Bite Size Maths: Building Mathematics Low Socioeconomic Student Capability in Regional/Remote Australia

14 December 2015 to 31 March 2017

Associate Professor Geoff Woolcott, Southern Cross University

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Bite Size Maths: Building Mathematics Low Socioeconomic Student Capability in Regional/Remote Australia

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Final Report 31 January 2017

Southern Cross University (SCU) - Lead University
Project Leader, Associate Professor Geoff Woolcott (SCU)

With the collaboration of partners in the Regional Universities Network (RUN):

- Central Queensland University (CQU)
- Federation University Australia (FedUni)
- University of New England (UNE)
- University of Southern Queensland (USQ)
- University of the Sunshine Coast (USC)

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Southern Cross University

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Southern Cross University (SCU)

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Emeritus Professor John Sweller

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Project Leader: Associate Professor Geoff Woolcott, Southern Cross University.

List of Acronyms

CQU	Central Queensland University
DET	Australian Government Department of Education and Training
FedUni	Federation University Australia
HEPPP	Higher Education Participation and Partnerships Programme
MOOC	Massive Open Online Course
RUN	Regional Universities Network
SCU	Southern Cross University
SoTL	Scholarship of Teaching and Learning
STEM	Science, Technology, Engineering and Mathematics
UNE	University of New England
UNSW	University of New South Wales
USC	University of the Sunshine Coast
USQ	University of Southern Queensland

Achievements Statement

Bite size maths: Building mathematics low socioeconomic student capability in regional/remote Australia is a $140,000 project funded in 2016 through the Department of Education and Training (DET) as part of the Higher Education Participation and Partnerships Programme (HEPPP) 2015 National Priorities Pool.

Southern Cross University (SCU) is the lead institution, with collaboration across the universities in the Regional Universities Network (RUN): Central Queensland University (CQU); Federation University Australia (FedUni); the University of New England (UNE); the University of Southern Queensland (USQ); and the University of the Sunshine Coast (USC). The project has been greatly enhanced by contributions from Emeritus Professor John Sweller, University of New South Wales (UNSW).

The project has delivered an innovative set of interactive modules (as an online learning system) that can be used singly or linked together in a Massive Open Online Course (MOOC— http://www.bitesizemaths.net). The project has delivered a resource that can be embedded into undergraduate mathematics courses or courses that have a mathematics component.

This is the first time a MOOC has been designed on the basis of human cognitive architecture, in this case the principles and effects of cognitive load theory. Trials for five modules have shown that the combination of worked examples and practice questions (the worked example effect in cognitive load theory) makes a significant difference to test results of students with limited mathematics experience. After the initial trials, a MOOC (comprised of 20 interactive modules) was built incorporating a number of improvements and innovations. For example, this is the first time that point-of-contact feedback, trialled and tested at SCU, has been employed as part of a MOOC. This feedback serves to let students know about their learning approaches, provides guidance on appropriate learning styles, and allows feedback from the students on how well the MOOC facilitated their learning.

The content of the interactive modules is based on the literature, as well as on a dedicated survey and face-to-face interviews with the RUN partners, all of which have a large proportion of low socioeconomic and regional/remote students. Many of these students have had less experience in mathematics than their urban counterparts. Furthermore, there is a broad range of mathematical capabilities within this group. The interactive modules are designed to allow students to tackle 'bite-size chunks' of the mathematics at which they must become proficient. The MOOC offers a self-paced introduction to key features of undergraduate mathematics, and is adaptive through the transitions provided by continual graded assessment and point-of-contact feedback.

The MOOC has the potential to be further developed as a resource for use in the university sector and across the national education sector, for both teaching and assessment, and for developing students with limited mathematics experience. Further development of the MOOC will be undertaken in 2017, and an online report of this process will be lodged with DET in January 2018.

Executive Summary

The project, *Bite size maths: Building mathematics low socioeconomic student capability in regional/remote Australia*, establishes the foundations for a change in the way that online education is offered to low socioeconomic students in regional/remote Australia. The *Bite size maths* project is a $140,000 project funded in 2016 through the Department of Education and Training (DET) as part of the Higher Education Participation and Partnerships Programme (HEPPP) 2015 National Priorities Pool.

The *Bite size maths* project has delivered an innovative set of interactive modules (as an online learning system) that can be used singly or linked together in a Massive Open Online Course (MOOC—http://www.bitesizemaths.net). The 20 interactive modules developed within the project provide a foundation for improvements in mathematics education across the higher education sector as well as throughout the school system in regional/remote Australia. The use of self-paced learning in the form of guided instruction and opportunities for practice have the potential to profoundly impact on the learning experiences of undergraduate students who have little or no experience in mathematics.

Mathematics forms the core of multiple course structures at universities, and previous research emphasises the importance of engaging undergraduate students in building a strong mathematics foundation. This is particularly the case in regional/remote Australia where universities, like those in the Regional Universities Network (RUN), focus particularly on professional careers, such as education and health care, that require mathematical competencies. Contemporary students need to be both proficient in and comfortable with mathematics, so as to bridge the gap between curriculum and understanding the mathematics that is required in such careers.

The *Bite size maths* project showed, for the first time, that a MOOC can be designed on the basis of studies of human cognitive architecture, in this case the principles and effects of cognitive load theory. Development and trials of five modules demonstrated that the combination of worked examples and practice questions (the worked example effect in cognitive load theory) makes a significant difference to test results of students who have little experience in mathematics. After the initial trials, a MOOC (comprised of 20 interactive modules) was built incorporating a number of improvements and innovations. These included other cognitive load effects, as well as point-of-contact feedback. This is the first time that point-of-contact feedback developed at SCU has been used as part of a MOOC. This feedback serves to let students know about their learning approaches, provides guidance on appropriate learning styles, and allows feedback from the students on how well the MOOC facilitated their learning. The end result is a set of integrated resources that can be embedded in undergraduate mathematics units as interactive modules or as a MOOC.

The interactive modules in the MOOC offer course-based resources that are designed to allow students to tackle ‘bite-size chunks’ of the coursework mathematics in which they must develop expertise. The MOOC offers a self-paced introduction to key features of undergraduate mathematics, and is adaptive in that it also offers continual graded assessment and point-of-contact feedback. The content of the modules is based on the literature, as well as on a dedicated survey and face-to-face interviews with the RUN partners, all of which have a large proportion of low socioeconomic and regional/remote

students. Many of these students have had less experience in mathematics than their urban counterparts. Furthermore, there is a broad range of mathematical capabilities within this group.

As one of the 21 projects funded under the HEPPP 2015 National Priorities Pool, *Bite size maths* addresses the HEPPP Priority Funding Area, “More effective programme implementation”. The *Bite size maths* project facilitates more equitable and effective program delivery via a mathematics intervention resource that caters for the wide range of student abilities and economic circumstances evident in the education sector in regional/remote areas. In so doing, the *Bite size maths* project targets low socioeconomic students who are at particular disadvantage, and provides modules that build student expertise and confidence.

Commonwealth and State governments, via the National STEM School Education Strategy (Education Council, 2015) have mandated increased emphasis on science and mathematics in pre-service teaching and increased rigour of pre-service courses. This project will assist not only education students, but also those in other courses that require mathematics skills. It provides higher education teachers, senior managers and policy advisors with a tested approach to support significant long-term improvements in the quality of mathematics learning in universities. Importantly, the *Bite size maths* project offers:

- A new vision of the way that mathematics can be learned in online settings and how this can be integrated in the preparation of graduates with mathematics capabilities suited to their professions, and
- A mechanism for university teachers to grow the mathematics capability of their students.

Successful take-up of the interactive modules or the MOOC requires:

- Leadership, clarity of purpose and influence whereby the *Bite size maths* partners champion the mathematics MOOC at regional and national levels
- Strong collaborative relationships between RUN partners to be nurtured and strengthened
- Planning for 2017 trials and subsequent roll-out of the interactive modules or the MOOC
- Communication about the resource to mathematics students at risk of failure, university mathematics teachers, staff in other disciplines, senior management teams at tertiary institutions, educational policy makers and other senior government strategists
- Review of institutional protocols around enrolment, pre-requisites, course accreditation and assessment in order to successfully embed the interactive modules and the MOOC
- Resourcing for trials, development and embedding of the interactive modules in mathematics units
- Mentoring mechanisms such as workshops for university educators and a website for feedback/support, and
- Promotion of the modules and the MOOC by the Department of Education and Training as a means of improving the mathematical capabilities of low socioeconomic or otherwise disadvantaged students at regional/rural universities.

This report presents the four main components of the project:

- Reviewing undergraduate mathematics in regional/rural Australia (identification of at- risk students, overview of intervention processes and identification of major issues)
- Developing and trialling of five online learning system modules
- Developing 20 interactive modules that comprise the MOOC, using feedback from the trial
- Reporting on the potential of the MOOC as a resource for use in the university sector.

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1.1 Background of the Higher Education Participation and Partnerships Programme (HEPPP) 2015 National Priorities Pool

The Higher Education Participation and Partnerships Programme (HEPPP) aims to ensure that Australians from low socioeconomic backgrounds who have the ability to study at university have the opportunity to do so. It provides funding to assist universities listed in Table A of the *Higher Education Support Act 2003* to undertake activities and implement strategies that improve access to undergraduate courses for people from low socioeconomic backgrounds, as well as improving the retention and completion rates of those students.

