

Designing Online Learning for Developing Pre-service Teachers' Capabilities in Mathematical Modelling and Applications

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The purpose of this paper is to describe the processes utilised to develop an online learning module within the Opening Real Science (ORS) project – *Modelling the present: Predicting the future*. The module was realised through an interdisciplinary collaboration, among mathematicians, scientists and mathematics and science educators that drew on the enquiry-based approach underpinning ORS as well as structuring devices and working practices that emerged during the course of the module development. The paper is a precursor to further research that will investigate the effectiveness of the module in terms of students' learning and attitudes as well as the module development team members' perspectives on the interdisciplinary collaboration that took place.

Introduction and Background

Falling participation in mathematics, science and technology in Australia has created serious concerns about Australia's capacity to sustain a knowledge-based economy and society (e.g., Australian Academy of Science, 2016). This decline has been linked to students' perceptions of mathematics and science as characterised by didactic instruction and that practical classes are "largely about recipes or watching teachers following recipes" (Office of the Chief Scientist, 2012, p. 9). In response to concerns about declining enrolments in mathematics, science and engineering, the report *Mathematics, Engineering and Science in the National Interest* (Office of the Chief Scientist, 2012) identified five key areas that must be addressed in order to strengthen mathematics and science teaching, namely: (1) Inspirational teaching; (2) Inspired school leadership; (3) Teaching techniques; (4) Gender issues; and (5) Scientific literacy.

An initiative developed to address these issues is the *Enhancing the Training of Mathematics and Science Teachers* (ETMST) program (2013-2016), which includes the project *Opening real science: Authentic mathematics and science education for Australia* (ORS) (Mulligan, Hedberg, Parker, Coady, & Cavanagh, 2014). The ORS project draws on

the expertise of mathematicians, scientists, mathematics educators and science educators in a unique collaboration that aims to engage pre- and in-service teachers with real science, and with real scientists and mathematicians. The purpose of the project is to enable the teaching of mathematics and science as they are practised – as a dynamic inquiry into the nature of real world phenomena. In support of pre-service teachers’ learning, the ORS teacher education program has developed 25 online learning modules across mathematics and science through academic collaboration that utilise authentic contexts and enquiry-based pedagogical approaches. These modules are made available to students via a Moodle site enabled with a range of online pedagogical tools.

The purpose of this paper is to describe the processes utilised to develop one online learning module within the ORS, *Modelling the present: Predicting the future* and to address the following research question:

How can collaboration between mathematicians, scientists, mathematics educators and science educators be utilised in designing an online learning module with a focus on mathematical modelling?

Conceptual Framework

The conceptual framework used to guide the development of the module *Modelling the present: Predicting the future* was based on two constructs: the Biological Sciences Curriculum Study (BSCS) 5Es Instructional model approach (Bybee, 2009), utilised 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 *Modelling the present: Predicting the future* module.

The 5Es enquiry-based approach to science education consists of five phases: engagement, exploration, explanation, elaboration and evaluation. Each phase has a role in developing students’ understanding of scientific and technological knowledge, attributes and skills (Bybee, 2009). A summary description of these phases is set out in Table 1.

Table 1 Summary description of the 5Es instructional model (Bybee, 2009, p. 8)

Engagement	The teacher or a curriculum task assesses the learners’ prior knowledge and helps them become engaged in a new concept through the use of short activities that promote curiosity and elicit prior knowledge. The activity should make connections between past and present learning experiences, expose prior conceptions, and organize students’ thinking toward the learning outcomes of current activities.
Exploration	Exploration experiences provide students with a common base of activities within which current concepts (i.e., misconceptions), processes, and skills are identified and conceptual change is facilitated. Learners may complete lab activities that help them use prior knowledge to generate new ideas, explore questions and possibilities, and design and conduct a preliminary investigation.
Explanation	The explanation phase focuses students’ attention on a particular aspect of their engagement and exploration experiences and provides opportunities to demonstrate their conceptual understanding, process skills, or behaviors. This phase also provides opportunities for teachers to directly introduce a concept, process, or skill. Learners explain their understanding of the concept. An explanation from the teacher or the curriculum may

	guide them toward a deeper understanding, which is a critical part of this phase.
Elaboration	Teachers challenge and extend students' conceptual understanding and skills. Through new experiences, the students develop deeper and broader understanding, more information, and adequate skills. Students apply their understanding of the concept by conducting additional activities.
Evaluation	The evaluation phase encourages students to assess their understanding and abilities and provides opportunities for teachers to evaluate student progress toward achieving the educational objectives.

The Numeracy Model for the 21st Century has been validated through a series of research projects (e.g., Goos, Geiger & Dole, 2011; Geiger, Forgasz & Goos, 2015). 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 summarised in Table 2 but described more fully in other publications (e.g., Geiger, Goos & Dole, 2014).

