessment of ORS activities in universities, particularly pre-service teachers developing and presenting own lesson plans.	Formative assessment of teacher scientific concepts and authentic rich task design. Measures of the understandings (knowledge and attitudes) held by participants before and after the module.
Increased capacity of mathematics and science teachers at primary and secondary levels.	Are pre-service participants able to design authentic mathematics and science lessons?	Increased enrolments in Mathematics and Science university education programs. Extra 'takeup' of resources and practices within universities and schools.	Follow-up survey and collection of lesson plans and mathematics and science programs from pre-service teachers and in-service participants in professional learning. Follow-up interviews/surveys with mentor teachers on noted impact.

ACU, Australian Catholic University. IPL, Intended Project Logic Statement. CSU, Charles Sturt University. MQ, Macquarie University. ORS, Opening Real Science. OLT, Office for Learning and Teaching. UC, University of Canberra. UND, The University of Notre Dame Australia. WSU, Western Sydney University.

Sources of data

It is expected that data will be collected from the following:

- Pre-service teachers and from units that chose to use the ORS modules
- Teacher education program academics
- Mentor teachers in schools
- Principals of schools. How they respond to the changed practicum model and the support of teachers.
- Pupils in the mathematics and science classrooms
- Collaborators who are implementing the modules into their pre-service programs
- Academics and scientists in high-profile research oriented positions (within the academy and in science organisations)
- OLT project evaluators
- Community collaborators
- Other OLT consortia

Summative evaluation plan

These questions and strategies will summarise the outputs and legacy of the project.

Outcomes (from IPL)	Summative questions	Evidence sources	Action/strategies
Increased cooperation within and between universities, schools, practising mathematicians and scientists and stakeholders.	What ORS modules are available? How do they reflect effective collaboration between the partners?	An established ORS network of practising educators, mathematicians and scientists.	Review and summary of what has been achieved from formative reports. Final OLT report Linkages made with existing networks (e.g. ACDS Teaching and Learning Centre www.acds.edu.au/tlce/ntre/), mathematics and science teaching networks.
A 'real science' approach to pre-service and in-service teaching.	Does each module employ an authentic approach to the topic? Can educators devise learning activities that are authentic tasks and reflect real scientific knowledge of how these link to current 'real-life' applications?	An ORS website with links to other educational resources. Work samples from teachers and pre-service educators.	School-based mentors will implement ORS across their school and actively support training of mathematics and science teachers. Total number of modules and their alignment with the Australian curriculum – mathematics and science.

Outcomes (from IPL)	Summative questions	Evidence sources	Action/strategies
New pre-service mathematics and science teacher education program.	Are the newly-developed ORS modules integrated into existing teacher education (or real science) programs?	Specialist primary mathematics and science teachers. Specialised Practicum for Mathematics and Science for Primary.	New units will be submitted to each university for accreditation, implementation and review.
Improved teacher capability in mathematics and science.	Do teachers use the 'real science' approach in their own teaching?	Increased numbers of primary mathematics and science learning activities undertaken in the classroom.	Teacher scientific concepts and authentic rich task design.
Increased capacity of mathematics and science teachers at primary and secondary levels.	Can pre-service participants design and evaluate authentic mathematics and science lessons?	Increased enrolments in Mathematics and Science university education programs.	Review of the collection of lesson plans/programs for mathematics and science programs from pre-service teachers and in-service participants in professional learning.

ACDS, Australian Council of Deans of Science . IPL, Intended Project Logic Statement. ORS, Opening Real Science. OLT, Office for Learning and Teaching.

Timeline

Formative evaluation will be consolidated for each meeting of the project team and the project Reference Committee. The summative evaluation will be a summary of all the project achievements and constitute a final report to the OLT.

Up to this time, the first establishment report has been provided to the Reference Committee and the project leaders' fortnightly meetings.

Appendix D: Contributors, committees, scholarships and fellowships

Opening Real Science project leadership team

- Professor Joanne Mulligan (Project Leader), Professor of Education (Mathematics and Science), Department of Educational Studies, Macquarie University
- Professor John Hedberg, Adjunct Professor of Education, Department of Educational Studies, Macquarie University
- Associate Professor Leanne Rylands, Centre for Research in Mathematics, School of Computing, Engineering & Mathematics, Head, Mathematics Education Support Hub (MESH), Learning Futures Portfolio, Western Sydney University
- Dr Michael Cavanagh, Director, Teacher Education Program, Department of Educational Studies, Macquarie University
- Professor Helen Pask, Professor of Physics and ARC Future Fellow, Department of Physics and Astronomy, Macquarie University
- Professor Leigh Wood, Professor of Higher Education, Associate Dean, Learning and Teaching, Faculty of Business and Economics, Macquarie University
- Professor Vince Geiger, School of Education Queensland, Faculty of Education, Australian Catholic University
- Sarah Rosen, Project Support, Opening Real Science, Department of Educational Studies, Macquarie University
- Professor Quentin Parker,* Faculty of Science and Engineering, Macquarie University
- Associate Professor Carmel Coady,* Adjunct Professor, Deans Unit School of Computing, Engineering and Math, Western Sydney University
- Professor Elizabeth Deane,* Adjunct Professor, Office of the DVC & VP (Research and Development), Western Sydney University
- Carolyn Dow,* Project Support, Opening Real Science, Department of Educational Studies, Macquarie University

Opening Real Science reference committee

- Professor Lori Lockyer (Chair), Department of Educational Studies, Macquarie University
- Professor Marguerite Maher (Deputy Chair), Dean of the School of Education, The University of Notre Dame Australia
- Dr Mark Butler, Head Teacher Science, Gosford High School
- Dr Michael Cavanagh, Director, Teacher Education Program, Department of Educational Studies, Macquarie University
- Professor Doug Clarke, Director, Mathematics Teaching and Learning Research Centre, Australian Catholic University
- Dr Paul Corcoran, Director Grants and Fellowships, Office of Learning and Teaching

- Professor Robert Fitzgerald, Director INSPIRE, Associate Dean Education Innovation, University of Canberra
- Ms Sharon Ford,* Director Secondary Education, NSW Department of Education
- Ms Susan Gazis, Senior Policy Officer, Professional Learning, NSW Education Standards Authority
- Professor Vince Geiger, Professor of Education, Learning Sciences Institute Australia, Australian Catholic University
- Dr Ed Gomez, Education Director, Las Cumbres Observatory Global Telescope Network
- Professor John Hedberg, Adjunct Professor of Education, Department of Educational Studies, Macquarie University
- Mr Rob Hollow, Education and Outreach Officer, CSIRO Astronomy and Space Science
- Dr Andrew Hopkins, Head of Research and Outreach, Australian Astronomical Observatory
- Dr Simon Johnston, Head of Astrophysics, CSIRO Astronomy and Space Science
- Dr Simon Leonard, Associate Professor of the Learning Sciences, University of Canberra
- Dr Naomi McClure-Griffiths,* CSIRO Astronomy and Space Science
- Professor David McKinnon, Professor of Education and Director Academic, Edith Cowan University
- Professor Mary Mooney, Deputy Dean, School of Education, Western Sydney University
- Professor Joanne Mulligan (Project Leader), Professor of Education (Mathematics and Science), Department of Educational Studies, Macquarie University
- Professor Ron Oliver, Pro-Vice-Chancellor Teaching and Learning, Edith Cowan University
- Professor Lindsay Parry, Head of School, School of Education, Charles Sturt University
- Professor Helen Pask, Professor of Physics and ARC Future Fellow, Department of Physics and Astronomy, Macquarie University
- Dr Roslyn Prinsley, National Advisor for Mathematics and Science Education and Industry, Office of the Chief Scientist
- Dr John Rafferty, School of Environmental Sciences, Charles Sturt University
- Ms Sylvia Schmidt,* Acting Director, Office for Teaching and Learning
- Mr Glen Toohey, Assistant Director, Learning and Teaching Support, Higher Education Group, Australian Government Department of Education and Training
- Professor Fred Watson, Head of Lighting and Environment, Australian Astronomical Observatory
- Professor Kevin Watson, Director of Research, The University of Notre Dame Australia

- Professor Leigh Wood, Professor of Higher Education, Associate Dean, Learning and Teaching, Faculty of Business and Economics, Macquarie University

Opening Real Science partner institution leaders

- Professor Joanne Mulligan (Macquarie University – lead institution)
- Professor Doug Clarke (Australian Catholic University)
- Professor Lindsay Parry (Charles Sturt University)
- Professor Ron Oliver (Edith Cowan University)
- Professor Marguerite Maher (The University of Notre Dame Australia)
- Professor Kevin Watson, (The University of Notre Dame Australia)
- Professor Robert Fitzgerald (University of Canberra)
- Professor Mary Mooney (Western Sydney University)
- Professor Fred Watson (Australian Astronomical Observatory)
- Dr Simon Johnston (CSIRO Astronomy and Space Science)
- Dr Ed Gomez (Las Cumbres Observatory Global Telescope Network)

Opening Real Science support team

- Professor John Hedberg (chair), Macquarie University
- Professor Joanne Mulligan, Macquarie University
- Professor Helen Pask, Macquarie University
- Professor Leigh Wood, Macquarie University
- Dr Michael Cavanagh, Macquarie University
- Professor Vince Geiger, Australian Catholic University
- Sarah Rosen, Macquarie University
- Dr Mingming Diao,* Macquarie University
- Dr Kathy Stewart, Macquarie University
- Dr Liz Date-Huxtable, Western Sydney University
- Dr Heath Jones,* Macquarie University
- Gary Tilley, Macquarie University
- Dr Matthew Turner,* Western Sydney University
- Scarlet An, Macquarie University
- Penny Irvine,* Macquarie University
- Wanda Snitch, Macquarie University
- Erin Mackenzie, Macquarie University
- Carolyn Dow,* Macquarie University
- Professor Quentin Parker,* Macquarie University
- Associate Professor Carmel Coady,* Western Sydney University

* Former member

Opening Real Science merit scholarship recipients

- 2014: Katherine Broadway BABEd(P), designed and implemented activities for pre-service teachers such as using iPads to conduct hands on astronomy activities
- 2015: Taylor Jansen BABEd(P), conducted ORS research resulting in her report *Chemistry Module Increases Pre-Service Teachers' Content Knowledge, Skills and Confidence in Science*
- 2015: Saniya Ahmad BABEd(P), conducted ORS research resulting in her report *An Insight into Pre-service Teachers' Views of Mathematics and their Numeracy Capabilities*
- 2016 Mark Gronow MEd Leadership, PhD candidate and ORS Scholarship recipient, commenced his PhD Scholarship to improve secondary mathematics teaching at pre-service and in-service teacher levels. His PhD is titled: *Pre-service Mathematics Teachers Noticing of Structural Thinking in a Community of Inquiry*.

Opening Real Science research fellowship recipients

The cross-faculty Research Fellowship in Science (Physics & Astronomy) and Education was funded and created at Macquarie University, to bring scientific and educational expertise to module development, engagement with pre-service teachers and collaboration with other researchers at Macquarie University and partner universities and other scientific organisations.

- Dr Heath Jones Grad Dip Ed (Secondary), BSc (Hons) PhD: August 2014 – January 2016. Dr Jones has expertise in the field of stellar evolution and teaching secondary science and physics to pre-service teachers.
- Dr Cormac Purcell BSc (Applied Science), PhD Astrophysics: August 2016 – December 2017. Dr Purcell has expertise in astrophysical analysis, data analytics and public outreach activities including public lectures, school visits, planetarium shows and telescope nights.
- Dr Angel Lopez-Sanchez PhD Physics (Astrophysics): June 2016 – December 2017. Dr Lopez-Sanchez has expertise as a research astronomer at the Australian Astronomical Observatory as well as lecturing and outreach activities.

Appendix F: ORS module scope and sequence



Appendix G: ORS module summaries

Title	Target program	Module team	Discipline	Module summary
1. <i>Discovering Real Science through Big History</i>	Pre-service teachers Years K–12	Tracy Sullivan MQ Joanne Mulligan MQ David Christian MQ Quentin Parker MQ John Hedberg MQ Mingming Diao MQ	Astronomy Physics Science Education	<i>Discovering Real Science</i> is the 'Gateway' module to ORS that is focused on the journey from the beginning of the universe to today's interconnected global societies.
2. <i>Science in the Community</i>	Pre-service teachers Years K–12	Joanne Jamie MQ Ian Jamie MQ Renee Cawthorne MQ Kathy Stewart MQ Scarlet An MQ	Chemistry Indigenous Science Environmental Science	<i>Science in the Community</i> facilitates the planning and implementation of exciting science activities for events such as Science Week and community-based science investigations and events. It allows students to engage in real chemistry activities.
3. <i>Consumer Chemistry</i>	Pre-service teachers Years K–9	Roy Tasker WSU Kathy Stewart MQ Joanne Jamie MQ Ian Jamie MQ Mingming Diao MQ	Chemistry Science Education	This module engages students in scientific inquiry and explores basic ideas in understanding the material world. Teacher education students use the molecular visualisation technique of 'Vis Chem' for deeper understanding of fundamental concepts in chemistry.
4. <i>Clocks in Rocks</i>	Pre-service teachers Years K–9	Ed Saunders MQ Helen Pask MQ Kathy Stewart MQ Scarlet An MQ	Earth Science Physics Science Education	<i>Clocks in Rocks</i> teaches students to use observational skills and learn how geologists use observations to understand the planet's history. They will learn how the Earth has changed over time and the role that humans play in the geological cycle.