The National Priorities Pool is a component of HEPPP which provides funding for projects that support the more effective implementation of HEPPP nationally and at the institutional level. This program supports activities that foster opportunity and success in higher education by people from disadvantaged backgrounds, including people from low socioeconomic backgrounds, Indigenous people, people with disability and people from rural/remote Australia. The objective of the National Priorities Pool is to inform more effective implementation of the HEPPP, both by updating the policy basis for the program and enhancing on-ground delivery at the national level and within individual institutions. It supports projects that develop evidence, trial innovative ideas, build capacity and reform systems to maximise opportunity and outcomes for low socioeconomic groups in higher education. For 2015-16 the National Priorities Pool awarded funding to projects that addressed the priority areas outlined in the 2014 National Priorities Pool Investment Plan, namely:

- Building the evidence base
- Fostering innovation, and
- More effective programme implementation.

1.2 Bite Size Maths: Building Mathematics Low Socioeconomic Student Capability in Regional/Remote Australia

1.2.1 Scope

The *Bite size maths* project establishes the foundations for a change in the way that online education is offered to low socioeconomic students in regional/remote Australia. The *Bite size maths* project is a $140,000 project funded in 2016 through the Department of Education and Training as part of the HEPPP 2015 National Priorities Pool.

With the development and trial of five mathematics interactive modules (as part of an online learning system) and the subsequent design and testing of 20 interactive modules combined into a MOOC, the *Bite size maths* project establishes the foundations for improvements in mathematics education across the higher education sector, as well as throughout the school system in regional/remote Australia (http://www.bitesizemaths.net). The use of self-paced learning in the form of guided instruction, and opportunities for practice, has the potential to profoundly impact on the learning experiences of undergraduate students who have little or no experience in mathematics. The *Bite size* *maths* project is built around the priority area of funding "more effective programme implementation".

1.2.2 Project plan

The project comprises four main components as shown in Figure 1.

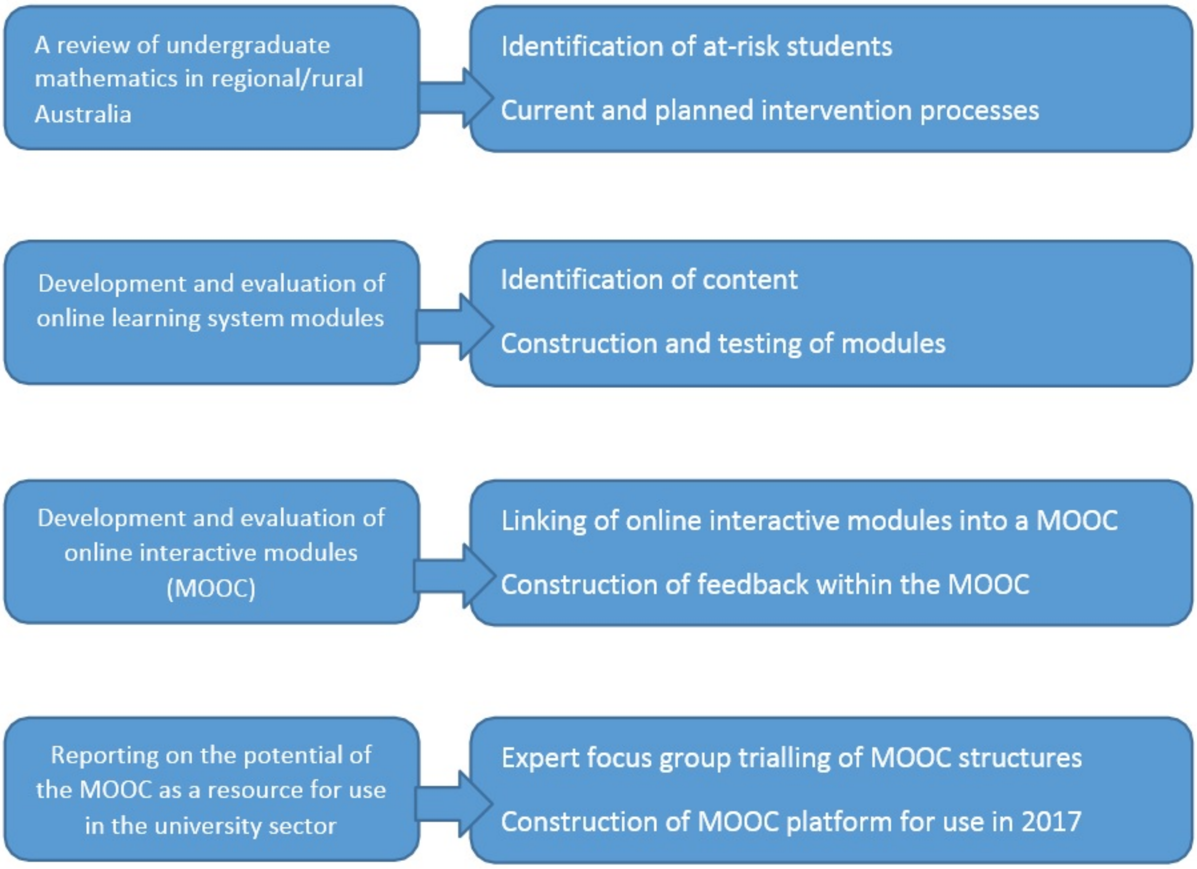

Figure 1: Project components

The *Bite size maths* project has the following objectives:

- To improve access to mathematics through provision of course-based resources designed to allow low socioeconomic students to tackle 'bite-size chunks' of mathematics at their own rate and at their own level of learning
- To develop these mathematics resources into five online learning system modules for use in the university sector for students with limited experience in mathematics, and
- To further develop these modules in an adaptive format (as 20 interactive modules) for use across the national education sector either independently as interactive modules or as part of a MOOC.

1.3 Project Team

The project team represents a broad spectrum of regional/rural universities. SCU is the lead organisation, partnering with five Regional Universities Network (RUN) institutions. All collaborating partners have worked together previously on Science Technology, Engineering and Mathematics (STEM) educational projects. (See Appendix 1 for linked projects and publications.) Emeritus Professor John Sweller (UNSW) provided advice and support throughout the project.

The SCU project team has a depth of expertise in mathematics education, learning theory and the technical aspects of developing online learning materials. It includes:

- Project Leader Associate Professor Geoff Woolcott who is currently leading the $1M STEM education project *It's part of my life* http://scu.edu.au/itspartofmylife/ (Enhancing the Training of Mathematics and Science Teachers, 2013)
- Professor William Boyd who provided support for project processes using the Scholarship of Teaching and Learning (SoTL) model
- Dr Christos Markopoulos and Mr Alan Foster who supported initial trials of the online learning system modules at SCU
- Dr Raina Mason (who successfully applied cognitive load theory in the teaching of computing at SCU) and Ms Carolyn Seton for technical expertise in constructing online learning system modules and adapting them as interactive modules to build a MOOC
- Dr Ouhao Chen (seconded from UNSW) who provided expertise on cognitive load theory
- Warren Lake who provided expertise on deep cognitive learning and adapted already- tested point-of-contact feedback protocols for use in the MOOC, and
- Patrick Bruck, Corinne Miller and Donna Shipway who provided project support.

The following representatives from five RUN partners collaborated on the initial review of undergraduate mathematics in regional/rural Australian universities, as well as providing undergraduate volunteers to take part in the 2017 MOOC trials: Dr Reyna Zipf (CQU), Nargiz Sultanova (FedUni), Dr Jelena Schmalz (UNE), Dr Robert Whannell (UNE), Associate Professor Linda Galligan (USQ), Associate Professor Peter Dunn (USC) and Dr Margaret Marshman (USC).

1.4 Collaboration and Communication

Project partners at SCU worked collaboratively to embed the new learning approaches in university curricula. All RUN partners also collaborated electronically and met face-to-face at a mid-year workshop. Several other face-to-face meetings of smaller groups from the RUN partners provided valuable feedback about issues in undergraduate education, as well as about content and timing of trials for the online learning system modules and the MOOC. Data analysis and regular feedback sessions with partners have informed the development of the five online learning system modules and the subsequent construction of the 20 interactive modules that form the MOOC.

1.5 Project Context

There is wide recognition of the need for a well-developed mathematical skill set in the contemporary world (Bruce et al., 2016; Bureau of Labour Statistics, 2011; Cresswell & Vayssettes, 2006; Kline, 1996; Organisation for Economic Co-operation and Development, 2003). Hanushek and Woessmann (2010) have noted that gross domestic product is impacted significantly by the extent to which a country can draw on a sound mathematical base, and the Australian Academy of Science (2016) reported that mathematics is important for Australia's gross domestic product. Nations can suffer a decline in competitiveness if they lack a sound foundation of mathematical skills across a range of employment categories (Chubb, Findlay, Du, Burmester & Kusa, 2012; Office of the Chief Scientist, 2014). Australia differs from many countries, including the USA and China, in that mathematics is not a requirement for high school graduation and university admission. In consequence, fewer students are choosing career pathways that require some study of mathematics (Chubb et al., 2012). Over the past 15 years, there has been a decline in the number of students studying mathematics at high school (Mack & Walsh, 2013). Australia has responded proactively to its science, technology, engineering and mathematics (STEM) crisis with a number of initiatives designed to make mathematics an attractive choice for study at both high school and university levels (Office of the Chief Scientist, 2016).