Table 2: Descriptions of the elements and critical orientation of the numeracy model

Mathematical knowledge	Mathematical concepts and skills; problem solving strategies; estimation capacities.
Contexts	Capacity to use mathematical knowledge in a range of contexts, both within schools and beyond school settings
Dispositions	Confidence and willingness to use mathematical approaches to engage with life-related tasks; preparedness to make flexible and adaptive use of mathematical knowledge.
Tools	Use of material (models, measuring instruments), representational (symbol systems, graphs, maps, diagrams, drawings, tables, ready reckoners) and digital (computers, software, calculators, internet) tools to mediate and shape thinking
Critical orientation	Use of mathematical information to: make decisions and judgements; add support to arguments; challenge an argument or position.

Module Development Team

Module development was carried out by a team of eight academics with backgrounds in mathematics, science, and mathematics and science education, who volunteered their expertise in biological evolution, financial mathematics, astrophysics and environmental science as well as experience in the teaching and learning of mathematical modelling and instructional design. 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.

Module Development Processes

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.

At the first meeting of the module development team (MDT), an overview of the 5Es model was presented by the team's instructional designer as a framework for the overall structure of the module. This provided the MDT with the means to think forward about the organisation of the module. After this presentation, the module leader asked members of the MDT to talk about their personal research interests and how this was connected to mathematical modelling. Topics of interest were diverse including the understanding of the evolution and transmission of disease-causing agents (epidemiology), the effect of market forces on the stock exchange in relation to investment and risk (financial mathematics), the nature of eclipsing binary stars (astrophysics) and the impacts of pollution in waterways (environmental chemistry). After a discussion of these topics in relation to the module, the group came to the conclusion that each could be authentically represented as a case study from which students could gain an understanding of the use of mathematical modelling. This decision led to a subsequent discussion of how to organise the case studies within the module in a manner consistent with the 5Es model and within the constraint of 36-40 hours of study over 4-5 weeks allocated for a module. The outcome of this deliberation was agreement that the module would consist of: an introduction; a case study mandatory for all students; a second case study chosen from three options; and a final reflection tied to a capstone assessment. Details of the module's organisation and alignment with the 5Es model are outlined in the Module Overview section of this paper.

Discussion then moved to how to structure each case study in a consistent and coherent format within the module. The MDT leader facilitated this discussion by asking members of the team to provide initial thoughts of what their case study might look like and then linked the resulting descriptions with the Numeracy Model for the 21st Century. The following features were evident in each description:

- a real world scenario was central (context)
- mathematical knowledge had an important role in understanding and addressing the problem scenario (mathematical knowledge)
- digital tools were needed to explore the specified aspects of the scenario (tools)
- there was an intent to promote positive student dispositions toward the use of mathematics to solve real world problems (dispositions)
- a decision or judgement was required in relation to the problem scenario (critical orientation)

Further discussion resulted in agreement that each case study should align with a template, developed by the module leader, based on the Numeracy Model for the 21st Century (Goos et al., 2014). Details of this template and an example of its use to structure module case studies are outlined in the Case Study Exemplar section of this paper.

After the initial meeting, members of the MDT worked on developing draft versions of their case studies, some in teams and some as individuals, in collaboration with the instructional designer and the MDT leader. Draft case studies were presented at a second face-to-face meeting so that members of the MDT could provide critique and feedback. Comments and suggestions were accommodated into the existing drafts and then finalised.

The instructional designer, in consultation with the MDT leader, added an introduction to the module and a concluding section in which students were required to reflect on the modelling process and respond to a capstone assessment item.

Module Overview

The module was based on the following learning outcomes:

- Understanding of the nature of models/modelling and how these are useful
- Understanding of the role of assumptions when developing a model
- The use of models to understand a phenomenon and/or make predictions
- Understanding 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

Opportunities to acquire and demonstrate the knowledge, skills and understandings associated with these outcomes were realised in the module via learning activities in the form of case studies and embedded reflective/assessment tasks. The structure of the module was developed to be consistent with the 5Es model of instruction. A description of the sections of the module and their alignment with the 5Es model is presented in Table 3.

Table 3 Modelling the present: Predicting the future outline and elements of the 5Es

Description	Alignment with 5Es
<i>Introduction</i>	
Description of the process of modelling and its importance. Overview of the unit, learning outcomes and assessment. Examples of how modelling is used to explain phenomena and make predictions (videos).	Engagement
<i>Case study 1</i>	
<i>Epidemiology: Humanity's greatest killers</i>	
Introduction to the nature of infectious diseases and how modelling can be used to predict transmission rates. Examination of specific epidemics, such as Ebola, to explore the mathematical modelling associated with understanding the spread of disease, based on biological mechanisms Assessment that required students to investigate mortality rates in relation to changes to influential factors in infectious disease spread based via the use of a prepared spreadsheet.	Engagement Exploration Explanation
<i>Case study 2 – choice from</i>	
<i>Trading: Understanding investment and risk; Environmental chemistry: Impacts of pollutants in Catchments; Astrophysics: Modelling the big, the strange, and the too far to see</i>	
While the contexts varied, each case study provided: a description and background to real world scenario and specified an open ended problem within the chosen context; introduced a	Engagement Exploration Explanation