Title	Target program	Module team	Discipline	Module summary
5. <i>Human Impact</i>	Pre-service teachers Years K–12	Kathy Stewart MQ Frances Bodkin WSU Liz Date-Huxtable WSU Scarlet An MQ	Earth Science Indigenous Science Sustainability	<i>Human Impact</i> uses Indigenous perspectives to teach the processes of community-based action and address an environmental issue. Students will analyse a real life case study of a rehabilitation project, as well as create and implement their own sustainability action plan.
6. <i>Fundamentals of Weather and Climate</i>	Pre-service teachers Years 5-10	Rod Lane MQ Mingming Diao MQ Kevin Cheung MQ Natalie Steel MQ	Earth & Environmental Science Education Geography	<i>Fundamentals of Weather and Climate</i> uses tropical cyclones as an example to illustrate the key principles for understanding weather, such as air pressure and the causes of wind and cloud formation.
7. <i>Inspired by Plants</i>	Pre-service teachers Years K–9	Kathy Stewart MQ Bronwen Wade-Leeuwen MQ Helmut Pretchl (Potsdam University Germany) Michael Burkhart (Potsdam Botanical Garden Germany) Scarlet An MQ	Biology Arts	<i>Inspired by Plants</i> explores the intersection between art and science, teaching students the science skills of close observation to create a model, drawing or digital representation of a plant or plant part. Students are taught art making techniques from a range of cultures and work in several media.
8. <i>The Living Laboratory</i>	Pre-service teachers Years K–9	Kathy Stewart MQ Naïla Even MQ Daniel Sloane MQ Scarlet An MQ	Biology	<i>The Living Laboratory</i> allows students to understand work of scientists who conduct their investigations in outdoor environments. Students will plan a scientific investigation to shed light on a question they have about their local environment.

Title	Target program	Module team	Discipline	Module summary
9. <i>Bioluminescence</i>	Pre-service teachers Years 9-12	Mariella Herberstein MQ Sham Nair MQ Julian May MQ Wilhelmina Van Rooy ACU Scarlet An MQ	Biology Physics	<i>Bioluminescence</i> explores the natural phenomenon whereby organisms generate light. This module employs the scientific method of inquiry to discover how and why this phenomenon occurs, and to explore how fascinating natural phenomena can yield valuable learning in science.
10. <i>Intelligent Materials</i>	Pre-service teachers Years 9-12	Simon Leonard UC INSPIRE Centre Rob Fitzgerald UC INSPIRE Centre Scarlet An MQ	Physics Design Science	<i>Intelligent Materials</i> or ‘smart’ materials change their properties in response to changes in their environment. This module engages a design thinking process to learn about the science and technology enable the properties of these materials, and how ‘tinkering’ and design thinking may be valuable tools in STEM education.
11. <i>Sound</i>	Pre-service teachers Years K–10	Helen Pask MQ Judith Dawes MQ Chris Sutton MQ Kathy Stewart MQ Mingming Diao MQ	Physics Science Education	<i>Sound</i> . Students will discover how sound is created, how it travels, how sounds differ and how teachers can explain and represent sound as a scientific phenomenon. Students will conduct their own investigation of an area of sound that interests them.
12. <i>Light</i>	Pre-service teachers Years 5-10	Helen Pask MQ Blake Entwisle MQ Judith Dawes MQ Kathy Stewart MQ Scarlet An MQ	Physics Biology	<i>Light</i> encourages students to explore the science of light and build an awareness of how light-based technologies promote sustainable development and provide solutions to global challenges in energy, education, agriculture and health.

Title	Target program	Module team	Discipline	Module summary
13. <i>Primary Astronomy</i>	Pre-service teachers Years K–9	David McKinnon ECU Michael Fitzgerald ECU Heath Jones MQ Scarlet An MQ	Astronomy Physics	<i>Primary Astronomy</i> explores the basics of solar system astronomy. This module challenges the common astronomical misconceptions about how the sun, moon and planets move, interact, and are perceived from Earth.
14. <i>Telescopes, Colour Imaging and the Cosmos</i>	Pre-service teachers Years 7-10	David McKinnon ECU Lena Danaia CSU Rob Hollow CASS Andrew Hopkins AAO Michael Fitzgerald ECU Scarlet An MQ	Astronomy	<i>Telescopes, Colour Imaging and the Cosmos</i> provides an introduction to fundamental aspects of modern astronomy required to build an observational understanding of the cosmos.
15. <i>Tracing the Life Cycle of Stars</i>	Pre-service teachers Years 7-10	David McKinnon ECU Michael Fitzgerald ECU Lena Danaia CSU Rob Hollow CASS Scarlet An MQ	Astronomy	<i>Tracing the Life Cycle of Stars</i> develops an understanding of the main phases of the life cycle of stars, their observable properties and their fundamental nature, by exploring concepts presented in Hertzsprung-Russell Diagrams and Colour-Magnitude Diagrams.
16. <i>Life and Death of Stars</i>	Pre-service teachers Years 10–12	Heath Jones MQ Quentin Parker MQ David Frew MQ Milorad Stupar MQ Scarlet An MQ	Astronomy	<i>Life and Death of Stars</i> takes students on a journey exploring the differences between stars and the way they form, evolve and eventually die. Students will learn about the technologies and techniques used to measure and understand the characteristics of stars.

Title	Target program	Module team	Discipline	Module summary
17. <i>Gateway to Numeracy</i>	Pre-service teachers Years K–9	Catherine Attard WSU Dorian Stoilescu WSU Leigh Wood MQ Ayse Bilgin MQ Carolyn Kennett MQ Scarlet An MQ Liz Date-Huxtable WSU	Mathematics	<i>Gateway to Numeracy</i> is a wide-ranging module introducing key concepts in numeracy, the application of mathematics to real life, and how children learn mathematics. The module facilitates ‘real life’ problem solving, integrating aspects of number and algebra, measurement and geography and statistics and probability.
18. <i>Smart Budgeting Primary</i>	Pre-service teachers Years K–5	Leigh Wood MQ Damian Bridge MQ Paul Clitheroe MQ Liz Date-Huxtable WSU Scarlet An MQ	Mathematics	<i>Smart Budgeting Primary</i> looks at the practical preparation of budgets, and applying mathematics principles to effectively manage budgets across multiple domains including personal, organizational or governmental budgets. Students will work through cases and activities in real world scenarios.
19. <i>Smart Budgeting Secondary</i>	Pre-service teachers Years 7–10	Leigh Wood MQ Damian Bridge MQ Paul Clitheroe MQ Liz Date-Huxtable WSU Scarlet An MQ	Mathematics	<i>Smart Budgeting Secondary</i> introduces the mathematical principles of effectively managing budgets including personal, organisational or government budgets by working through case studies and real world scenarios.
20. <i>Investing & Protecting</i>	Pre-service teachers Years 7–10	Leigh Wood MQ Damian Bridge MQ Liz Date-Huxtable WSU Scarlet An MQ	Mathematics	<i>Investing & Protecting</i> explains the mathematical principles underpinning financial management concepts including investing, superannuation, credit and protection through insurance. Students learn through real world scenarios, case studies and activities.

Title	Target program	Module team	Discipline	Module summary
21. <i>Statistical Literacy Primary</i>	Pre-service teachers Years K–5	Carmel Coady WSU Michael Cavanagh MQ Joanne Mulligan MQ Ayse Bilgin MQ Vince Geiger ACU Liz Date-Huxtable WSU Scarlet An MQ	Mathematics	<i>Statistical Literacy Primary</i> introduces students to the everyday use of numbers and comparisons of numbers to justify the decisions that we make. Students will learn to interpret, interrogate and critique statistical claims in the media and to use statistical reasoning to argue a claim of their choosing.
22. <i>Statistical Literacy Secondary</i>	Pre-service teachers Years 7–10	Carmel Coady WSU Michael Cavanagh MQ, Joanne Mulligan MQ Ayse Bilgin MQ Vince Geiger ACU Liz Date-Huxtable WSU Scarlet An MQ	Mathematics	<i>Statistical Literacy Secondary</i> develops more advanced statistical literacy skills. Students will develop skills in making use of statistics in their role as education professionals, as well as critique and investigate statistical claims in the media surrounding educational issues.
23. <i>2 Infinity and Beyond</i>	Pre-service teachers Years 9–12	Carmel Coady WSU Michael Cavanagh MQ Carolyn Kennett MQ Liz Date-Huxtable WSU Scarlet An MQ	Mathematics	<i>2 Infinity and Beyond</i> leads students to explore historical conceptions and misconceptions of infinity. They will create an artwork incorporating an infinite geometric series using IT tools, and apply the concept of mathematical limits to air pollution issues.

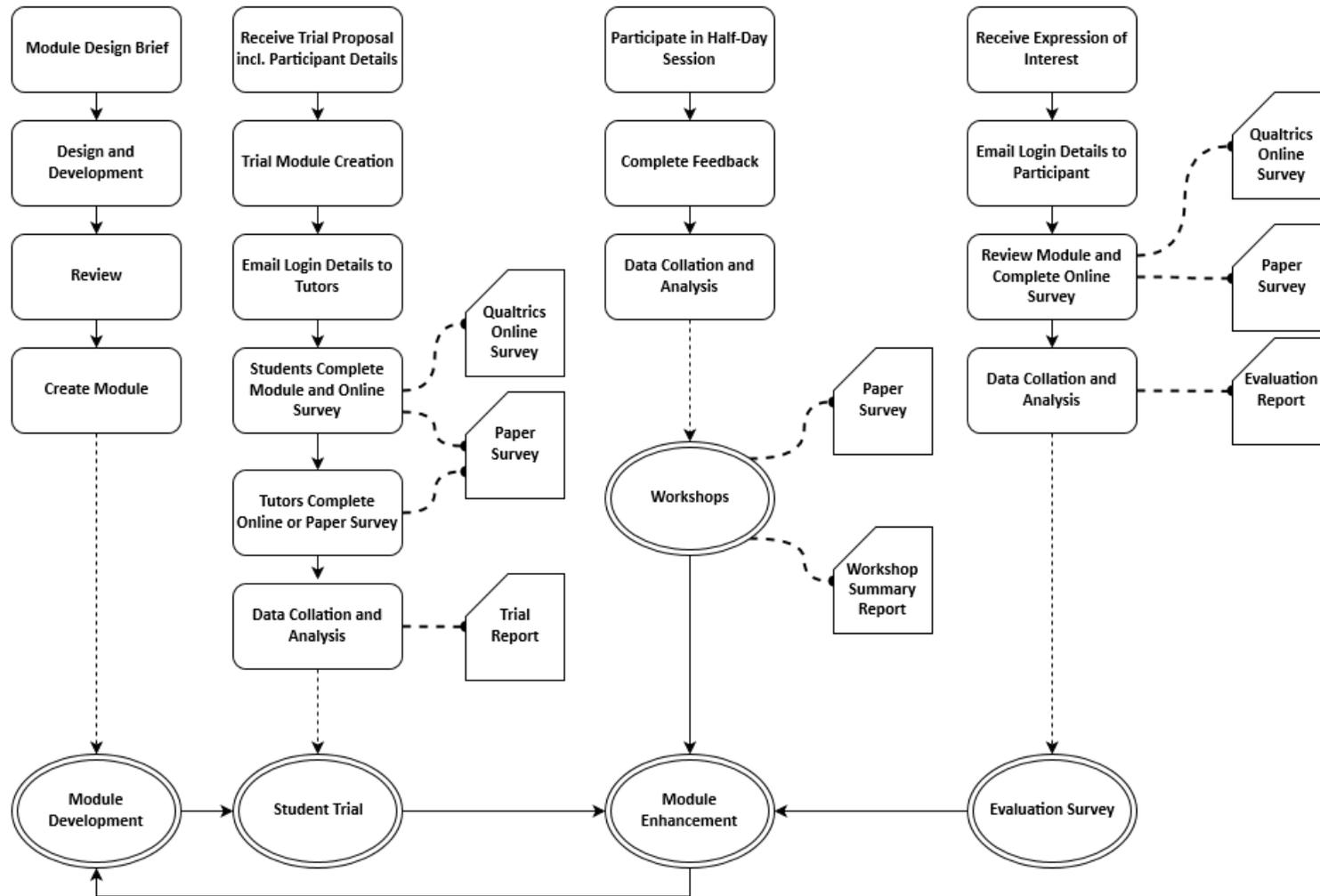
Title	Target program	Module team	Discipline	Module summary
24. <i>Modelling the Present—Predicting the Future</i>	Pre-service teachers Years 9–12	Vince Geiger ACU Ian Wright MQ Heath Jones MQ Mariella Herberstein MQ Rehez Ahlip WSU Liz Date-Huxtable WSU Scarlet An MQ	Mathematics	<i>Modelling the Present—Predicting the Future</i> explores the use of mathematical modelling to understand real world problems. Students will delve into big data using case studies to explore recent advances in the treatment of disease, management of water pollution, measurement of light emissions of stars and predicting the price of commodities.
25. <i>Frontiers of Real Science</i>	Pre-service teachers Years K–12	Helen Pask MQ Kathy Stewart MQ Rosanna Murphy MQ Michael Cowley MQ Scarlet An MQ	All	<i>Frontiers of Real Science</i> equips students for the challenges of teaching science in the classroom. This module examines limiting stereotypes and beliefs and sociocultural challenges surrounding science and scientists. Students will also engage with a real scientist and develop their skills in communicating science concepts to a range of audiences.