While mathematics is a discipline for university study in and of itself, this set of knowledge and skills also forms the basis for many other university courses. These include science, engineering, nursing, education, psychology and business (AAS, 2016; Croft, Harrison & Robinson, 2009; Kruenzi, 2008). All too often, Australian high school students with limited mathematical background face requirements in their first year of university study that are beyond their skill set. This lack of preparedness for introductory undergraduate mathematics is a significant problem, leading to early attrition and/or academic failure (Groen et al., 2015). For many Australian universities, attrition is a major challenge impacting negatively on both the institution's reputation and its cost structures (AAS, 2016; Croft et al., 2009).

As well as impacting negatively on universities, lack of preparedness for university mathematics also exacts a cost on the individual student. There is a wide range of mathematical competencies in students enrolling in first year mathematics unit, especially for those studying business, education and nursing (Croft et al., 2009; Kajander & Lovric, 2005; Rylands & Coady, 2009). For many of these students struggling with introductory mathematics, there is a real risk that their self-esteem will be eroded. Boyd, Foster, Smith and Boyd (2014) have shown that students' low perceptions of their capacity for success in mathematics study can result in increased anxiety which, in turn, can set in motion a cycle of self-fulfilling failure. Furthermore, lack of mathematical preparedness can compromise the ability of some students to enter the career of their choice.

1.6 Project Strategy

The overarching strategy for the bite size mathematics project involves:

- Identifying target group students (low socioeconomic and other disadvantaged students at risk of attrition/failure) in regional/rural universities
- Establishing baseline data via a review of national database statistics on disadvantage and regionality, and via a survey and face-to-face interviews with RUN partners
- Developing and trialling five online learning system modules which are designed using cognitive load theory's worked example and modality effects
- Developing 20 interactive modules for use independently and as a MOOC) based on cognitive load theory's design principles (worked and faded worked examples in

differential learning pathways depending on expertise) which incorporates point-of-contact feedback about learning approaches, and

- Refining the MOOC and providing insights into the challenges of establishing such an online learning tool.

A table showing project activities, milestones and key performance indicators is provided in Appendix 2.

Table 1 provides the evidence base used to guide module development as well as some exemplar references.

Table 1: Evidence base guiding module development – some exemplar references

UNDERGRADUATE MATHEMATICS AND REGIONAL AUSTRALIA		COGNITIVE LOAD THEORY & ONLINE LEARNING		MOOC DEVELOPMENT		UNDERGRADUATE STUDENTS AND MATHEMATICS
Lack of preparedness for undergraduate mathematics e.g. business, nursing and education (Croft et al., 2009; Groen et al., 2015; Rylands & Coady, 2009). Variety of mathematics support e.g. mentoring and other motivational programs, but focus on content (Croft et al., 2009; Groen et al., 2015).	>>	Cognitive load theory is a well- known instructional design theory applied widely in online learning (Chen, Woolcott & Sweller, In Press).	>>	Since 2008, MOOCs important in delivering free online content knowledge and in offering networking and other connectivity (Moe, 2015; Siemens, 2013).	>>	
Australian undergraduates have the same broad competencies as other industrialised nations (AAS, 2015, 2016; Kajander & Lovric, 2005; Mack & Walsh, 2013). Regional Australian universities support dedicated introductory mathematics units or those with an essential introductory element (Whannell & Allen, 2012).	>>	In cognitive load theory, instruction (including online) acts to alter contents of long-term memory, after information is processed by a limited capacity, limited duration working memory (Sweller, 2010).	>>	Many MOOCs follow traditional teaching formats using business models and are not optimal for online learning, as far as learning quality goes (Fischer, 2014).	>>	
The number of regional students who enrol in and complete higher-level mathematics subjects may be small in comparison to larger urban universities (Barrington & Evans, 2016; Maltas & Prescott, 2014). Student attitudes and perception of their capacity to study mathematics contributes to student anxiety and self- fulfilling failure (Boyd et al., 2014; Yeigh, Woolcott, Donnelly, Whannell, Snow & Scott, 2016).	>>	Cognitive load theory effects demonstrated in randomised, controlled trials indicate superior learning compared to a more conventional instructional condition (Sweller, 2004, 2010).	>>	MOOCs are not designed around human cognition, but consider motivation, participation and study time (Champaign et al., 2014; El- Hmoudova, 2014; Hew, 2015; Zheng, Rosson, Shih & Carroll, 2015).	>>	

2 Approaches and Processes

2.1 A Review of Undergraduate Mathematics in Regional Australia

> *In all Australian universities, there has been a decline in the number of bachelor degrees (including bachelor of science and bachelor of engineering degrees) that require even intermediate high school mathematics as a prerequisite for entry. This has prompted students to avoid school mathematics subjects or else to favour elementary options, leading to a decline in high school enrolments in intermediate and advanced mathematics courses. This puts pressure on standards in universities, has led to a reduction in the content taught and in the achievement levels needed to pass a subject, and has contributed to the closure of mathematics departments in several universities. Consequently, the availability of undergraduate majors in the mathematical sciences is vulnerable or excessively narrow in scope in many capital city institutions and is inadequate in regional universities.* Australian Academy of Science (2016, p. 30).

The universities who engaged in this study (the Regional Universities Network, RUN) are all regionally located, with the majority providing distance education or blended education across multiple campuses. Only one of the RUN institutions offers no online mathematics. Several of these universities have been at the forefront of distance (external) education and community outreach for over three decades, and are now leaders in online education. There are a number of first year mathematics subjects offered at each university, and these universities may also offer so-called enabling or bridging subjects (sometimes called foundation or alternative entry pathways), as well as mathematics within other subjects in non-mathematics courses such as nursing and environmental science.

Australian regional/rural universities have a higher proportion of students from disadvantaged groups than do urban institutions. Lake and Boyd (2015) and Lake, Boyd and Boyd (2015) provided statistics from one RUN university for the number of education students who were members of various disadvantaged groups (Table 2). While data on students' membership of disadvantaged groups were not sourced across all the RUN institutions, researchers on the *Bite size maths* project were confident in making the assumption that similar patterns of disadvantage would be observable across all six institutions involved.

Table 2: Educational disadvantage at a regional university

CATEGORY OF EDUCATIONAL DISADVANTAGE	PERCENTAGE OF TOTAL STUDENTS STUDYING EDUCATION
Women	80%
Regional and remote	74%
First-in-family to attend university	64%
Mature age	33%
Low socioeconomic	31%
Aboriginal and Torres Strait Islander	2%

One third of students studying education were from low socioeconomic backgrounds. Lake and Boyd (2015) and Lake et al. (2015) noted that many of these students attended schools with a strongly applied focus. As such, mathematics was often not offered to students, or taught only at a rudimentary level. Two-thirds were first-in-family to attend university. Such students lack the traditions of scholarship and the family support that might assist them to adapt quickly and easily to university life (Clarke, Nelson & Stoodley, 2011). Eighty percent of the education students were women, a group found to lack preparedness for studying mathematics. Another social factor that may contribute to mathematics preparedness is Aboriginal and Torres Strait Islander background. Lastly, a third of education students at this institution were mature age. Such students are well removed from their mathematics study at high school, which can impact negatively on their preparedness for tertiary study (Whannell & Allen, 2012).

Given their demographics, early attrition and academic failure in mathematics units is a particular problem for RUN institutions. Indeed, this is also the case across all first-year units. Figures from the Department of Industry (https://education.gov.au/selected-higher-education-statistics-2014-student-data) show a much higher rate of attrition for domestic commencing bachelor students at RUN institutions than for the Australian university sector as a whole (Table 3). For the nine years 2005 to 2013, national attrition rates averaged 13.71%, whereas the average attrition rate for the RUN sector was 22.88%. The *Bite size maths* project has developed an elaborated schema for identifying mathematics students at risk of attrition or academic failure, which is of use across all Australian universities. An outline of the schema is provided in Appendix 3.

Table 3: Attrition rate (adjusted calculation) domestic commencing bachelor students

UNIVERSITY	2005	2006	2007	2008	2009	2010	2011	2012	2013	AVG
National	15.04	14.62	14.76	12.77	12.48	13.09	12.79	13.43	14.79	13.71
CQU	30.95	30.71	28.87	27.7	27.23	26.04	27.26	25.2	24.99	27.66
FedUni	15.35	18.29	16.58	19.82	13.13	16.12	17.33	19.13	21.29	17.45
SCU	26.68	24.78	24.92	22.39	23.38	20.94	22.25	24.12	23.49	23.66
UNE	24.67	24.16	22.22	19.6	20.49	20.24	20.52	21.62	22.04	21.73
USC	27.73	27.73	26.63	20.46	19.5	20.14	21.07	21.37	22.05	22.96
USQ	24.95	25.06	24.35	22.34	21.84	24.2	23.13	24.16	24.73	23.79
RUN TOTAL	25.06	25.12	23.93	22.05	20.93	21.28	21.93	22.60	23.10	22.88

Because RUN institutions are acutely aware of the problems (both institutional and personal) of early attrition and academic failure, they have put in place a number of initiatives to identify and support students 'at risk'. The *Bite size maths* project has added to the body of knowledge about these practices and processes via a survey of RUN staff involved in introductory undergraduate mathematics units. Information was gathered on:

- Identifying students 'at risk'
- Institutional support for students 'at risk'
- Institutional research on mathematics student attrition/failure, and
- Major issues that contribute to the high rates of attrition or academic failure.