digital tool (e.g., a prepared spreadsheet) for investigating and responding to the problem; activities designed to promote students' understanding of the scenario, the problem and familiarity with the digital tool; assessment in which students were required to make predictions about aspects of the scenario/problem.	Elaboration
<i>Reflection and capstone assessment item</i>	
Students must develop teaching resources for secondary mathematics students in which: the idea of mathematical modelling is introduced via a real world scenario; assumptions which underpin the chosen model are described; the model is used to make a prediction about a problem associated with the scenario; the usefulness and validity of the model are evaluated.	Engagement Exploration Explanation Elaboration Evaluation

As documented in the table, the module provided a learning pathway that was initially highly scaffolded but provided for an expectation of increasing levels of independence as students progressed through the module.

Case Study Exemplar

As foreshadowed in the section on the module development process, a template based on the Numeracy Model for the 21st Century, was developed by the module leader in order to provide a consistent frame for case studies. In this section, a specific case study is outlined in order that the underpinning principles of design are made explicit. The template framed case studies according to the following format:

Table 4 Case study template

Section	Activity	Resources	Numeracy model dimension
Introduction	Scenario and background: the nature of the scientific/mathematical field of study and its importance and relevance; a general question to be addressed through the module.	Text description Videos	Context Dispositions
Working with tools	Introduction to tools used for investigating the scenario/problem via use of a mathematical model. Step by step instructions to help students gain familiarity with tool while addressing a specific straightforward question about the scenario.	Examples include spreadsheets, online tools, relevant formulas and equations	Context Mathematical knowledge Tools Dispositions Critical orientation
Additional question(s)	More open-ended and question(s) of increased complexity in which a scenario is explored using a mathematical model. Prediction(s) are required in responses to questions. Use of relevant digital tool necessary	Relevant digital tool or online resources	Context, Mathematical knowledge Tools Dispositions Critical

to respond to question(s). Online support available upon request.	orientation
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While provided as a guide and not a prescriptive structuring device, each case study followed the general form of the template. An outline of the case study entitled *Astrophysics: Modelling the big, the strange and the too far to see*, is presented in Table 5 by way of illustration. The table includes an additional column that shows the dimensions of the numeracy model addressed in each section.

Table 5 Module outline and dimensions of the numeracy model

Section	Activity	Resources	Numeracy model dimensions
Introduction (general)	Astrophysics looks at things that are big, old and far away. General question: So how is it that we know so much about the universe?	Text description	Context Dispositions
Introduction (specific)	Double trouble: In Star Wars, the planet Tatooine has two suns. Is a double sunset a work of fiction, or is a binary star system possible? Write your answer in a post. To find out whether double stars are fact or fiction, watch the video.	Text description Video	Context Dispositions
Question 1 and working with tools	Stars in orbit: Look at the video and imagine that these stars are so far away that they cannot be resolved. In other words, all you see is a single 'star'. What do you think a graph of total light versus time would look like? Draw a graph of light versus time. Discuss your reasoning for its shape in a post.	Graph paper Video	Context Mathematical knowledge Tools Dispositions
Question 2 and working with tools	Eclipsing Binaries: Binary systems, where the orbits are nearly edge on, are called eclipsing binaries. This is because the light from one star is momentarily eclipsed as the other star passes in front. What features of an eclipsing star system might change the shape of the light curve we observe? In your Learning Diary see how many others you can list.	Video Learning diary	Context Mathematical knowledge Tools Dispositions Critical orientation
Question 3 and working with tools	Exploring a binary star model: Can we understand the nature of stars from the way light from eclipsing binary stars change? Using the Eclipsing Binary Simulator (University of Nebraska Lincoln, http://astro.unl.edu/naap/ebs/animations/ebs.html) we can model how the shape of the	Eclipsing Binary Simulator Learning Diary	Context Mathematical knowledge Tools Dispositions Critical

light curve changes as different parameters are manipulated using sliders. Choose one of the stars from the list provided. Manipulate the parameters in the Eclipsing Binary Simulator to match the simulated light curve to the observations. Once matched, write the orbital parameters in the tables at the bottom of the page. Determine general rules about how these parameters affect the light curves in a particular way.	orientation
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Conclusion

The purpose of this paper was to describe and analyse the processes of design used in developing an online learning module on mathematical modelling within the ORS project. These processes were based on the enquiry-based approach underpinning ORS (use of the 5Es model, selection of mathematicians, scientists, mathematics and science educators in the MDT) and emergent structuring devices and practices (use of the numeracy model, the ways in which MDT members interacted and made use of their expertise within the project). 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. These principles and practices were in alignment with the overarching aim of the 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. The paper is a precursor to further research that will investigate the effectiveness of the module in terms of students' learning and attitudes as well as the MDT members' perspectives on the interdisciplinary collaboration that took place.

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