AAO, Australian Astronomical Observatory. ACU, Australian Catholic University. CASS, CSIRO Astronomy and Space Science. CSU, Charles Sturt University. ECU, Edith Cowan University. MQ, Macquarie University. UC, University of Canberra. UND, The University of Notre Dame Australia. WSU, Western Sydney University.

Appendix H: ORS module design checklist

Heading	Explanation of what will be developed
Topic name	Working title of the module
Introduction	Introduces the major sections of the plan as well as the primary people involved in proposing the module
Background	Describes any information needed to provide the review team with an understanding of the background of the module
Purposes	Delineates the purposes of the module, describes how the module might link to others if appropriate
Audiences	Specifies the potential audience of the module and how you propose to modify aspects of it for specific audiences
Proposed design	Consider how you will use the 6Es model to create interest and engagement, some early experimentation to explore the underlying principle or phenomena, the language needed to describe the phenomena scientifically, how the learners will elaborate on their initial ideas to test their questions and finally how each phase will be evaluated authentically. Please include particular terminology, principles, processes and phenomena etc. that may need to be introduced prior to using this module
Links to the Australian Curriculum	The clearer and more detailed these links are, the more likely that you will be able to develop your module to link to others – talk with Kathy Stewart to get advice
Proposed resources	Links to existing resources (e.g. YouTube), also what needs to be created and how it can be done
Researching/ trialling the module	Specifies which learners, instructors and other personnel will participate in trials and to collect evidence
Logistics and personnel	Who will be responsible for the implementation, analysis, and reporting aspects of the design; list who is to do each component
Timeline	Presents schedule for design, development, trialling, evaluation and revision on the spreadsheet template
Budget	Clarifies the finances needed for the development of the module. Personnel are the major cost factor, present in hours for existing staff. Other cost factors include travel and materials development

Appendix I: ORS module development and design process



Appendix J: ORS learning design tools

Science inquiries	Moodle tools	Application	Comment
Resources showing real science concepts (6 Es)	Add Resource Upload file (video/audio/word/PowerPoint/PDF)	Upload video / audio file Upload word /PDF	Limitation of file size Limitation of internet speed
Visual/audio presentation of real science concepts (6 Es)	Add Resource Create a label or page	Embed online video (eg: YouTube/Vimeo) Add an image icon	Continued validity of links to online videos and images Copyright issues
Extra/latest sources for relevant real science concepts (Engage, Explain, Explore, Elucidate)	Add Resource Links to web page	Simply link or embed a web page to the online modules	Continued validity of the links to web pages
Assessment of understanding real science concepts and share experimental results/evidence (Explain, Explore, Elucidate)	Discussion Forum Use for many types of learning activities	Set up discussion forum to allow students to dialogue their understanding of real science concepts, communicate with peers/teaching staff, collaborate with peers for experiments	Each student may be involved on various discussion forums No individual portfolio
Writing a diary or log; evaluating the understanding or real science concepts, reporting experiments, sharing study experience (Explain, Explore, Elaborate, Evaluate Elucidate)	Blog Allows for creation of blogs within a unit (separate to the core Moodle blog system): unit-wide blogs (everyone in the same unit posts to the same blog), group blogs or individual blogs	Students will be asked to create their own blog at the very beginning Students use their blog to explain, explore, elaborate and evaluate	Blogs need to be set up for unit-wide, group or individual use Blogs cannot be exported as a package Students lose access to their blogs after graduation
Collaboration with peers to explain and explore real science concepts and collection of evidence (Explain, Explore, Elucidate)	Wiki Use for many types of learning activities	Students can generate and explain scientific content collaboratively for assessment Discussion can be generated around collaborative work using 'comments' The history of collaboration will be explored	Hard to manage and edit appearance Everyone can view and edit
Define real science concepts and terms (Explain, Explore, Elucidate)	Glossary Use for learning activities that gather resources or present	Students can contribute to entries Original author can edit	This is an input only and information transfer tool Limited feedback

Science inquiries	Moodle tools	Application	Comment
	information		
Share real science concepts, terms and experimental files in searchable ways (Explain, Explore, Elucidate)	Database Allows students to collect, share and search created artefacts	Students share their experimental evidence	Not intended for discussion
Review peers' experiments and reports, evaluate group contribution (Explain, Explore, Elucidate)	Workshop Used for peer review	Students review their peers' experimental plan, report and give feedback	Only the student who submitted receives feedback Fairness of student evaluation
Presenting real science concepts and evaluate students' understanding (Explain, Explore, Evaluate, Elucidate)	Lesson Use for presenting sequenced information or testing	Starting the explanation and exploration with sequenced information (eg; videos, images, words) Use sequenced quiz to evaluate	Manageable learning sequence Only an individual activity but not a group activity
Formative or summative assessment of learning; check learning process (Explain, Explore, Evaluate, Elucidate)	Quiz Use to assess learning, formative or summative	Evaluate students' understanding of real science concepts Learning process checking	Use quiz as a checklist Manage and guide learning process and sequence
Self-enrolment of groups (6Es)	Group selection Allows users to auto-enrol in groups	Allocate students into different groups for team work	Set up group in advance More suitable for smaller/medium classes
Evaluate the major assessment task (Elaborate, Evaluate, Elucidate)	Assignment Use to collect, assess & provide feedback on assignments	Students are required to submit a report for their major assessment task	No group assignment

Appendix K: ORS module evaluation for teacher education professionals form

Opening Real Science (ORS): Authentic Mathematics and Science Education for Australia

Module Evaluation: Teacher Education Professionals

Name: (optional) _____ Position: _____

Institution/School: _____ Course/Program: _____

Module evaluated: _____ *(please complete one form per module evaluated)*

The ORS Modules aim to drive a major improvement in the quality of mathematics and science teaching and learning by integrating mathematics and science concepts, and building the competence, skills and confidence of pre-service teachers. With this purpose in mind:

1. Overall, how would you rate this module?

Very poor Poor Somewhat poor Somewhat good Good Very good

2. Thinking about the module, indicate how strongly you agree or disagree with each of the following statements:

	Strongly Disagree	Disagree	Somewhat Disagree	Somewhat Agree	Agree	Strongly Agree
1. I felt engaged when I started viewing the module	<input type="radio"/>					
2. The module includes a variety of activities which allows pre-service teachers to explore the topic	<input type="radio"/>					
3. The module enables pre-service teachers to offer accurate explanations of the scientific/mathematical concepts covered	<input type="radio"/>					
4. The assessment task/s allow pre-service teachers to demonstrate their understandings of the topics	<input type="radio"/>					
5. The module encourages pre-service teachers to think scientifically / work mathematically	<input type="radio"/>					

Appendix L: ORS module reviewer evaluation form

ORS Module Evaluation Form
(adapted from MQ Teaching & Learning Resources)

Module name:

Overall, how would you score this module? Circle your rating with 10 being excellent

0 1 2 3 4 5 6 7 8 9 10

Why did you give this ranking?

How easy is the topic/module/unit to navigate?

Is it clear what you are supposed to do? Describe any issues.

List two features of the topic/module you found enjoyable or effective.

How would you improve the topic/module?

Overall comments

Appendix M: ORS trialling data summary across university partner institutions

Primary maths

Module title	Partner university	Trial date	Student year level	Delivery mode	Trial length	Sample size				Tutor survey (Y/N)	Module review	TEPs (n)	W'shop survey	W'shop report
						At start	Completed	Consented	Evaluation					
<i>Gateway to Numeracy</i>	U3	S2 2015	3rd year	online	6 weeks	107	74	101	52	1	Y	5	Y	Y
	U5	S2 2015	1st year	online	1 semester	29	21	12	0	1				
	U4	Dec. 2015	n/a	online	unknown	7	3	6	3	1				
	U3	S1 2016	2nd year	mixed		40	21	41	30	1				
	U5	S1 2016	1/3rd year	online	1 semester	43	2	40	27	1				
<i>Smart Budgeting Primary</i>	U1	S1 2015	1st year	online	1 semester	148	67	151	46	1	Y	4	Y	Y
	U3	S2 2015	3rd year	online	6 weeks	109	104	98	47	1				
	U3	S1 2016	2nd year	mixed		37	18		14	1				
<i>Statistical Literacy Primary</i>	U1	S1 2015	1st year	online	1 semester	195	16	151	9	1	Y	9	Y	N
	U3	S2 2015	3rd year	online	6 weeks	95	93	83	39	1				

Module title	Partner university	Trial date	Student year level	Delivery mode	Trial length	Sample size				Tutor survey (Y/N)	Module review	TEPs (n)	W'shop survey	W'shop report
						At start	Completed	Consented	Evaluation					
	U3	Summer 2016	3rd year	online	3 weeks	33	21	28	25	1				

S, semester. TEP, teacher education professional. U, University partner code⁴. W'shop report, enhancement workshop group report. W'shop survey, enhancement workshop survey.

⁴ University partner institutions were assigned a code as these data need to preserve anonymity

Secondary maths

Module title	Partner university	Trial date	Student year level	Delivery mode	Trial length	Sample size				Tutor survey (Y/N)	Module review	TEPs (n)	W'shop survey	W'shop report
						At start	Completed	Consented	Evaluation					
<i>2 Infinity and Beyond</i>	U5	Winter 2015	elective	mixed	2 weeks	25	22	21	19	1	Y	5		
<i>Investing & Protecting</i>											Y	2	Y	Y
<i>Modelling the Present— Predicting the Future</i>	U5	S2 2016			2 weeks	36	1		22	TBA	Y	6		
<i>Smart Budgeting Secondary</i>	U6	S1 2015	primary teachers retraining	online	4 weeks	29	28	21	19	0	Y	5	Y	Y

Module title	Partner university	Trial date	Student year level	Delivery mode	Trial length	Sample size				Tutor survey (Y/N)	Module review	TEPs (n)	W'shop survey	W'shop report
						At start	Completed	Consented	Evaluation					
	U6	S2 2015	primary teachers retraining	online	4 weeks	12	10	10	3	1				
<i>Statistical Literacy Secondary</i>	U5	S1 2016	1/3rd year	online	1 semester	45	2	40	17	1	Y	6	Y	

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K–12 science

Module title	Partner university	Trial date	Student year level	Delivery mode	Trial length	Sample size				Tutor survey (Y/N)	Module review	TEPs (n)	W'shop survey	W'shop report
						At start	Completed	Consented	Evaluation					
<i>Discovering Real Science through Big History</i>	U1	S1 2015	1st year	online	1 semester	237	77	151	35	1	Y	9		Y
	U2	S1 2015												
	U4	S2 2015	elective	mixed	unknown	3	3	1	2	1				
	U2	S2 2015	4th year	online	1 semester	24	9	10	8	1				
	U3	Summer 2016	2nd year	online	3 weeks	9	2	10	3	1				
	U3	S1 2016	2nd year	mixed	10 weeks	28	16	21	6	1				
	U4	S1 2016	unknown	mixed	4 weeks	5	1	3	0	1				
	U7	S1 2016	1/2nd year	mixed	4 weeks	298	229	159	41	5				
<i>Frontiers of Real Science</i>											2		Y	
<i>Human Impact</i>	U4	Dec. 2015	n/a	online	unknown	5	3	5	3	1	Y	6		Y
	U5	S1 2016				75	1		26	1				

Module title	Partner university	Trial date	Student year level	Delivery mode	Trial length	Sample size				Tutor survey (Y/N)	Module review	TEPs (n)	W'shop survey	W'shop report
						At start	Completed	Consented	Evaluation					
<i>Science in the Community</i>	U3	Summer 2016	2nd year	online	3 weeks	8	6	8	3	1	Y	9	Y	Y
	U3	S1 2016	2nd year	mixed		28	25		13	2				

S, semester. TEP, teacher education professional. U, University partner code ⁶.W'shop report, enhancement workshop group report. W'shop survey, enhancement workshop survey.