2.1.1 Identifying students at risk of attrition or academic failure

Processes to identify students at risk of attrition or academic failure in introductory undergraduate mathematics units at RUN universities vary widely between institutions, within institutions and even within individual mathematics units. RUN partners reported that the types of data and the processes used to gather these data range from diagnostic tests and formal unit assessments, to informal observation of students in tutorials. While the ideal might be to conduct pre-enrolment diagnostic tests, in reality most at-risk students are only identified within the first three weeks of the semester. The survey of RUN partners showed that when data is gathered about student performance, it may or may not be analysed, and feedback may or may not be provided to the students in question. Resource issues impact on the capacity of mathematics staff to identify and support at-risk students.

2.1.2 Institutional support for students at risk of attrition or academic failure

The survey identified a range of institutional support services for students 'at risk' including the provision of enabling units, Tertiary Preparation Program and Learning Centre initiatives, mentoring, support sessions, drop-in centres and study groups. RUN partners reported that the uptake of support by first-year students was very low (possibly only 5% of the cohort), although drop-in centres showed more promising usage patterns. Respondents were concerned that there were no evidence-based support programs available for at-risk mathematics students. Universities often operated with anecdotal evidence of the effectiveness of the diverse support services on offer. Of particular concern was the fact that students did not access support in a timely manner. Staff working on introductory undergraduate mathematics units at RUN universities also pointed out that institutional strategies to support students at risk of attrition or academic failure were not always in place, and that there was an over-dependence on tutors to provide assistance to students who lacked preparedness for the course material and who were struggling. The RUN partners also commented on the lack of funding and the failure to integrate a well-targeted support network at the institutional level.

2.1.3 Institutional research on mathematics students' attrition/failure

Respondents reported that institution-wide research into early attrition and academic failure has been patchy and not always effective. The mathematics staff surveyed indicated that they were undertaking some research into student attrition or academic failure, and how to best address this problem. Two examples include the *Bite size maths* project and another project examining the effectiveness of diagnostic testing in early identification of students 'at risk' in one RUN institution (Lake et al., 2017). Again, respondents noted that there was a paucity of research in this area because of the lack of dedicated funding. Of great concern too was the failure in many instances to transfer research findings into actual institutional practices and processes.

2.1.4 Major issues that contribute to the high rates of attrition or academic failure

Respondents identified a number of issues contributing to high rates of attrition or academic failure in introductory undergraduate mathematics units. These clustered around institutional processes and student factors. The RUN partners expressed frustration at both the failure of pre-enrolment processes to identify students 'at risk', and the lack of preparation courses for these students once they had been identified. Personal factors included students' anxiety and lack of confidence with mathematics, and their lack of cognitive preparedness for tertiary mathematics study.

In-depth interviews were also conducted at three of the RUN institutions. As was the case for the written survey, the three face-to-face interviews indicated that many students are ill prepared when they enter introductory mathematics units. While students experience difficulties with algebra, fractions, graphs, logarithms and unit conversions, there is a more fundamental barrier to student success in introductory undergraduate mathematics. Quite simply, many are not *au fait* with the language and conventions of mathematics, and this impedes their learning. The interviewees were positive about embedding modules from the online learning system into their course content. A significant benefit was the opportunity for students to keep practicing until they had mastery of a particular concept. The project team has taken on board feedback from interviewees that stressed the importance of ensuring that the interactive modules complemented existing unit structure, and of keeping students on- task until completion of a module.

The survey instrument is provided in Appendix 4. Analysis of in-depth interviews and the survey responses will be available in a forthcoming publication.

2.2 Development and Evaluation of Five Online Learning System Modules

2.1.5 Mathematics learning and human cognitive architecture

The term 'human cognitive architecture' refers to the memory structures, sensory memory, working (short-term) memory, and long-term memory, which are fundamental to how learners think, learn and solve problems. A key feature of human cognitive architecture is that it comprises a limited working memory, which can only deal with a small amount of new information at a time, and a long-term memory, which can hold an unlimited number of elements (schemas) on a relatively permanent basis (Sweller, 2004). Over the past 20 years a number of researchers (notably Sweller) have undertaken research on human cognitive architecture to better understand what aspects support problem-solving and learning. Sweller (2004) has noted that human cognitive architecture and effective instructional design are inseparably intertwined. His cognitive load theory has become one of the most cited learning theories in contemporary educational design (see e.g., Bruer, 2016).

Over many years, Sweller and colleagues (Sweller, 1994, 2004, 2010, 2012; Sweller & Cooper, 1985; Sweller & Sweller, 2006; Sweller, Ayres & Kalyuga, 2011) have developed, tested and refined cognitive load theory to produce an elaborated and considered set of principles that describe human cognitive architecture and its information processing capabilities and limitations. Furthermore, Sweller has provided a set of guidelines for instructional design that are predicated on his understanding of human cognition. Cognitive load theory provides a sound foundation on which to build an integrated approach to instructional design that is both theoretically robust and practical.

The *Bite size maths* project has developed five online learning system modules for mathematics students using two cognitive load theory guidelines for instructional design, namely the worked example and modality effects. Pilot testing was conducted on the five online learning system modules, and refinements were made. Subsequently, a MOOC was built that also incorporated cognitive load theory's problem completion effect. This MOOC is comprised of 20 interactive modules. The worked example, problem completion and modality effects are described more fully in Appendix 5.

In order to better understand this design process, two workshops were developed and delivered by Dr Raina Mason. The first workshop was conducted in February for a wide range of staff at SCU. As a consequence of the workshop, a lecturer in Chemistry at SCU has developed for his introductory unit, two one-and-a-half-hour sessions based on cognitive load theory effects. The second workshop was held in Sydney in July for RUN partners participating in the *Bite size maths* project. Again, the workshop was delivered by Dr Raina Mason, who provided technical information about the process of constructing online modules based on cognitive load theory effects.

As part of the *Bite size maths* project, a library search was undertaken across a range of databases to determine if cognitive load theory had been used in the development of online resources to support mathematics students studying at universities (Appendix 6). The search revealed that such an approach has not been previously undertaken. This project is unique in that it uses cognitive load theory to develop online materials to support students at risk of attrition or academic failure in their first year of university mathematics study. Furthermore, it uses robust experimental design (with a control group) to test the effectiveness of these materials.

2.1.6 How the online learning system modules used the worked example effect in instructional design

This project has developed five online learning system modules to support at-risk first year students taking mathematics units. Every module has five snippets, and each snippet incorporates the worked example effect as a means to enhance student learning. As such, a worked example is presented, followed immediately by a similar problem-solving task. This paired work example and problem-solving task sequence is repeated a second time. A large number of studies have demonstrated the success of instructional design based on cognitive load theory's worked example effect (e.g., Chen, Kalyuga & Sweller, 2016; Cooper & Sweller, 1987; Sweller & Cooper, 1985). Few studies, however, have examined the potential of this effect, or other cognitive load theory effects, for enhancing learning in interactive environments. An opportunity is provided at the end of each snippet to try out (and reinforce) newly acquired knowledge via a post-test of six questions.

There is a widely-held view that knowledge and skills are gained as small increments (Hew, 2015; Goswami, 2008; Woolcott, 2016). Sweller and Sweller (2006) have noted that working memory has a limited capacity to deal with novel information, and similarly, that long-term memory is better served by avoiding large and rapid inputs of new information. In keeping with the notion of incremental information acquisition, module tasks have been backward engineered such that the first four snippets build the knowledge and skills required to complete the final snippet. For example, in Snippet 5 of Module 2, participants are required to simplify the expression, $9 + 2(y - 3) - 7y$. The preceding four snippets are constructed for step-by-step learning such that students become competent in:

- Multiplying a positive and negative number (Snippet 1), for example, $2 \times (-3) = -6$
- Expanding an expression across brackets (Snippet 2), for example, $2(y - 3) = 2y - 6$

- Adding a sequence of positive and negative numbers together (Snippet 3), for example, 9 – 6 + 2 = 5
- Collecting algebraic 'like terms' (Snippet 4), for example, $7y - 2y + 3y = 8y$

2.1.7 How the online learning system modules used the 'modality effect' in instructional design

In order to take advantage of the modality effect, each snippet was designed for simultaneous delivery of information by visual and auditory means. Scripts were written for each snippet. These were consciously composed to ensure that there was consistency in the way material was presented and explained across each of the snippets within a module. Figure 2 provides an example of a script.

Worked example 1	*Section 1*
	Welcome to Module 1, Snippet 1 (3 seconds)
	• This snippet will show you how to perform two number operations in the correct order without using your calculator.
Evaluate 6×2^4.	• Here, we will look at how to calculate six times two raised to the power of four (sometimes called two to the fourth).
	• There is a positive sign in front of the number six, but it is not usually written in.
	• We will use a rule called BOIDMAS (or BOIMDAS) – short for Brackets of Indices, Multiplication, Division, Addition and Subtraction. This tells you which ones to do first, in this case Indices.
$2^4 = 2 \times 2 \times 2 \times 2$	• First you need to evaluate the number with the index (or power as it is sometimes called).
$= 16$	• This means that two is multiplied by itself four times to give sixteen.
$6 \times 16 = 22$	• Then we multiply the six by the sixteen because multiplication is done after the index calculation is completed.
Practice question 1	
Evaluate 5×3^4.	You have ten seconds to try this question.
405	• Did you get 405? • Congratulations!

Figure 2: Script for Snippet 1, Module 1 - Order of operations, integers

In order to have simultaneity of auditory and written material, the written component of the presentation was animated. Quite simply, as the words were being said for each step required to solve the problem presented in the snippet, the corresponding figures were initially hand written. The use of scripts allowed for good integration between video footage and auditory commentary. The podcasts for these five trial modules were produced and edited using the online software Camtasia (version 8, TechSmith). Post-tests and cognitive load surveys were added to the podcasts for each scripted snippet. All scripts, post-tests and snippets were independently audited for mathematics content, production and other errors.

2.1.8 Measuring cognitive load in the pilot test

A subjective rating survey was included after the two paired tasks in each snippet as a measure of cognitive load. Data were gathered on how easy or difficult it was to study and solve the tasks using a nine-point Likert Scale ("Extremely easy" to "Extremely difficult"). An example is provided in Figure 4. An online comment box was also included at the end of each module.

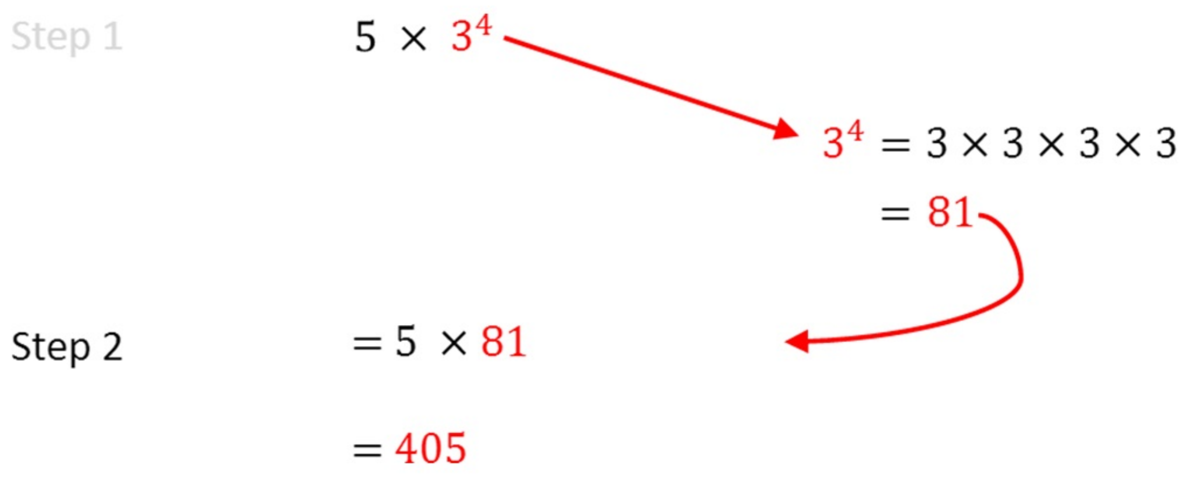

Figure 3: Screen image of a worked example visual style

How easy or difficult was it to study and solve these tasks? Select your answer on a scale from "Extremely easy" to "Extremely difficult".

1 2 3 4 5 6 7 8 9 10

Extremely easy **Extremely difficult**

In the later modules, the handwriting was replaced by appropriate text in PowerPoint. An example of a completed PowerPoint sequence is provided below (Figure 3). The worked examples were animated to provide coherence between the audio commentary and visual elements of the podcast.

Figure 4: Measure of cognitive load using a nine-point Likert scale

2.1.9 Pilot testing of the online learning system modules

In 2016, five online learning system modules were tested on volunteers from an introductory undergraduate mathematics course at a RUN university. Participants were randomly assigned to a worked example group or to a problem-solving group. The latter group was given the same problem-solving task as the former group, but with no worked examples.

The podcasts were offered as a supplementary resource within the introductory mathematics course. Data were gathered on the:

- Number of participants who attempted the online learning system modules/snippets
- Number of attempts at the online learning system modules/snippets
- Results of cognitive load survey for each snippet, and
- Results of the post-tests for each module.

Modules were made available to students in the first ten weeks of the semester on the learning management system Blackboard (together with other online materials for the unit). For example, students could access the podcasts in the week following the delivery of the relevant mathematical content. Some students encountered technical issues watching the online learning system modules, since Blackboard did not support the Quicktime format used to create the videos, and a 'YouTube' options was also used. Only data from students' first attempts at problems were used in the study and only Modules 2 and 5 yielded usable data. As a result the analysis was conducted on the 10 tests for these two Modules.

2.1.10 Analysis of results of the pilot test for the online learning system modules

Using Analysis of Variance (ANOVA) from the Statistical Package for the Social Sciences (SPSS for Windows 14.0, IBM), post-test scores in Modules 2 and 5 were analysed to determine if there were differences in learning outcomes between the two groups. The analysis showed that students in the worked example group performed better than those in the problem- solving group. Using worked examples to structure an online learning system module provided better learning outcomes than did a problem-based learning environment. Means and standard deviations for both groups are provided in Table 4.

Table 4: Mean (standard deviation) values for tests 1 to 10 in Modules 2 and 5

	WORKED EXAMPLE GROUP	PROBLEM-SOLVING GROUP
MODULE 2		
Snippet 1, Test 1	5.94 (0.24)	5.81 (0.54)
Snippet 2, Test 2	4.72 (0.83)	4.37 (0.89)
Snippet 3, Test 3	5.72 (0.83)	5.13 (1.31)
Snippet 4, Test 4	3.94 (0.42)	3.56 (1.03)
Snippet 5, Test 5	4.67 (0.97)	4.06 (1.24)
Module 5		
Snippet 1, Test 6	6.00 (0.00)	4.87 (2.16)
Snippet 2, Test 7	5.94 (0.24)	5.00 (2.03)
Snippet 3, Test 8	4.61 (0.61)	4.19 (1.52)
Snippet 4, Test 9	5.00 (0.00)	4.06 (1.88)
Snippet 5, Test 10	5.94 (0.24)	4.75 (1.95)

Analysis of the cognitive load questions showed that participants faced higher levels of cognitive load (2.69) in the problem-solving group than in the worked example group (2.36). Participant comments were generally positive about the paired worked example approach, for example:

Yes, I would say this has helped and *Yes this was beneficial for my learning, thank you.*

By way of contrast, some of the participants in the problem-solving group suggested that worked examples would be useful, for example:

Has this helped me in my mathematics learning? Not really. The videos needed to show the working out. A step-by-step guide would [of] been appreciated.

and

Somewhat helped. It would be better if it provided step by step instructions for questions as I got stuck on a few. Somewhat helpful but does not explain how to arrive at the correct answer.

This pilot study investigated the effectiveness of an online learning system modules designed using cognitive load theory's worked example and modality effects. Data indicates that superior learning occurred when worked examples and paired problem-solving exercises were used to communicate mathematical information as podcasts in an online learning environment.

2.2 Development and Evaluation of 20 Interactive Modules within the Massive Open Online Course (MOOC)

2.2.1 MOOCs, motivation and instructional quality

MOOCs provide access to free online courses for large numbers of people. They have been spectacularly successful in terms of the number of people who are choosing to commence these courses. Their appeal includes the fact that enrolments are not bound by institutional walls, and that courses may be undertaken without necessarily sitting tests to obtain a formal qualification (McAuley, Stewart, Siemens & Cormier, 2010; Hew, 2015). They are also popular because they offer free content and opportunities for networking (Moe, 2015; Siemens, 2013). While many people have commenced MOOCs, there is a sharp drop-off in the number completing them (Khalil & Ebner, 2014). Jordan (2016) reported rates as low as 0.7%, with rates varying according to course length (longer courses having lower completion rates), start date (more recent courses having higher percentage completion), and assessment type (courses using only auto grading having higher completion rates). Research to better understand inherent problems within MOOCs suggests that students engage with MOOCs when relevant content is presented in ways that suit different learning methods and within contexts that allow for social interaction (El-Hmoudova, 2014; Hew, 2015; Wang & Baker, 2015; Zheng, Rosson, Shih & Carroll, 2015).

A number of researchers have expressed concern at both the lack of good design in MOOCs (Bali, 2014; Fischer, 2014) and the dearth of research into MOOC design (Bali, 2014; Deimann & Vogt, 2015; Moe, 2015). It has been argued that the poor quality of learning outcomes for those using MOOCs is, to a large extent, caused by the failure to properly consider content, design and instructional delivery mode when developing a MOOC (Fischer, 2014; Ossiannilsson, Altinay & Altinay, 2015). MOOCs may have failed to deliver successfully because their design has not taken into account the cognitive demands placed on learners by this online delivery mode (Clarà & Barberà, 2014; Siemens, 2013). The *Bite size maths* project has designed a unique MOOC which addresses this problem by using cognitive load theory to develop content and structure learning pathways within the MOOC.

2.2.2 MOOC design

The *Bite size maths* project used feedback from the pilot test of the five online learning system modules to develop a MOOC comprised of 20 interactive modules. As for the pilot test where each module was built from five snippets, each of these 20 interactive modules was constructed as five online interactive podcasts. Mathematical problems were 'reverse-engineered' and the five interactive podcasts allowed students to acquire 'bite-size chunks' of information such that they were able to solve complex mathematical problems. Using feedback from the pilot test, a number of improvements were made which took the online learning system modules to a new level of sophistication as interactive modules within the MOOC.