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Primary science

Module title	Partner university	Trial date	Student year level	Delivery mode	Trial length	Sample size				Tutor survey (Y/N)	Module review	TEPs (n)	W'shop survey	W'shop report
						At start	Completed	Consented	Evaluation					
<i>Clocks in Rocks</i>	U3	Summer 2016	2nd year	online	3 weeks	8	7	8	5	1	Y	3	Y	
	U3	S1 2016	2nd year	mixed		28	25		20	2				
<i>Consumer Chemistry</i>	U2	Summer 2014	1st year	mixed	1 day	47	15	20	33	1	Y	8	Y	Y
	U3	July 2014	4th year	groups	1 week	14	14	58	14	1				
	U2	S1 2015												
	U5	S2 2015	2/3rd year	mixed	1 semester	115	70	102	22	1				
	U2	S2 2015	4th year	online	1 semester	14	13	12	9	1				
	U4	S2 2015	n/a	online	unknown	8	6	6	5	1				
	U7	S1 2016	1/2nd year	mixed	4 weeks	298	222	159	62	5				
<i>Inspired by Plants</i>	U3	Summer 2016	2nd year	online	3 weeks	9	9	11	3	1	Y	6		Y

Module title	Partner university	Trial date	Student year level	Delivery mode	Trial length	Sample size				Tutor survey (Y/N)	Module review	TEPs (n)	W'shop survey	W'shop report
						At start	Completed	Consented	Evaluation					
	U3	S1 2016	2nd year	mixed		32	22		9	2				

S, semester. TEP, teacher education professional. U, University partner code⁷, W'shop report, enhancement workshop group report. W'shop survey, enhancement workshop survey.

⁷ University partner institutions were assigned a code as these data need to preserve anonymity

Primary science (continued)

Module title	Partner university	Trial date	Student year level	Delivery mode	Trial length	Sample size				Tutor survey (Y/N)	Module review	TEPs (n)	W'shop survey	W'shop report
						At start	Completed	Consented	Evaluation					
<i>Primary Astronomy</i>	U5	S2 2015	1st year	mixed	1 semester	67	61	58	65	1	Y	4	Y	Y
	U4	Dec. 2015	n/a	online	unknown	6	0	6	4	1				
	U3	Summer 2016	2nd year	online	3 weeks	12	8	11	8	1				
	U3	S1 2016	2nd year	mixed		30	23		19	2				
<i>Sound</i>	U3	S2 2014	1st year	online	3 weeks	255	191	174	79	1		3		Y
	U5	S2 2015	2/3rd year	mixed	1 semester	110	93	102	37	1				
	U3	S2 2015	1st year	online	10 weeks	307	213	154	161	1				
	U1	S2 2016				86	0		16	TBA				
<i>The Living Laboratory</i>	U5	S1 2016	1st year	mixed	8 weeks	247	227	256	97	1		2		Y

S, semester. TEP, teacher education professional. U, University partner code⁸. W'shop report, enhancement workshop group report. W'shop survey, enhancement workshop survey.

⁸ University partner institutions were assigned a code as these data need to preserve anonymity

Secondary science

Module title	Partner university	Trial date	Student year level	Delivery mode	Trial length	Sample size				Tutor survey (Y/N)	Mod review	TEPs (n)	W'shop survey	W'shop report
						At start	Completed	Consented	Evaluation					
<i>Bioluminescence</i>											Y	2		Y
<i>Fundamentals of Weather and Climate</i>	U3	July 2014	4th year	groups	1 week	44	44	98	44	1		2		Y
	U2	S1 2015												
	U3	S1 2015	2nd year	online	1 semester	356	219	168	172	1				
	U4	S2 2016				298	1		179	TBA				
<i>Intelligent Materials</i>											Y	1		
<i>Life and Death of Stars</i>	U2	S2 2015									Y	4	Y	Y
<i>Light</i>	U3	Summer 2016	2nd year	mixed	3 weeks	9	7	26	4	1	Y	4		Y
	U3	S1 2016	2nd year	mixed		30	23		16	2				
	U1	S2 2016				86	0		13	TBA				
<i>Telescopes, Colour Imaging</i>	U6	S2 2015									Y	2	Y	Y

Module title	Partner university	Trial date	Student year level	Delivery mode	Trial length	Sample size				Tutor survey (Y/N)	Mod review	TEPs (n)	W'shop survey	W'shop report
						At start	Completed	Consented	Evaluation					
<i>and the Cosmos</i>														
<i>Tracing the Life Cycle of Stars</i>	U6	S2 2015								Y	1	Y	Y	

S, semester. TEP, teacher education professional. U, Univeristy partner code⁹, W'shop report, enhancement workshop group report. W'shop survey, enhancement workshop survey.

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Totals

Module title	Partner university	Trial date	Student year level	Delivery mode	Trial length	Sample size				Tutor survey (Y/N)	Module review	TEPs (n)	W'shop survey	W'shop report
						At start	Completed	Consented	Evaluation					
	Total no. Trials	58				4226	2388	2600	1608	60		4.4		
		-6												
		52												

TEP, teacher education professional. U, University partner code¹⁰W'shop report, enhancement workshop group report. W'shop survey, enhancement workshop survey.

¹⁰ University partner institutions were assigned a code as these data need to preserve anonymity

Appendix N: *Consumer Chemistry* exemplar report

Consumer Chemistry was trialled extensively, so was selected to demonstrate trialling procedures with large samples.

Six trials of the *Consumer Chemistry* module across five university pre-service primary programs were completed from 2014–16. The table below provides a summary of the scope and depth of each trial.

Across the six trials, the completion rates (the percentage of students who completed required online activities) ranged from 31.91 per cent (Trial 1) to 100 per cent (Trial 2). The mean completion rate for the trials was 72.52 per cent. Generally, lower completion rates occurred in trials where the module was conducted as an ‘add-on’ to the students’ mandatory science education program requirements, or when insufficient tutor guidance was provided. Of the students who completed the module, 42.65 per cent completed the student evaluation survey.

Summary of trials for <i>Consumer Chemistry</i>							
Trial	Partner University	Degree program	Student year level	Delivery mode	Trial length	Number students	Number surveys
1	U2	BEd	1 st	mixed	1 day	15	33
2	U3	BEd (Primary)	4th	mixed	1 week	14	0
3	U5	BEd (EC Primary)	2/3 rd	mixed	1 sem	70	22
4	U2	BEd (EC Birth–12)	4th	online	1 sem	13	9
5	U4	varied	n/a	online	workshop	6	5
6	U7	BEd (EC, Primary)	1/2 nd	mixed	4 weeks	222	62
Total						340	145

U, University partner code¹¹

Pre-service teachers provided an overall rating of the module by responding to the question, ‘Thinking about the online module you completed, *Consumer Chemistry*, how would you rate it overall?’. Responses were given using a 6-point Likert scale (1 = very poor and 6 = very good). The mean overall ratings for this module were between 4.5 and 5.0 out of 6, therefore well above the mean ranking.

In all three trials, the question to which pre-service teachers responded most positively was ‘the variety of activities allowed them to explore the topic’. The question they responded least positively to was ‘feeling engaged at the start of the

¹¹ University partner institutions were assigned a code as these data need to preserve anonymity

module', although the mean scores indicate that the majority of students did feel engaged at the start of the module.

Appendix O: Summary of teacher education professional module reviews

Group	Module	Measure	n(TEPs)	Key comments
K–12 science	<i>Discovering Real Science</i>	100%	9	'Effective', 'understanding', 'big picture', 'ease of understanding'
	<i>Frontiers of Real Science</i>	50%	2	'Remotely likely at best', 'effective ... with different ways of communicating their knowledge'
	<i>Human Impact</i>	80%	5 ^B	'Quite effective', 'Very strong ... illustrates that there are many paths to learning about science ...', 'partially effective ... increased content is needed'
	<i>Science in the Community</i>	67%	9	'Supports improved understandings of scientific concepts', 'Good for practically engaging with science, but not building understanding', 'Helps [pre-service teachers] physically plan and implement a science experiment'
Primary science	<i>Consumer Chemistry</i>	75%	8	'Increased content is needed', 'use of experimentation ... is a positive of the module', 'lots of good ideas and plenty of confidence building around hands on activities ... not sure it develops key concepts systematically', 'Very good', 'Probably good for those with no science background'
	<i>Clocks in Rocks</i>	67%	3	'Great summary', 'effective as a stand-alone instructional lesson on the topic', 'language and theory ... so detailed ... discourage teachers ... if had little or no geological background', 'dense'
	<i>Inspired by Plants</i>	50%	6	'improvement required to strengthen the module. There are few scientific/mathematical concepts featured', 'module will provide ... a clear understanding', 'may be effective for this purpose', 'partially effective', 'simple topic ... strong links'
	<i>The Living Laboratory</i>	100%	2	'Very effective and more holistically than some other modules', 'supports improved understandings'
	<i>Primary Astronomy</i>	100%	4	'supports improved understandings', 'this is a real strength of this module ... difficult to finish this module and not have a solid understanding', 'Great', 'beneficial to pre-service teachers'
	<i>Sound</i>	100%	3	'supports improved understandings of scientific

Group	Module	Measure	n(TEPs)	Key comments
				concepts', 'Good content', 'extremely effective'
Secondary science	<i>Bioluminescence</i>	100%	2	'done quite effectively through the tasks and activities', 'content supports improved understanding'
	<i>Intelligent Materials</i>	0%	1	'Partially effective as stand-alone ... Increased content is needed along with more engaging activities.'
	<i>Life and Death of Stars</i>	100%	4	'effective as a stand-alone', 'Very good ... allowed me to extend my thinking on physics', 'Very Good ... relevant and connects well with current curriculum', 'content supports improved understandings'
	<i>Light</i>	75%	4	'content supports improved understandings of scientific concepts', 'Very good', 'does a good job ... could engage students more with a variety of mediums', 'A great starting point.'
	<i>Telescopes, Colour Imaging</i>	100%	2	'Extremely effective in dismissing common misconceptions', 'content supports improved understandings of scientific concepts'
	<i>Tracing the Life Cycle of Stars</i>	100%	1	'content supports improved understandings of scientific concepts'
	<i>Fundamentals of Weather and Climate</i>	100%	2	'introduces scientific concepts through practical investigations/demonstration ... gain scientific knowledge, but also the skills of running hands-on, practical science', 'supports improved understandings of scientific concepts'
Primary Maths	<i>Gateways to Numeracy</i>	80%	5	'an increase in the mathematical concepts presented ... would be beneficial', 'really boost confidence and flexibility with numbers', 'effective', 'supports improved understanding', 'took a little while to work out what the focus was'
	<i>Smart Budgeting (Primary)</i>	50%	4	'not too sure if I personally understood the scientific concepts throughout this module', 'Fairly effective ... however some concepts are assumed ... may need some optional explanations', 'module content does not support improved understanding'
	<i>Statistical Literacy (Primary)</i>	33%	9	'Not a lot of material which helped to improve mathematical understandings', 'assessment are not helpful in practically applying this knowledge to work with data', 'no clear distinction for how this statistical data understanding would be transferred to students', 'Quite effective. Good detail', 'unsure how effective'

Group	Module	Measure	n(TEPs)	Key comments
				this module would be for pre-service teacher'
Secondary Maths	<i>2 Infinity and Beyond</i>	60%	5	'Not really', 'extremely exciting ... all would gain knowledge and insight ... did feel that there were many aspects ... far too difficult', 'effective as a stand-alone instructional lesson', 'provides a very in depth look', 'Can't say'
	<i>Investing & Protecting</i>	50%	2	'Good', 'content does not support improved understandings'
	<i>Modelling the Present— Predicting the Future</i>	67%	6	'[concept] covered in depth', 'gives great insight into how mathematical concepts relate to the outside world', 'Can't say', 'effective as a stand-alone instructional lesson'
	<i>Smart Budgeting (Secondary)</i>	40%	5	'Personally ... very worthwhile. How well this translates into the classroom would be difficult to say', 'content does not support improved understandings', 'Very good', 'Effective', 'don't believe it is an effective tool ... high levels of prior learning'
	<i>Statistical Literacy (Secondary)</i>	50%	6	'Very', 'informative and interesting', 'effective as a stand-alone instructional lesson', 'could be overwhelming', 'Increased content is needed', 'not a lot of material which helped to improve mathematical understanding'

TEP, teacher education professional.