Improvements included:

- At a technical level, the platform used to produce the videos was changed
- Based on cognitive load theory's problem completion effect (Appendix 5), faded worked examples were included where either the ultimate or penultimate step of the example was incomplete. Students were then required to answer the question without the missing information.
- The model of Lake, Boyd, Boyd and Hellmundt (in press) was adapted (with permission) to provide a snapshot of the MOOC's architecture
- Learning pathways were incorporated in the MOOC model to provide different ways to move through interactive modules and podcasts (Figure 5). Students' levels of expertise (as determined by continual graded assessments) dictated which learning pathway they took. Learning pathways are described more fully in Appendix 7, and
- Pre- and post-module questionnaires to probe students' learning approaches, motivations and strategies were included in the MOOC.

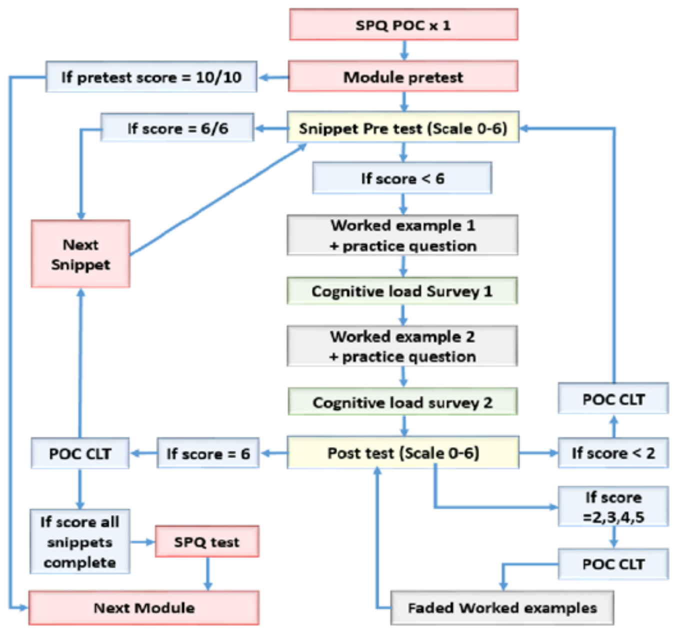

Figure 5: Model of MOOC showing learning pathways

2.2.3 Embedding questionnaires on student learning approaches, motivations and strategies in the modules (and the MOOC)

The MOOC designed by the *Bite size maths* project team is unique in that it has embedded feedback for students about their learning approaches, motivations and strategies. The MOOC's pre- and post-module questionnaires are based on a well-established strand of pedagogical research which differentiates between deep and surface approaches to learning, and demonstrates the superiority of deep learning (Diseth, 2003; Entwistle, Tait & McCune, 2000; Regan, 1996). Over many years, Biggs (e.g., Biggs, 1976, 1979, 1985, 1987a, 1987b, 1987c, 1999) has developed, tested and refined a robust tool called the Study Process Questionnaire that measures learning approach, motivation and strategy. The *Bite size maths* project used an updated version of the questionnaire (Biggs, Kember & Leung, 2001) to measure deep and surface learning approaches. Table 5 shows the questions included in the interactive module pre-test. Students provided their response along a five-point Likert Scale ("Strongly agree" to Strongly disagree"). The module post-test included a set of parallel questions (Appendix 8).

Table 5: Questions in interactive module pre-test

INTERACTIVE MODULE PRE-TEST (CONTEXTUALISED)	APPROACH MEASURED
1. I find that studying gives me a feeling of deep personal satisfaction.	Deep Motive
2. My aim is to pass the course while doing as little work as possible.	Surface Motive
3. I feel that virtually any topic was highly interesting once I get into it.	Deep Motive
4. I do not find my course very interesting so I keep my work to the minimum.	Surface Motive
5. I find that studying academic topics can at times be as exciting as a good novel or movie.	Deep Motive
6. I find I can get by in most assessments by memorising key sections rather than trying to understand them.	Surface Motive
7. I work hard at my studies because I find the material interesting.	Deep Motive
8. I find it not helpful to study topics in depth. It confuses and wastes time, when all I need is a passing acquaintance with topics.	Surface Motive
9. I come to my classes with questions in mind that I want answering.	Deep Motive
10. I see no point in learning material which is not likely to be in the examination.	Surface Motive

2.2.4 Embedding point-of-contact feedback for students using the MOOC

While survey questionnaires have been used extensively to improve teaching and learning (Richardson, 2005), with few exceptions, students completing questionnaires are not given feedback on survey results (Watson, 2003). When feedback is given, it is not always provided in a timely manner. Brookhart (2008) and Parikh, McReelis and Hodges (2001) have argued that point-of-contact feedback is an essential component of student learning. It also allows educators to make changes to unit content to better accommodate student needs (Watson, 2003). The *Bite size maths* project is the first to embed point-of-contact information about learning into a MOOC. Point-of-contact feedback information is provided as part of the interactive module pre-test. Feedback is based on the specific answer given by an individual to a particular item within the Study Process Questionnaire. Figure 6 provides an example of the point-of-contact feedback provided for Question 2 (surface learning approach). Point-of- contact feedback for all 10 questions is provided in Appendix 9. By providing immediate feedback as part of the Study Process Questionnaire, students are able to examine their meta- learning and better understand their learning approaches, motivations and strategies. It is expected that this meta-learning will be applied in other learning situations. Students also had the opportunity to evaluate the effectiveness of the point-of-contact feedback via the question *Did the feedback help you to get a better sense of what you need to do to succeed in your course?*

Feedback for Question 2

Literature sources use to inform feedback: King & Baxter-Magolda, 1996.
Scale: Surface Motive
Question: My aim is to pass the course while doing as little work as possible.

Text for each feedback:

Student response = strongly agree or agree: Your answer indicates that you may have a low level of motivation towards this unit or your degree. However, often there are other reasons for this level of motivation, such as a heavy workload. Research indicates that competing events outside university study can cause distraction, thus affecting your motivation. If your main aim is to pass your course or unit, consider the implications for your learning approach, particularly if you are enrolled in a core unit that is drawn upon in other units. Perhaps consider adjusting your academic efforts by looking for ways in which you can increase your motivational levels.

Student response = strongly disagree or disagree: Your answer indicates that you are likely approaching your studies with an appropriate level of motivation. Research indicates that competing events outside university study can cause distraction, thus affecting your motivation.

Student response = neither agree nor disagree: Your answer indicates that it is unclear whether you are approaching your studies with an appropriate level of motivation. Research indicates that competing events outside university study can cause distraction, thus affecting your motivation.

Figure 6: Point-of-contact feedback on one Study Process Questionnaire item that measures a surface approach to learning

2.2.5 Design and deployment of a unique MOOC for at-risk students studying mathematics

To date, no mathematics MOOC has been designed using cognitive load theory effects or incorporating point-of-contact feedback on learning. The MOOC designed and developed by the *Bite size maths* project team has a number of unique features. These include the use in the MOOC of:

- Cognitive load theory to inform its design via:
  - Two sets of worked examples and problem-solving tasks
  - Faded worked examples (completions)

    - Simultaneous delivery of visual and auditory information, and
    - Incremental build-up of knowledge and skills to avoid cognitive overload
- Design of a set of learning pathways within the MOOC – a type of adaptive strategy
- A Study Process Questionnaire providing psychometric measures of deep and surface learning
- Point-of-contact feedback to students about their learning approaches, motivations and strategies, and
- Design of an overarching model that provides a dynamic view of the MOOC.

The MOOC is designed to allow students to tackle 'bite-size chunks' of the mathematics at which they must become proficient. It offers a self-paced introduction to key features of undergraduate mathematics, and is adaptive through the transitions provided by continual graded assessment and point-of-contact feedback.

2.2.6 Trial of MOOC structures (20 interactive modules)

Initial trials of the five online learning system modules revealed a number of structural issues that needed to be addressed including:

- Access problems from some types of mobile devices, for example, incompatibility issues with browsers
- The Blackboard platform did not fully support the online learning system modules designed for this project, and
- The Blackboard platform did not provide access to the online learning system modules for people from outside the RUN university which was conducting the trial.

To overcome these problems, the five online learning system modules were migrated to Moodle. Subsequent to that, the 20 interactive modules that comprise the MOOC were developed. When these interactive modules were trialled on the Moodle platform, further issues arose. While Moodle allowed access to the MOOC from a range of different browsers and mobile device types, there were initial difficulties in setting up the loop structures, in particular the point-of-contact feedback loops, required for the interactive modules. Once Moodle was set up to support the loops, the system was trialled by an expert focus group. These expert users determined that Moodle was probably not the most suitable platform for the MOOC, because there were still access issues for some, and problems with in site navigation.

The 20 interactive modules were then migrated from Moodle to a web browser administered and monitored from outside the RUN university where the trial was being conducted. The expert focus group took part in further MOOC trials hosted on the independently- administered web browser. The feedback loops were found to be more user-friendly on this platform. Based on these trials, the MOOC was again modified within the web host system. The expert focus group trial was iterated until the system ran smoothly through all the feedback loops and across all the 20 interactive modules within the MOOC structure.

3 Project Outputs and Findings

The *Bite size maths* project addressed the HEPPP 2015 National Priorities Pool priority area *More effective programme implementation.* Specifically, the project delivered improvements to current practice in program delivery as illustrated below.

- The project developed 20 mathematics online learning system modules could be used independently or integrated into a MOOC to support students at regional/rural institutions, many of whom are low socioeconomic, Aboriginal and Torres Strait Islander, mature age, women, and/or first-in family to attend university. These groups are at risk of early attrition or academic failure.
- The project gathered and analysed data from RUN universities to better understand the current state-of-play for students studying introductory undergraduate mathematics. This provided a snapshot of current practices for identifying at-risk students, their use of support services, and the barriers to their success. The data highlighted students' lack of cognitive preparedness for tertiary mathematics
- To address this issue, five online learning system modules were developed based on cognitive load theory's worked example effect. Trials of the mathematics online learning system modules showed improvements in students' scores when using the worked examples rather than traditional problem-solving approaches.
- Based on insights from the online learning system module trial, the project developed 20 interactive modules and established their collective functioning in a MOOC. This MOOC has inbuilt point-of-contact feedback for students about their learning approach. It offers opportunities for students' meta-learning about their learning styles which are transferable to other disciplines, and
- The modules themselves can be flexibly integrated into existing introductory undergraduate mathematics units, and staff at RUN universities expressed enthusiasm about their use.
- The modules are self-paced and can be taken by students in their own time. They offer pathways of learning so that students can progressively build up 'bite-size chunks' of knowledge that allow them to solve complex mathematical problems.
- This cognitive load theory-based MOOC, with all its novel elements, can be used across other disciplines at a tertiary level as well as in broader educational contexts.

Table 6: Summary of deliverables and results

DELIVERABLES	DESCRIPTION OF RESULTS
Deliverable 1	• Assembling of identification processes for at-risk mathematics students from current databases. • Identification and collection of data from existing sources. • Construction of bite size chunks video resources. • Design of additional data collection and assessment criteria.
Deliverable 2	• Implementation and analysis using online assessment processes, surveys and interviews, update process from collected data.
Deliverable 3	• Update of resource based on collected evidence from data collection and analysis, planning and trialling of online learning system modules.
Deliverable 4	• Completion of online learning system modules.

DELIVERABLES	DESCRIPTION OF RESULTS
	• Development of a MOOC (interactive modules). • MOOC trialling.
Deliverable 5	• Project completion, recommendations made and finalisation of report. • Complete MOOC and assess online capability.

3.1 Resources Developed by the Project

The *Bite size maths* project developed a number of resources which are of use to a range of stakeholder groups. These include a *Schema for identification of at-risk students* (Appendix 3). This resource is of use to staff working on introductory undergraduate mathematics units, staff from other disciplines teaching at the first-year level, and management teams within universities whose focus is on early attrition and academic failure.

Another resource developed by the *Bite size maths* project is a set of baseline data from a survey and face-to-face interviews with staff working on introductory undergraduate mathematics units at RUN universities. This data provides information on current practices for identifying at-risk students, institutional support mechanisms to assist these students, research on struggling students and their access to support programs, and issues contributing to high rates of attrition or academic failure. This data set provides a snapshot of the current state-of-play in introductory mathematics education at regional/rural institutions. As such, it is of use to staff working on introductory undergraduate mathematics units, to management teams within universities whose focus is on attrition or academic failure, to higher education policy makers who seek to improve the effectiveness and lower the cost structures of tertiary education, to secondary school educators, and to academics researching into attrition/failure at universities.

The *Bite size maths* project developed and trialled a set of five online learning system modules for mathematics which were based on cognitive load theory's worked example and modality effects. Each module addressed a mathematics problem identified in the survey (above) as being of particular challenge to first-year university students. Trials showed superior learning when using modules built on cognitive load theory principles than when the traditional problem-solving approach was used. Such online learning system modules are an exciting new tool to support mathematics learning. They can be flexibly integrated into existing mathematics units (whether face-to-face, online or mixed-mode delivery), as well as having application in other tertiary disciplines and in other educational contexts.

Using input from the online learning system module trials, the *Bite size maths* project developed and refined a mathematics MOOC comprised of 20 interactive modules. This is the first MOOC to be built using cognitive load theory (worked examples, faded worked examples and audio/visual modality). The MOOC is also unique in that point-of-contact feedback has been incorporated so that students may better understand their learning approaches, motivations and strategies (Appendix 9).

The interactive modules and the MOOC offer introductory mathematics students a very practical way to improve both their deeper understanding and mathematical competence. Because they are structured to build expertise in 'bite-size chunks', student confidence is also enhanced. This is a key factor for success in university mathematics.

It is expected that both the interactive modules and the MOOC will be used by staff teaching introductory undergraduate mathematics units at regional/rural universities. These online tools will supplement their teaching materials and approaches, and help to address the problems of early attrition and academic failure for disadvantaged groups. The point-of-contact feedback within the MOOC also provides key information to teachers about the learning approaches of their student cohort. Staff in other disciplines have already shown an interest in developing modules based on cognitive load theory, and this trend is expected to continue.

The MOOC will also be of interest to senior management teams and to higher education policy makers keen to address the STEM crisis, as well as to academics researching cognitive load theory, the effectiveness of point-of-contact surveys, and learning in a more general sense.

The resources developed by the *Bite size maths* project will be refined as they are rolled out via:

- Feedback from staff working on introductory undergraduate mathematics units at RUN institutions including information about:
    - Types of mathematical problems for which students need learning support
    - Interactive podcasts which students find particularly difficult, and
    - Students' comments about their experiences when engaging with MOOC interactive modules
- Student feedback whereby students have the opportunity to comment on their learning experience within modules, and
- 2017 trials of the 20 interactive modules and the MOOC which will provide quantitative measures of the effectiveness of these online tools in improving mathematics competency, e.g. comparison of:
    - Pre- and post-test scores on each snippet
    - Attrition and academic failure rates for years prior to and after 2017 (where possible), and
    - Final academic grades for years prior to and after 2017 (where possible).

3.2 Critical Success Factors

Critical factors positively impacting the *Bite size maths* project to date include:

- Wide skill set within project team (mathematics education, cognitive load theory, point-of-contact feedback, and technical aspects of developing online learning)
- Collaborative RUN partners who provided information on the state-of-play of introductory mathematics education in their respective institutions
- Mentoring and advice from Emeritus Professor John Sweller
- Workshops at SCU and for all RUN partners which developed knowledge about cognitive load theory and online podcasts, and
- Drawing on a sound research base for MOOC development (e.g., cognitive load theory and point-of-contact feedback on learning).

Critical factors negatively impacting the *Bite size maths* project to date include:

- Problems with the hosting platform for the MOOC, and
- Difficulties encouraging students to volunteer for the module trials.

Critical success factors for rolling out the MOOC from 2017 to 2019 include:

- Leadership, clarity of purpose and influence—the *Bite size maths* team will need to champion the mathematics MOOC at regional and national levels. It will be important to build the evidence base to demonstrate that the 20 interactive modules and/or the MOOC actually enhance mathematics learning for disadvantaged groups in regional/rural Australia.
- Relationship building—the strong relationships that exist between the RUN partners will need to be nurtured and further strengthened.
- Project planning—the *Bite size maths* project team will need to develop and implement a plan for the 2017 trials and subsequent roll-out of the 20 interactive modules. Continuous improvement loops will need to be part of any plan.
- Participants for the 2017 Trials—for the 2017 MOOC trial across the RUN universities, a strategy will need to be devised by the partners to increase student participation in, and completion of all of the 20 interactive modules.
- Communication strategy—the *Bite size maths* team will need to communicate with a range of stakeholders to ensure that the MOOC is known, accessed and improved. Stakeholders include introductory mathematics students who are at risk of attrition/failure, university mathematics teachers, staff in other disciplines, senior management teams at tertiary institutions, educational policy makers and other senior government strategists. Academic papers and presentations, as well as information-sharing seminars, will provide vital information about the MOOC’s interactive modules, its unique design, usefulness and potential.
- Governance—RUN partners will need to address institutional protocols around enrolment, pre-requisites, course accreditation and assessment in order to successfully embed the interactive modules within introductory mathematics units.
- Resource management—RUN partners will need to address resource issues so that the MOOC may be trialled and adapted on an ongoing basis beyond 2017, and
- Monitoring and evaluation—protocols and processes will need to be developed such that all RUN partners have a uniform method for gathering and analysing data from first-year students who undertake the 20 interactive modules and the MOOC. This should include information about test performance, as well as point-of-contact feedback about learning approaches. Feedback and improvement loops will need to be put in place so that the MOOC can adapt and evolve to better serve at-risk mathematics students.

4 Project Impact

4.1 Direct Impacts

4.1.1 Direct impact on introductory undergraduate mathematics students

Trials conducted as part of the *Bite size maths* project showed that online learning system modules which delivered 'bite-size chunks' of information enhanced the learning of undergraduate students taking introductory mathematics units. Using input from the trial of five online learning system modules, a MOOC comprised of 20 interactive modules was developed. The MOOC, and the use of the modules independently, has the potential to enhance the mathematical capabilities of regional/rural undergraduates so that they can successfully complete their university courses and operate proficiently within their future professional lives.

Because the interactive modules in the MOOC are based on cognitive load theory with 'reverse-engineered' worked examples, students have the opportunity to develop deeper understanding of mathematical principles than they might otherwise do via more traditional learning approaches.

Many students, and especially those from disadvantaged groups at regional/rural universities, lack preparedness for mathematics learning at the tertiary level. The MOOC and the interactive modules provide viable and cost-effective tools to assist these students in bridging the gap between their mathematical knowledge and what is required at university level.

The *Bite size maths* project's survey and face-to-face interviews with RUN partners indicated that lack of confidence is a major factor in early attrition and academic failure in tertiary mathematics education. Because the MOOC modules are structured using 'bite-size chunks' of information, and because it the MOOC and/or modules can be undertaken privately, at the students' own pace and in their own time, it is expected that students' confidence in mathematics will be enhanced.