Appendix P: ORS enhancement workshop survey

ORS Enhancement: Module Review

Module name: _____

The following excerpts from the original ORS proposal describe the purpose of the modules. Please read and then respond to the questions below.

“Opening Real Science will deliver new teaching modules that engage teachers in real science and enable them to teach mathematics and science as they are actually practised: as dynamic, forward- looking and collaborative human endeavours.”

“By combining a solid understanding of key concepts in the five discipline areas with examples of, and scaffolds for, inquiry-based learning, education students will develop their own confidence, skills and understanding. The modules will support them to carry out mini-research projects utilising some form of realistic data collection (e.g. by survey, laboratory experimentation, or analysis of online data), analysis and interpretation. By asking and investigating their own questions, they can build their capabilities to initiate and frame curriculum-aligned mathematical and scientific investigations in their own classrooms.”

1. How well does the ORS module encourage pre-service teacher education students to ask and investigate questions about the world in which they live?

<input type="checkbox"/>					
Not at all	Very Poorly	Poorly	Adequately	Well	Very Well
Comments:					

2. How well does the ORS module introduce pre-service teacher education students to real scientists and their research?

<input type="checkbox"/>					
Not at all	Very Poorly	Poorly	Adequately	Well	Very Well
Comments:					

3. How well does the ORS module articulate the concepts of scientific questioning, fair testing and data integrity?

<input type="checkbox"/>					
Not at all	Very Poorly	Poorly	Adequately	Well	Very Well
Comments:					

4. Can authentic inquiry-based learning happen within this module?

<input type="checkbox"/>					
Not at all	Very Poorly	Poorly	Adequately	Well	Very Well
Comments:					

Any further comments? Please add below.

Comments:

Appendix Q: Mentor teacher professional experience report

Mentor Teacher Evaluation of Primary Science Professional Experience 2014

Pre-service Teacher: _____ School: _____

Mentor/Science Teacher: _____ Grade: _____

Teacher Competency	Yet to be demonstrated	Working towards	Demonstrated	Exceeds expectations
Overall Planning and Preparation				
Written science lesson plans/unit	o	o	o	o
Develop science resources	o	o	o	o
Compile science learning portfolio/folder	o	o	o	o
Lessons align with science syllabus	o	o	o	o
Implementation				
Uses open ended/constructive questioning	o	o	o	o
Uses scientific methodology and higher order tasks (e.g. Hypothesising, predicting, observing, fair testing, data collection, etc.)	o	o	o	o
Assessment				
Develops "rich" science tasks	o	o	o	o
Assesses science concepts and processes	o	o	o	o
Describes assessment criteria (e.g. Rubric/indicators)	o	o	o	o
Classroom Interaction				
Individual/group work	o	o	o	o
Management strategies	o	o	o	o
Teaching strategies (e.g. Enquiry approach)	o	o	o	o
Professionalism				
Demonstrates interest and enthusiasm for science	o	o	o	o
Initiative in learning science innovation	o	o	o	o
Response to professional advice	o	o	o	o
Area/s of strength				
Area/s to be developed				
General comments				

At this stage of their professional development in science I would consider this Pre-service Teacher to be:

Unsatisfactory Needs development Satisfactory Above satisfactory

Mentor Teacher Signature _____ Date _____

Pre-service Teacher Signature _____ Date _____

Appendix R: Professional experience implementation issues

Feedback after each trial indicated that a number of issues had been encountered. These include:

Selection of mentor teachers

Mentor teachers were generally only approached directly if they had previously participated in the program or were well-known by ORS staff. On other occasions school principals were approached on advice that their schools were interested in developing their science or mathematics programs and pedagogies, and these schools nominated staff as ORS mentor teachers. At times this resulted in teachers being unaware of the aims and procedures for the professional experience or being unsuited to the mentoring role due to either lack of commitment to or confidence in the specialist areas.

Selection of pre-service teachers

The original invitation to pre-service teachers to participate in the professional experience attracted students from years 2 to 4 of teacher education programs. Feedback from mentor teachers indicated that most pre-service teachers needed at least two previous professional experiences to have sufficiently developed skills in classroom management and planning units of work to be ready to focus on inquiry-based learning in science and/or mathematics.

*We understood the prac students were coming as expert science teachers and would teach science ... Both [third year] students were not confident teachers.
– 2016 mentor teacher, focus group*

Misunderstandings about the science/mathematics expertise of mentor teachers and/or pre-service teachers

In some trials there were misunderstandings on the part of some mentor teachers and pre-service teachers that their partner brought particular expertise in science or mathematics, despite advice to the contrary being provided. This led to some disappointments, particularly in cases where neither the mentor teacher nor the pre-service teachers possessed such expertise.

Confusion about the relationship between the ORS modules and the specialist professional experience

In later trials all pre-service teachers and mentor teachers were given access to the online modules (by email and/or at a meeting) to raise their awareness of the resources and also to seek feedback on their usefulness in improving the knowledge base of pre-service teachers. This resulted in some confusion about whether the modules were intended to be adapted for use in the professional experience.

Administration requirements and coordination

As pre-service teachers were undertaking this professional experience as part of the normal professional experience requirements of their teacher education, this

required considerable coordination with the professional experience staff who administer school placements. Also, as these specialist professional experiences were trials for the ORS project, there were many administrative tasks for data collection (e.g. collection of consent forms, mentor teacher evaluation forms and interview arrangements). These tasks were shared between the specialist university advisor and the ORS research officer.

Appendix S: Professional experience evaluation interview questions

Opening Real Science (ORS) Specialist Mathematics and Science Professional Experience

MENTOR TEACHER INTERVIEW GUIDE

INTRODUCTION

Thank you for agreeing to participate in this interview. Your input to this project is highly valued. This research forms part of the Opening Real Science project, which aims to drive a major improvement in the quality of mathematics and science teaching and learning, and build the competence, skills and confidence of pre-service teachers.

One way we hope to achieve this is through offering pre-service teachers the opportunity to take part in a specialist practicum, or professional experience, focusing on science and/or maths teaching.

The purpose of our interview today is to further explore your experience as a mentor teacher. The interview will take up to one hour and is divided into two parts. Part 1 is some background about you, your school and how mathematics and science are taught. Part 2 focuses on the ORS professional experience for which you provided mentor support.

I will be recording and transcribing the interview to ensure that I capture our conversation accurately. I will then replace your name/s with codes in the record of the interview so that no individuals can be identified. The data collected will be kept confidential. Your comments today will not be provided back to your school, but will be used to evaluate the effectiveness of the ORS Mathematics and Science professional experience model.

INTERVIEW GUIDE

Part one: Background Information

Q1: Invite participants to state their name, how long they have been teaching, stage they currently teach, and whether this was their first experience supervising a pre-service teacher.

Q2: How is science currently taught in your school?

(Probe; classroom teacher versus specialist science teacher; using a particular program e.g. Primary Connections; how much time is dedicated to science?)

Q3: If it were up to you, what model do you think would work best in your school? Why?

Q4: How is mathematics currently taught in your school? (E.g. in class; graded maths groups; teacher programmed or following a particular program/textbook? How much time is dedicated to maths)

Q5: How do you feel about teaching science and maths?

(Probe; confidence e.g. in planning authentic rich tasks)

Part two: ORS professional experience

Q1: What made you decide to take part in the Opening Real Science project as a mentor teacher?

Q2: What expectations did you have when you agreed to take part in the project? Were these expectations met?

Q3: (For teachers who have previously supervised pre-service teachers): In what ways, if any, was the ORS professional experience different to previous one you've supervised?

Q4: The model adopted in this project is for pre-service teachers to complete a block placement in school, emphasising science and/or maths teaching, with the support of you, the mentor teacher, and a specialist supervisor. From your perspective, what are the advantages in this approach? What are the disadvantages? What impact did the professional experience have on your teaching?

Q5: One goal of the ORS professional experience is for pre-service teachers to better develop their skills in teaching science and/or maths. Do you feel your pre-service teacher achieved this?

(Probe; to what extent were pre-service teachers able to implement 5E model: Engage, Explore, Explain, Elaborate, Evaluate?)

(Probe; in what ways were pre-service teachers able to incorporate the real world of science into their lessons? Describe any factors that helped or hindered their capacity to do this.)

Q6: Did the evaluation form allow you to say what you really wanted to say about your pre-service teacher?

Q7: The aim of the ORS project is to promote student engagement and capability in Science and Mathematics through improving the training of pre-service teachers. Please describe the extent to which the students in your class engaged in the Science lessons and developed their understandings of topics taught.

(Probe; how engaged were students in your class? Did the lessons develop their interest in science and/or their understandings of topics covered?)

Q8: Supervising pre-service teachers may sometimes result in professional learning for mentor teachers. What, if anything, did you learn through supervising this professional experience?

Q9: Has your own teaching practice changed at all as a result of participating in the ORS professional experience? If so, how?

Q10: Thinking about the future; What aspects of the ORS professional experience could be improved?

Q11: Would you participate in another ORS professional experience in maths and science? Why/why not?

Q12: Would you recommend taking part in the ORS professional experience to a fellow teacher?

Q13: This project is called the Opening Real Science project. What does "real science" mean to you?

Q14: Do you have any other comments or feedback about the professional experience?

Thank you for participating in this project. Your responses will be used to inform the Opening Real Science professional experience placement for future pre-service and mentor teachers.

Opening Real Science (ORS) Specialist Mathematics and Science Professional Experience

PRE-SERVICE TEACHER INTERVIEW GUIDE

Introduction

Thank you for agreeing to participate in this interview. Your input to this project is highly valued. This research forms part of the Opening Real Science project, which aims to drive a major improvement in the quality of mathematics and science teaching and learning, and build the competence, skills and confidence of pre-service teachers.

One way we hope to achieve this is through offering pre-service teachers the opportunity to take part in a specialist professional experience, focusing on science and/or maths teaching.

The purpose of our interview today is to further explore your experience of this specialist professional experience.

There are two parts to the interview. The first is a discussion about your teaching, the role of your mentor teacher and the ORS model. The second part explores what real science means to you. The interview will take approximately one hour to complete.

I will be recording and transcribing the interview. This is to ensure that I capture our conversation accurately.

I will then replace your name/s with codes in the record of the interview so that no individuals can be identified. The data collected will be kept confidential.

This evaluation of the Opening Real Science project is run independently from the university unit you are enrolled in. Your comments today will not in any way influence your grading for any university study. The information you provide will be used to evaluate the new model of professional experience and may also be used in reporting to the Office for Learning and Teaching, and reported at conferences and in journal articles. You will not be identified individually in any such reports.

Part one: Opening Real Science professional experience

Q 1. What influenced you to participate in the Opening Real Science professional experience placement? (Explore motivating factors such as improve understanding of science; gain experience teaching science; access to a specialist mentor teacher; placement proximity).

Q 2. What expectations did you have of the ORS professional experience? (If they completed a previous practicum, how they expected it to be different) Were these expectations met?

Q 3. What were the benefits of taking part in the ORS professional experience compared to the regular professional experience? Were there any advantages or disadvantages?

Q 4: How confident do you feel in your ability to plan authentic rich tasks in science and/or maths?

Q 5: Thinking about the teaching you did on your practicum, could you describe what you see as the best science lesson or sequence of lessons you taught? What makes this lesson (or lessons) stand out from others? (Probe: – to what extent were you able to implement a 5E model: Engage, Explore, Explain, Elaborate, Evaluate)

Q 6: The aim of the ORS project is to promote student engagement and capability in mathematics and science through improving the training of pre-service teachers. How engaged were the students in your class in the science lessons you taught? Did the lessons develop their interest in science and/or their understandings of concepts covered?

Part two: Mentor teachers

Mentor teachers may have a significant impact on your professional experience. It is important that expert supportive mentor teachers are involved.

Q 1. Can you comment about how the mentor teacher supported you, and in what ways;

Q 2. Would you recommend a peer undertake a specialist ORS placement with your mentor teacher? Why / why not?

(Probe: how expert/committed were mentor teachers in teaching science; how committed/flexible were mentor teachers in enabling pre-service teachers to teach science).

Part three: ORS activities outside of school

The ORS project also offers the opportunity to take part in specialist placements and workshops outside of school and university.

Q 1: Did you complete any such specialist placements?

Q 2: If yes, how useful was this experience? (Explore increasing content knowledge, how to teach, resources, making contacts with scientists / educators)

Part four: The ORS modules and science network

The project has been developing a number of modules to help primary pre-service teachers develop their understanding of science concepts and teaching.

Q 1: Were you offered access to these modules during your professional experience?

If yes, did you access them?

If yes, please describe how you used them.

If not, why not?

The project aims to foster greater collaboration between educators and scientists.

Q 2: Did you have any contact with real scientists during your professional experience?

If yes, how was this established, and describe any benefits to you and your teaching.

Part five: The real world of science

Q 1: This project is called the Opening Real Science project. (Provide paper and pen). Provide an example of what you understand 'real science' to mean.

Thank you for participating in this project.

Appendix T: Mentor teacher and university advisor comments from professional experience

Examples of the responses provided by mentor teacher at post interview from the primary science professional experience are exemplified as follows. These comments support the evidence from the pre-service teachers and university advisors that indicated the effective impact of the professional experience.

MT = mentor teacher; UA = university advisor

2015

Mentor teachers

'A great deal of scientific thought and thinking process was developed in the students'. (MT1)

'Pre-service teacher has proven herself to be a very impressive beginning teacher in science and all other KLAS'. (MT2)

'Pre-service teacher has an enthusiasm and passion for science and science education. She takes risks and engages students ...' (MT3)

'Pre-service teacher excelled herself in the preparation of lessons and was extremely organised with the rich resources that she used'. (MT4)

'Enthused students about science!' (MT5)

'Developed engaging experiments, student focused lessons, questioning, hands-on'. (MT)

'Working across all 5Es'. (MT)

University advisors

'The students were enthralled by the live animal observations and clearly wanted to learn more about them ... the use of ICT helped focus the children and give clearer observation possibilities'. (UA1)

'Pre-service teacher showed great initiative and collaborative skills to make the investigation relevant and meaningful to the children and developed concepts associated with "fair testing"'. (UA1)

'Pre-service teacher promoted higher-order thinking skills with an emphasis on predicting, measuring and controlling variables'. (UA2)

2016

Mentor teachers

'Pre-service teacher planned a variety of lessons that delved into scientific concepts and planned, set up and guided students through experiments'. (MT)

‘She makes learning science and other KLAs much fun and fosters curiosity for students to explore the subject further on their own’. (MT)

‘A very impressive science component of this practicum. Pre-service teacher confidently delivers science lessons that allow students to engage, ponder, question and achieve’. (MT)

‘Excellent knowledge of content and student ability levels. Enthusiasm for integrating science in the classroom’. (MT)

‘Pre-service teacher has excelled in this practicum placement and given a lot of thought to planning high quality, engaging science, maths and other lessons’. (MT)

‘Pre-service teacher has an excellent approach to teaching science and maths ... I am certain she will be an inspirational teacher who instils a love of science in students’. (MT)

University advisors

‘Pre-service teacher has been particularly successful in developing an inquiry based mindset to their learning over a sequence of focused lessons’.

‘Students were engaged in the activity and challenged to develop their own investigation into marble runs’.

‘It was evident that pre-service teacher had worked to increase the students’ ability to be inquiring learners’.

‘Pre-service teacher is capable of promoting students to be inquiring learners able to use their curiosity and creativity to solve problems through investigation’.

‘Pre-service teacher showed great initiative on this practicum and on the ORS project in particular, to develop a unit of work for the whole grade thus making a valuable contribution to the school’.

‘Pre-service teacher [showed] a comprehensive understanding of both theoretical and practical approaches to lesson preparation. Presentation and review. Her particular work in building inquiring minds amongst her students was commendable’.

Appendix U: Module report: *Modelling the Present— Predicting the Future*

Rationale for the module

The ability to apply mathematics to the real world underpins many aspects of personal, civic and work life. The process of using mathematics to solve problems in the real world is known as mathematical modelling. An inability to use mathematics has been shown to limit an individual's career aspirations, social well-being, and financial security (e.g. Paulos, 2000). Further, mathematical modelling is a fundamental capability required within STEM careers – a sector that is vital to maintaining the nation's productivity in an increasingly globalised world characterised by rapid technological and economic change (Australian Academy of Sciences, 2006). Thus, for students to choose and have access to careers within STEM, and related professions, they must be supported by approaches to teaching that inspire them to feel confident and competent with applying mathematics to the real world (Office of the Chief Scientist, 2012). The overarching aim of this module is to develop pre-service teachers mathematical modelling competencies so that they prepared to promote their future students' capabilities with applying mathematics to real world problems.

Additionally, because this module provides explicit treatment of the mathematical modelling process, it deals with a fundamental underpinning of all other modules – which aim to strengthen pre-service teachers' mathematical knowledge by challenging them to engage with how mathematics is used in the real world.

Module proposal

This module explores the power of mathematics for solving real world problems and delves into the visionary thinking that results from big data analyses. In doing so, the module provides support for the development of a number of key mathematical modelling competencies, including:

- understanding of the nature of models/modelling and how these are useful
- understand the role of assumptions when developing a model
- use of already developed models to understand a phenomenon and/or make predictions
- understand the appropriateness or otherwise of applying a particular model to a specific phenomenon/problem
- evaluating the validity/appropriateness of predictions/outcomes
- developing actions that extend from predictions/outcomes
- evaluating appropriateness of actions implied by models – extra mathematics factors such as values, morals, social norms

Case studies were used to explore the mathematical underpinnings of recent advances in the treatment of disease and the management of water pollution, as well as the Black and Scholes model of financial markets and the detection and

description of star systems. The module is designed to promote skills essential to all other modules where mathematics is used to explain and predict real world phenomena as the focus of mathematics or science disciplines. In particular, the module links to other mathematics modules, *Statistical Literacy Secondary*, *Smart Budgeting Secondary*, *Investing & Protecting* and *2 Infinity and Beyond*, by extending concepts and their applications to real world using actual data and models. The case studies demonstrate mathematical models that relate to the four science disciplines included in the Opening Real Science project: biology/medicine, chemistry, environmental science and astronomy/physics. Assessment in the module allows the student to investigate a current real world model of 'big data' of their choice, explain how it works, elaborate on its applications, evaluate its effectiveness and elucidate future frontiers for the model or modelling approach, as well as prepare for its use in a senior secondary mathematics class.

Module development process

Members of the team either self-identified by responding to an expression of interest distributed to relevant staff (mathematicians, scientists, and mathematics and science educators) of participating universities or were invited on the basis of their expertise. The expertise of the module team included: Mariella Herberstein (evolutionary biology), Julian May and Rehez Ahlip (financial mathematics), Heath Jones (astrophysics), Ian Wright (environmental chemistry), Vince Geiger (mathematical modelling), Leanne Rylands (mathematician) and Liz Date-Huxtable (instructional design). The Design Develop Implement (DDI) process was adapted by completing the design and development, trialling and enhancement phases of the process punctuated by a series of workshops to critically review its progress.

The conceptual framework used to guide the development of *Modelling the Present—Predicting the Future* was based on two constructs: the Biological Sciences Curriculum Study (BSCS) 5Es instructional model approach (Bybee, 2009), used to sequence and organise all modules across the project, and the numeracy model for the 21st century (Goos, Geiger & Dole, 2014), used to structure case studies within the module.

The numeracy model for the 21st century has been validated through a series of research projects. This model incorporates the essential components of widely accepted definitions of numeracy while emphasising the role of critical thinking and tools for learning, especially digital tools. The model incorporates the four dimensions of contexts, mathematical knowledge, tools, and dispositions that are embedded in a critical orientation to the use of mathematics to solve problems in the real world. These dimensions are described more fully in other publications (e.g. Geiger, Goos & Dole, 2014).

The process of module development was collaborative and emergent consisting of four phases: selection of content, identifying structure, and planning for subsequent phases; initial case study development; draft case study review; and finalisation of the module by linking of case studies.

The structure of each case study was formulated to provide introductory context to a modelling activity, stimulus questions to generate ideas about the how the mathematical model works, further questions on the application and interpretation of the model, its assumptions and limitations, as well as making and evaluating predictions from the model as a formative assessment. The final assessment comprised developing a modelling case study for a senior mathematics class. The four case studies were completed on the Moodle learning management system in January, 2016. See Geiger et al. (2016) for further detail.

Feedback from reviews and trials

Review of module

A comprehensive review of the module was submitted by Professor Peter Galbraith (UQ) on 1st April, 2016, and revisions were completed on 20th May, 2016, in time for the ORS enhancement workshop on 30th May, 2016. Further enhancement of the module was completed on 26th August, 2016 as a result of additional feedback from this meeting.

Module revisions included:

1. scaffolding all case study 'tools' using either with supporting documentation (including the use of screen grabs) or Adobe Captivate videos that provided elaboration on the use of buttons and/or sliders. This scaffolding also included questions about the underlying mathematics behind the manipulation of buttons/sliders.
2. developing a tutor guide.
3. scaffolding of online delivery through a directing set of questions for each activity (added to tutor guide).
4. developing a discussion forum/set of questions to bring out the 'value-ladenness' of models within each case study.
5. addition of an outcome for the modelling process to make a clear connection to key scientific concepts.
6. fine tuning of time allocations for each case study.
7. structuring of the introductory audio recording around stimulus questions.
8. reworking of the case study based on the Black and Scholes model for financial market behaviour to focus just on shares as well as a choice for final assessment based on the S&P500 Index.

Trialling of the module

A secondary mathematics pre-service teacher education class at ACU-Sydney completed a trial of the module during semester 2, 2016. The feedback from this trial is still undergoing analysis.

Reflection on the process

A unique aspect of this module was the approach to design utilised by the Module Development Team (MDT). The design was underpinned by an inquiry-based approach common to all ORS modules, the 5Es model (Bybee, 2009) and inclusion of mathematicians, scientists, mathematics and science educators in MDTs. Additionally, however, emergent structuring devices and practices such as the use of the numeracy model (Goos, Geiger, Dole, 2014) and the ways in which MDT members interacted and brought together their specific expertise in a unique collaboration shaped the structure and the scaffolding architecture of the module. Thus, both module and case study development were underpinned by principles of design and practices seeking to promote collaboration among experts within the STEM disciplines. As a result, these principles and practices were in alignment with the overarching aim of the ORS Project—to draw on the expertise of mathematicians, scientists, mathematics educators and science educators in order to engage pre- and in-service teachers with real mathematics and science so that these subjects can be taught as they are practised.

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Appendix V: Professional experience recommendations

Recommendations for professional experience in mathematics and science for teacher education and schools

The ORS professional experience has shown strong benefits for pre-service teachers who do not have a background in science or mathematics and who may not be undertaking a specialisation in primary science or mathematics teacher education (BOSTES NSW, 2016).

It is recommended that:

1. Teacher education programs adapt a flexible and innovative approach to professional experience to encourage specialist experience in mathematics and science, to suit their program contexts and their pre-service teachers' backgrounds.
2. Select schools and mentor teachers with care, by establishing, or building upon existing relationships with mentor teachers; only involve a manageable number of committed schools. Ideally, more than one mentor teacher at each school is encouraged to support a collaborative approach among mentor teachers, pre-service teachers and university advisors.
3. Begin with a small cohort of pre-service teacher volunteers, selected with care and focus on students who have completed at least one consistent, successful professional experience period. An expression of interest process supports commitment. This needs to be established and articulated to students and staff well in advance as part of the teacher education program guidelines.
4. Provide an orientation/professional learning meeting for both mentor teachers and pre-service teachers to i) establish expectations and processes, ii) provide access to ORS modules and iii) allow mentor teachers and pre-service teachers to meet and plan prior to the professional experience period. Feedback from mentor teachers indicated that a full day orientation would be preferred if it included professional learning in science and/or mathematics.
5. Recruit suitable specialist primary mathematics and science advisors possibly from the school sector. Establish processes for collaboration between university mathematics and science academics and professional experience and mentor teacher advisors for supporting ORS pre-service teachers.
6. Professional experience advisors liaise closely with teacher education program staff where program development and evaluation can take account of the ORS approach and use of the modules.
7. Liaise closely with university professional experience coordinators, academic staff and administrative staff, to integrate appointment of pre-service teachers to schools within the larger professional experience system. This would require lead-up time (at least six months).

8. Support an ongoing network of cooperating schools and relationships with the university. Schools and mentor teachers appreciate professional learning opportunities, and mathematics and science resources. Mentor teachers can also provide guidance to teacher education program development.

Sustaining a specialist professional experience approach will require integration into university programs and some additional ongoing funding for specialist university advising and mentor teacher relief time.

An ongoing commitment to specialist science or mathematics implies some additional funding as follows:

1. The provision of the ORS mentor teacher once off payment was highly valued by schools. This can cost between \$350 – \$500 per mentor teacher. It is recommended that this funding be attached to the mentor teacher attendance of a full day orientation meeting and the evaluation of the specialist professional experience.
2. In the standard professional experience programs, university advisors are often employed casually and are generally paid to make one visit to students on professional experience. If specialist university advisors are to be employed and expected to supervise closely, additional costs would be expected.
3. Additional administration and coordination support for selecting and coordinating pre-service teachers, schools and mentor teachers may be necessary.



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Learning & Teaching



Opening Real Science (ORS) is a unique collaboration between Australia's leading teacher educators, scientists, mathematicians and ICT experts. It will develop innovative pre-service programs to equip teachers to inspire and motivate students through authentic, inquiry based learning.

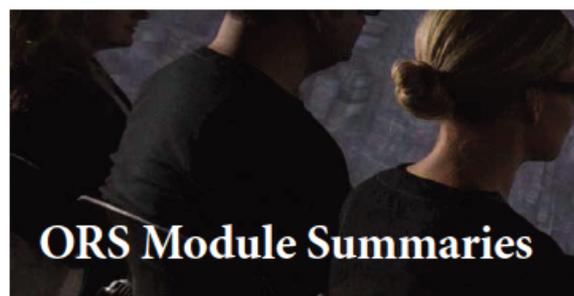
ORS is part of the Australian Government's Initiative: Enhancing the Training of Mathematics and Science Teachers program (ETMST). This program was established in response to recommendations from Professor Ian Chubb AC, Australia's Chief Scientist, in his 2012 report *Mathematics, Engineering and Science: In the national interest*.

Led by Macquarie University, this \$2.3m Australian Government funded project will drive major improvement in the quality of mathematics and science learning by delivering innovative teacher education modules. ORS will also develop a unique professional experience model to build the competence and confidence that Australian teachers need to engage their students in motivating investigations around real science in our world.

Together with our partners, Western Sydney University, Australian Catholic University, University of Canberra, University of Notre Dame Australia, Edith Cowan University, Charles Sturt University and CSIRO Astronomy and Space Science, the Australian Astronomical Observatory and Las Cumbres Observatory Global Telescope Network, the ORS project is focused on five key outcomes:

1. Developing and trialling 25 mathematics and science on-line learning modules for primary and secondary teacher education, equivalent to 8 university semester units
2. Identifying and building a network of outstanding school mentors who practise real science
3. Developing and implementing a model of professional experience so pre-service teachers can work collaboratively with school mentors
4. Developing specialised teacher education programs in primary and secondary mathematics and science
5. Building and maintaining a network of mathematicians and scientists (in and outside the university network), educators, school mentors and educational stakeholders to sustain the project into the future.

If you would like more information on the ORS project please visit the website; http://www.educ.mq.edu.au/education_research/opening_real_science/ or contact the ORS office in the School of Education Macquarie University 02 9850 8675



Discovering Real Science is the 'Gateway' module that will take you on a journey from the beginning of the universe to today's interconnected global societies.



Frontiers of Real Science puts you in touch with real scientists and their cutting-edge research.



Consumer Chemistry engages you with the process of scientific inquiry in real chemistry so you see the relevance of chemistry in everyday life packaged with chemistry concepts.



Science in the Community enables you to plan and conduct your own exciting science activities for events such as Science Week and community-based science investigations and events inspiring you to engage in real chemistry activities.



Clocks in Rocks reveals the geology all around us. Every resource we have is either farmed or mined, and both are related to geology. Geologists are historians and detectives, using the other branches of science as a toolkit to look for clues.



Human Impact. Can our impact be moderated or altered to deliver positive outcomes for other species inhabiting our world? Every species has an impact on their local environment. However human impact can be detected in every environment.



Fundamentals of Weather and Climate. Have you ever wondered how the weather works? Using tropical cyclones as an example, you will learn the key principles for understanding weather such as air pressure and the causes of wind and cloud formation.



Intelligent Materials. Intelligent or 'smart' materials change their properties in response to changes in their environment. Could our use of these materials change our society?



Inspired by Plants focuses on the amazing variety of structures in leaves, fruits, flowers and cones. Art and science intersect when you practice the science skills of close observation to create a model, drawing or digital representation of a plant or plant part.



The Living Laboratory. Gardens are living laboratories for scientists researching plant growth, habitat restoration, developing plants for agriculture and the horticulture industry. You too can be a scientist with your own living laboratory.



Bioluminescence is a complex natural phenomenon exhibited by several life forms which perform a biochemical reaction to produce light, which may be used for a distinct biological purpose such as communication and predation.



Sound. Discover how sound is created, how it travels, how sounds differ and how we describe sound. You will build your understanding of sound by conducting your own experiments.



Light is something we often take for granted. We explore the science of light and build an awareness of how light-based technologies promote sustainable development and provide solutions to global challenges in energy, education, agriculture and health.



Primary Astronomy explores the basics of solar system astronomy. We challenge the common astronomical misconceptions about how the sun, moon and planets work and the phases of the moon.



Telescopes, Colour and the Cosmos provides an introduction to fundamental aspects of modern astronomy required to build an observational understanding of the cosmos.



Tracing the Life Cycle of Stars develops an understanding of the main phases of the lifecycle of stars, their observable properties and their fundamental nature, by exploring concepts presented in Hertzsprung-Russell Diagrams and Colour-Magnitude Diagrams.



Life and Death of Stars takes you on a journey exploring the differences between stars and the way they live, evolve and eventually die. You will develop as a confident teacher of scientific material to students of all ages using authentic scientific process.



Gateway to Numeracy deals with 'real life' problem solving using mathematics and integrating aspects of number and algebra, measurement and geometry and statistics and probability.



Smart Budgeting Primary looks at the practical preparation of budgets for a person or student. You will apply mathematics principles to effectively manage budgets across multiple domains either personal, organisational or government budgets by working through cases and activities in real world scenarios.



Statistical Literacy Primary guides you through the everyday use of numbers and comparisons of numbers to justify the decisions that we make. Statistics is a way of making sense of factors or variables.



Smart Budgeting Secondary guides you through mathematics principles to effectively manage budgets across multiple domains; personal, organisational or government budgets by working through case studies and real world scenarios.



Investing and Protecting guides you through mathematics principles to financial management concepts including investing, superannuation, credit and protection through insurance. You will work through real world scenarios, case studies and activities.



Statistical Literacy Secondary shows you how to add rigor to numerical claims and comparisons and how to examine other people's claims using statistical evidence and reasoning.

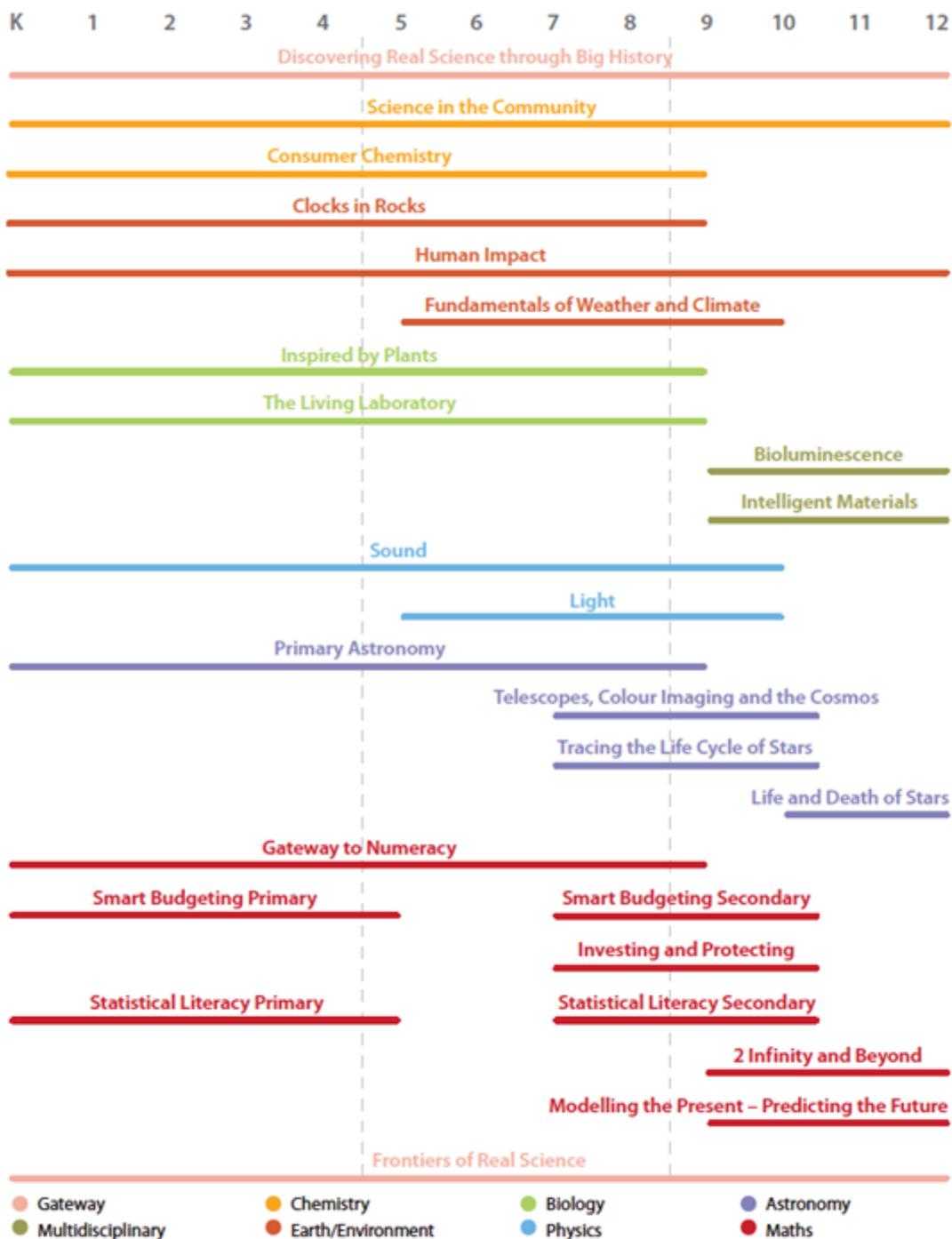


2 Infinity and Beyond is a familiar term to a generation of students, but what does it mean? How big or far away is it? Is there only one type of infinity? Can we estimate it or even imagine it? And what use is it in modelling our world using mathematics?



Modelling the Present - Predicting the Future explores the use of mathematical modelling to understand real world problems. You will delve into big data using case studies to explore recent advances in the treatment of disease, management of water pollution, measurement of light emissions of stars and predicting the price of commodities.

ORS Modules for Pre-service Teachers



Opening
Real Science

For more information visit www.educ.mq.edu.au/education_research/opening_real_science/ or contact the ORS office in the School of Education Macquarie University 02 9850 8675.

Appendix X: Summary of dissemination activities

Date	Title	Event type	Publisher/host	Purpose	Audience
01/12/2016	Connecting Young Children's Mathematics Learning	Conference	The Mathematical Association of Victoria (MAV)	Keynote presentation	Mathematics and STEM educators, professionals
23/11/2016 – 24/11/2016	STEM Education Research Centre (SERC) Spatial Reasoning Seminar	Conference	University of Canberra, ACT	Invited commentary and panel discussion	STEM researchers and teachers
10/11/2016	Opening Real Science - Primary Maths	MQ student workshop	Macquarie University	Improve primary financial and statistical literacy understanding	Pre-service primary students
07/11/2016 - 08/11/2016	Educating the Educators – 2nd Conference on international approaches to scaling-up professional development in maths and science education	Conference	mascil (Mathematics and science for life!) project: Freiburg, Germany	Creating STEM online materials for pre-service teachers through interdisciplinary collaboration between mathematics educators, mathematicians and scientists	Teacher educators and researchers
07/11/2016	ReMSTEP Conference	Conference	Reconceptualising Mathematics and Science Teacher Education Programs (ReMSTEP): Melbourne	Linking teachers and students with mathematics and science	Mathematics and science educators
20/10/2016	ORS Professional learning workshop on science	Workshop	Carlingford West Public School	Professional learning workshop on using ORS	Primary mathematics and science teachers

Date	Title	Event type	Publisher/host	Purpose	Audience
28/09/2016 – 30/09/2016	Enhancing the Training of Mathematics and Science Teachers	Conference	22nd UniServe Science Conference: Australian Conference on Science & Mathematics Education: University of Queensland	Discuss shifts in higher education practice that can effect and support change through our preparation of the next generation of mathematics and science teachers nationally. Explore key findings and implications of ETMCT projects nationally	Tertiary mathematics and science educators
27/09/2016	Opening Real Science	Taster day	Macquarie University	Macquarie taster day: science, medical and human sciences	Macquarie University community, students, teachers, general public
21/09/2016	Opening Real Science – Primary Astronomy	Macquarie University student workshop	Macquarie University	Workshop on astronomy teaching and learning conducted by Dr Cormac Purcell	Pre-service primary students
14/07/2016	Can't Be What You Can't See – Science Technology Engineering, Arts and Mathematics (STEAM)	Conference	Learners Conference 2016 – Common Ground: Vancouver, Canada	The University of Notre Dame Australia dissemination of report	International teachers/academics involved in learning and teaching
03/07/2016 – 06/07/2016	Australian Science Teachers Association	Conference	CONASTA 65: Conference of the Australian Science Teachers Association, Brisbane	Attendance for collaboration and dissemination of ORS project ideas	Science teachers
11/07/2016	Implementing ORS across multi-campus (Charles Sturt University) workshop	Trialling planning and support	Charles Sturt University and Macquarie University	Partner university collaboration and support for initial trialling program	Partner university – teacher education program

Date	Title	Event type	Publisher/host	Purpose	Audience
28/04/2016 – 29/04/2016	Learning and Teaching 2030: Collaborating to Shape the Future of Learning and Teaching	Conference	Office of Learning and Teaching Conference, Melbourne	Attendance and workshops	Government; primary, secondary and tertiary educators and researchers
3/05/2016 – 12/05/2016	ORS workshop: trialling and implementation	Trialling support	Australian Catholic University	Partner university collaboration and support for initial trialling program	Partner university – teacher education program
24/02/2016	ORS practicum orientation workshop	Workshop	Macquarie University	Workshop orientating participating student in the ORS practicum	Primary and secondary education students
2015	Australian Council of Deans of Education	Conference	Australian Council of Deans of Education	Attendance and participation in discussion group on STEM	Higher education and stakeholders
26/11/2015 – 27/11/2015	Australasian Symposium on Pen-Enabled Tablets in teaching STEM Subjects	Conference	Science Technology Engineering Mathematics Tertiary Education Centre: Auckland University of Technology	Participation in STEM discussion groups	Science educators, teachers
05/11/2015	Enhancing the Training Of Mathematics and Science Teachers – Opening Real Science	Conference Presentation	Inspiring STEM Education Forum: Southern Cross University, Gold Coast	Overview of ORS project scope and development	Educators, researchers
30/09/2015	Australian Conference on Science and Mathematics Education 2015	Conference	21st UniServe Science Conference: Australian Conference on Science &	Australian Conference on Science and Maths education. Workshops and ETMST discussion	Tertiary maths and science educators. Roundtable on ORS

Date	Title	Event type	Publisher/host	Purpose	Audience
			Mathematics Education: Curtin University		
15/09/2015	Consumer Chemistry	Presentation	Macquarie University, Learning and Teaching Week	Presentation of the Consumer Chemistry ORS module	General public, Macquarie University community, educators, students
01/09/2015	ORS: Engaging Primary Teacher Education Students With Science and Mathematics	Conference	Australian Conference on Science and Mathematics Education 2015	Engaging primary pre-service teachers with mathematics and science: workshop participation	Mathematics and science teachers and higher education sector
21/08/2015 – 22/08/2015	ORS workshop	Workshop	Macquarie University	Module workshop <i>Science in the Community</i> module team	ORS university partners
20/08/2015	The University of Notre Dame Australia ORS trialling workshop	Workshop	The University of Notre Dame Australia (UNDA)	Discussion of maths modules and trialling plan	Partner university - teacher education program
17/08/2015 – 18/08/2015	Australian Catholic University ORS trialling workshop	Workshop	Australian Catholic University	Partner university collaboration and support for initial trialling program	Partner university – teacher education program
15/08/2015	ETMST evaluation and dissemination forum	Forum	OLT	ETMST project teams present, collaborate and exchange ETMST strategies	Project teams, OLT staff, higher education learning and teaching professionals
13/08/2015	National Science Week 2015	Launch and Festival	National Science Week Office	Indigenous Science National Indigenous Science Education Program (NISEP) and ORS participation	University partners disseminate <i>Science in the Community</i> module development

Date	Title	Event type	Publisher/host	Purpose	Audience
16/07/2015	ORS Design Model: Learning & Teaching in Science	Presentation	Macquarie University	Overview of ORS project scope and development	Macquarie University community, tertiary educators, researchers
27/05/2015	Design Slam! Opening Real Science: 6S's to Opening Real Science	Presentation	University of Western Sydney	Showcasing of ORS modules, considering ORS module review reports, and hosting of critical review and discussion of module development	Students, teachers
25/05/2015	Design Slam! Opening Real Science Significance	Presentation	Questacon: University of Canberra	Showcasing the impact and significance the ORS projects aims to have on STEM education in Australia	Science educators, teachers, education bodies
27/03/2015	ETMST evaluation and dissemination forum	Forum	OLT	ETMST project teams present, collaborate and exchange ETMST strategies	Project teams, OLT staff, higher education learning and teaching professionals
20/12/2014	Initiatives Aim to Lift Numbers of New Teachers	Publication	<i>Sydney Morning Herald</i>	Explain 'real' science and overview of ORS	General public
04/12/2014	ORS presentation to Edgeworth Heights and Windale Public Schools, Newcastle	Schools presentation	Macquarie University	Mentor teacher network recruitment	Primary teachers
24/11/2014 – 28/11/2014	Malaysian teacher delegation visit	Malaysian teachers tour	Macquarie University	Professional learning in maths and science. ORS presentations and 2 ORS special maths and science school visits	6 Malaysian primary teachers
25/11/2014	Big History Project	Colloquium	Macquarie University	Big History Project and collaboration	Macquarie University Physics and

Date	Title	Event type	Publisher/host	Purpose	Audience
				with ORS	Astronomy
15/11/2014 – 18/11/2014	Edith Cowan University visit	ORS partner visit	Edith Cowan University	Presentation and collaboration for ORS: module development, trialling and implementation into TEP	Edith Cowan University academics and pre-service teacher educators
10/11/2014	Opening Real Science: Authentic Mathematics and Science Education for Australia	Presentation	Powerhouse Museum, Sydney	Overview of ORS project scope and development	General public, students, educators
07/11/2014	Inspiring Mathematics and Science in Teacher Education	Forum	Southern Cross University	Collaboration between ETMST projects identify TEP structures; gauge readiness for maths and science change and transferability	Primary, secondary and tertiary educators from mathematics and science key learning areas
03/11/2014 – 04/11/2014	It's Part of My Life: Engaging University and Community to Enhance Science and Mathematics Education'	Forum	Southern Cross University	Collaboration and strategies between ETMST projects	Pre-service teachers, accreditation bodies
28/10/2014 – 03/11/2014	Science Engagement Strategies	Japanese teacher exchange	Australian Science Teachers Association	Science engagement strategies	Primary and middle school science teachers
21/10/2014	Equip and Inspire: Educating for the Future	MQ@50 Alumni event	Macquarie University	Mathematics and science teaching now and into the future	Early childhood to university mathematics and science educators, alumni

Date	Title	Event type	Publisher/host	Purpose	Audience
16/10/2014	Support Learning Communities across Science and Technology	Workshop	Science and Technology Education Research Network	Overview of ORS project aims to build on collaborative networks	Science educators, researchers, education bodies, teachers
01/09/2014	Opening Real Science, 6Es Design Framework and Learning Activities in Moodle	Conference	Macquarie University	Presentation of core ORS design concepts	Macquarie University community, teachers, general public
19/08/2014	Opening Real Science: Authentic Mathematics and Science Education for Australia	Presentation	The University of Notre Dame Australia	Overview of ORS project scope and development	Students, teachers, general public
28/07/2014	Bringing Kids Out of Their Shells, Via a Ground-Breaking Opening Real Science Program	Media release	<i>Daily Telegraph</i>	ORS engaging teaching practices, science literacy	Pre- and in-service mathematics and science teachers, educators
27/07/2014	Education Revolution to Change How Science and Maths Are Taught in Schools	Media release	<i>Herald Sun</i>	ORS 'hands-on' teaching science	Pre- and in-service mathematics and science teachers, educators
19/04/2014	Sky No Limits to Students	Publication	<i>Manly Daily, Sydney</i>	Seaforth Public School astronomy at Macquarie University	General public
13/04/2014	Future Growth: Do the Maths	Publication	<i>Sunday Herald</i>	Importance of mathematics education in the future. Demonstrating the need for ORS outcomes and for lifting the number of mathematics teachers in	General public

Date	Title	Event type	Publisher/host	Purpose	Audience
				Australia	
08/04/2014	Opening Real Science media launch	Media launch	Macquarie University	Macquarie University launch of ORS project by Macquarie University Dean Professor Janet Greeley	OLT stakeholders, key Macquarie University personnel, pre-service teachers, primary school students and parents
30/12/2013	Initiatives Aim to Lift Numbers of New Teachers	Publication	<i>Sydney Morning Herald</i>	Professor Joanne Mulligan quoted explaining 'real' science and overview of the ORS project	General public
5/04/2013	Macquarie University AAAstro open night	ORS display booth	Macquarie University	ORS and 'real' science, network	Macquarie University personnel, students, teachers, general public

ETMST, Enhancing the Training of Mathematics and Science Teachers. OLT, Office of Learning and Teaching. ORS, Opening Real Science. STEM, science, technology, engineering and mathematics. TEP, teacher education professional.

Appendix Y: Publications and conferences

Journal articles

- Bilgin, A. A. B., Date-Huxtable, E., Coady, C., Geiger, V., Cavanagh, M., Mulligan, J. T., and Petocz, P. (2017). Opening Real Science: Evaluation of an online module on statistical literacy by pre-service primary teachers. *Statistics Education Research Journal*, 16(1), 120-137.
- Bybee, R. W. (2010). Advancing STEM education: A 2020 vision. *Technology and Engineering Teacher*, 70(1), 30-35.
- Campbell, C., and Chittleborough, G. (2014). The 'new' science specialists: Promoting and improving the teaching of science in primary schools. *Teaching Science*, 60(1), 19-29.
- Geiger, V., Mulligan, J., Huxtable, E., Ahlip, R. Jones, H., May, J. , Rylands, L. & Wright (in press). An interdisciplinary approach to designing online learning: Fostering pre-service mathematics teachers' capabilities in mathematical modelling. *ZDM Mathematics Education*.
- Lane, R. (2015). Primary geography in Australia: Pre-service primary teachers' understandings of weather and climate. *Review of International Geographical Education Online*, 5(2), 19.
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- Tilley, G. (2014). Junior science academy at Macquarie University. *Science Education News*, 63(4), 40-41.
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- Tilley, G. (2014). Promoting girls in science. *Science Education News*, 63(3), 44-46.
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- Wilson, M. J., Diao, M., and Huang, L. (2014). 'I'm not here to learn how to mark someone else's stuff': an investigation of an online peer-to-peer review workshop tool online. *Assessment & Evaluation in Higher Education*, 40(1), 15-32.

Conference papers and abstracts

- Bilgin, A. A., Coady, C., Mulligan, J. T., Geiger, V., Cavanagh, M., Petocz, P., and Date-Huxtable, L. (2015). Opening Real Science: Statistical literacy for pre-service primary teachers through flexible delivery. *Proceedings of IASE Satellites Advances in Stats Education 2015*. Rio do Janeiro, Brazil: Universidade Federal do Estado do Rio de Janeiro.
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- Diao, M. (2014). Moodle generating science inquiry activities. *Proceedings of 2014 MoodleMoot AU – Evolution*. Cairns, Australia: MoodleMoot.
- Geiger, V. & Mulligan, J. T. (2016). Creating STEM online materials for pre-service teachers through interdisciplinary collaboration between mathematics educators, mathematicians and scientists. *Proceedings of Educating the Educators: International Approaches to Scaling Up Professional Development in Maths and Science Education*. University of Education Freiburg, Germany: MASCIL.
- Geiger, V., Date-Huxtable, L., Ahlip, R., Herberstein, M., Jones, D. H., May, E. J., Rylands, L., Wright, I., and Mulligan, J. T. (2016). Designing online learning for developing pre-service teachers' capabilities in mathematical modelling and applications. In B. White, M. Chinnappan & S. Trenholm (Eds.), *Proceedings of 39th Annual Conference of the Mathematics Education Research Group of Australasia: Opening Up Mathematics Education Research* (pp. 260-268). Adelaide, Australia: MERGA.
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