4.1.2 Direct impacts on staff working on introductory undergraduate mathematics units

Staff working on introductory undergraduate mathematics units at RUN universities reported enthusiasm about using the MOOC modules as part of their unit delivery. Additionally, the 20 interactive modules by themselves can be embedded in flexible ways to best suit the existing unit structure. When surveyed, RUN partners noted the need for evidence-based, timely support for students at risk of attrition or academic failure. By designing modules that are founded on a rigorous and well-recognised cognitive architecture, the *Bite size maths* project has provided a mechanism for university teachers in regional/rural universities to grow the mathematics capability of at-risk students, many of whom are from disadvantaged groups.

4.1.3 Direct impact on mathematics pedagogy experts

The *Bite size maths* project has developed and trialled a new way of delivering online mathematics learning. Furthermore, a number of unique features were incorporated in both the five online learning system modules and subsequently in the 20 interactive modules which comprise the MOOC. Participating RUN institutions have shared new ways of thinking about mathematics pedagogy and deepened their understanding of the cognitive structures of learning.

The project provides a framework for sustainable collaboration across disciplines within higher education, as well as across the broader education community. Australian mathematics education as a whole will benefit from this initiative.

4.1.4 Direct impact on the professional standards of future teachers and the quality of teaching

The Australian Professional Standards for Teachers (AITSL, 2012), Standard 2 *Know content and how to teach it*, requires teachers to know, select and organise content, and to design learning sequences that best facilitate student learning. Standard 2.5 *Literacy and numeracy strategies* highlights the importance of providing quality mathematics education to students. Trials of the five online learning system modules have indicated that mathematical learning is enhanced by the use of this tool. The *Bite size maths* project has designed a resource that will improve pre-service teachers' knowledge of mathematical content, and increase their confidence and competence when teaching mathematics.

Standard 1.2 of the Australian Professional Standards for Teachers *Understand how student learn*, makes explicit the need for teachers to understand and respond to different learning strategies within their classrooms. The MOOC has embedded point-of-contact feedback for pre-service teachers on their learning approaches, motivations and strategies. They are encouraged to reflect on their learning strategy, and the point-of-contact feedback provides tailored information about the implications of their learning approach. Because the MOOC encourages pre-service teachers to reflect on their own meta-learning, they will be better prepared to recognise and understand how their future students learn.

4.1.5 Direct impact on learning in other disciplines

While the online learning system modules have to date been tested only on education students, they can also be embedded in other higher education curricula in flexible ways. Furthermore, the 20 interactive modules lend themselves for use in any unit where students have limited mathematics experience, and, hence, the MOOC itself may prove invaluable in a range of introductory units in the higher education sector.

4.2 Recommendations

It is recommended that regional/rural universities across Australia embed the 20 interactive modules and/or the MOOC developed by the *Bite size maths* project into introductory undergraduate mathematics as a means of:

- Rapidly increasing undergraduate students' engagement and skills in mathematics, and
- Providing a mechanism for pre-service teachers to meet the Australian Professional Standards for Teachers, e.g. *Know the content and how to teach it.*

It is further recommended that the mathematics MOOC be implemented at a national level, that the approach be adopted by other disciplines and that similar interactive modules be developed in other educational contexts (e.g. schools). An open education platform would be most suited to this task, funded nationally but administered by a single university.

Target:

- MOOC and interactive modules embedded in introductory undergraduate mathematics units across regional Australia by end of 2018, and
- Mathematics MOOC released nationally and internationally by the end of 2019.

National implementation to be led/sponsored by the Australian Council of Deans of Education in conjunction with its counterpart the National Council of Heads of Mathematical Sciences.

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Appendix 1: Linked Projects and Publications

Linked Projects

External Competitive Grants

2017-2019	ARC Discovery *Connecting mathematics learning through spatial reasoning*, J. Mulligan, M. Mitchelmore (Macquarie University) G. Woolcott (Southern Cross University) and B. Davis (University of Calgary, Canada).
2013-2016	Department of Education and Training (and the Office for Learning and Teaching), as part of the Enhancing the Training of Mathematics and Science Teachers program ($1 Million) *It's part of my life: Engaging university and community to enhance science and mathematics education (IPOML)*. G. Woolcott (project leader) with RUN partners.
2014-2017	AMSPP ($987,5000) *Inspiring Science & Mathematics Education (iSME)* (lead SCU). L. Sullivan, A. Scheffers, G. Woolcott.
2013-2016	AMSPP Priority Project ($998,880) *RUN Maths and science digital classroom* (lead USQ). G. Woolcott with RUN partners.
2015	Canadian Social Sciences and Humanities Research Council (CAN$30,000), *Spatial Reasoning Knowledge Synthesis Project (SRNMP)*. Woolcott invited by Prof C. Bruce (Trent University, Canada).
2015-2016	IOSTEM Early Years Mathematics Initiative Meetings (CAN$100,000) *Spatial Reasoning Network Mapping Project (SRNMP)*. Woolcott invited by Prof B. Davis (University of Calgary, Canada).

Internal Grants (SCU only)

2016	Applying an alternative mathematics pedagogy for students with weak mathematics foundation: Phase 2: Pilot implementation of diagnostic tool and Smart Sparrow-based curriculum intervention, SCU Higher Education Participation Project (HEPP) Grant. G. Woolcott with project leader, W. (Bill) Boyd, and C. Markopoulos, A. Foster, W. Boyd & M. Wallin.
2016	Student-centred service integration based on identification of risk factors in undergraduate university education, SCU Higher Education Participation Project (HEPP) Grant. G. Woolcott with R. Keast & A. Graham.
2015	Connecting spatial reasoning and mathematics conceptual development using network analysis, DVC(R) Seed Grant. G. Woolcott with C. Markopoulos, SCU & J. Mulligan, Macquarie University.
2015	Applying an alternative mathematics pedagogy for students with weak mathematics foundation: Phase 1: Meta-analysis of alternative pedagogies, SCU Higher Education Participation Project (HEPP) Grant. G. Woolcott with project leader W. (Bill) Boyd, and C. Markopoulos, A. Foster, W. Boyd, T. Boyle & M. Wallin.

2015 *Identification of risk in first-year education*, SCU Higher Education Participation Project (HEPP) Grant. G. Woolcott with R. Keast & A. Graham.

2014 Mathslinks: Network analysis of spatiotemporal connectivity in mathematics conceptual development, SCU School of Education Grant. G. Woolcott.

2013 Graduate teachers should be classroom ready: Transforming teacher education through university-school partnerships, SCU Teaching and Learning Small Grant. G. Woolcott with S. Hudson.

2013 Examining spatiotemporal links in mathematics concept learning in classroom and online environments, SCU School of Education Small Grant. G. Woolcott.

Linked Publications 2014-2017

Undergraduate Texts

Woolcott, G., & Whannell, R. (Eds). (2017 In Press). Teaching Secondary Science: *Theory and practice.* Melbourne, Australia: Cambridge University Press.

Hine, G., Raeburn, R., Anderson, J., Galligan, L., Carmichael, C., Cavanagh, M., Ngu, B., & White, B. (2016). *Teaching Secondary Mathematics.* Port Melbourne, Australia: Cambridge University Press.

Refereed books, book chapters, journal articles and conference publications 2014-2017

Books

Grootenboer, P., & Marshman, M. (2016). *Mathematics, affect and learning*. Singapore: Springer,

Marshman, M., Geiger, V., & Bennison, A. (Eds.) (2015). Mathematics education in the margins: Proceedings of the 38th annual conference of the Mathematics Education Research Group of Australasia (MERGA). Sippy Downs, QLD: MERGA.

Book Chapters

Woolcott, G. (2016). Technology and human cultural accumulation: The role of emotion. In S. Tettegah & R. E. Ferdig (Eds.), *Emotions, technology, and learning* (Vol. 1 in series: *Emotions and technology: Communication of feelings for, with, and through digital media* editor S.Y. Tettegah, pp. 243-263). London: Academic Press.

Galligan, L., McDonald, C., Hobohm, C., Loch, B., & Taylor, J. (2015). Conceptualising, implementing and evaluating the use of digital technologies to enhance mathematical understanding: Reflections on an innovation-development cycle. In J. Lock, P. Redmond & P. A. Danaher (Eds.), *Educational Developments, Practices and Effectiveness: Global Perspectives and Contexts* (pp. 137-160). New York, NY: Palgrave Macmillan.

Journal Articles

2017 or in press

Chen, O., Kalyuga, S., & Sweller, J. (in press). When instruction is needed. *The Educational and Developmental Psychologist.*

Chen, O., Kalyuga, S., & Sweller, J. (in press). The relations between the worked example and generation effects on immediate and delayed tests. *Learning and Instruction.*

Chen, O., Woolcott, G., & Sweller, J. (in press). Using cognitive load theory to structure

MOOCs and other computer-based learning. *Journal of Computer Assisted Learning.*
Francis, K., Bruce, C., Davis, B., Drefs, M., Halliwell, D., Hawes, Z., McGarvey, L., Moss, J., Mulligan, J., Okamoto, Y., Sinclair, N., & Woolcott, G. (in press). Multidisciplinary perspectives on a video case of children designing and coding for robotics. *Canadian Journal of Science, Mathematics and Technology Education.*
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Appendix 2: Project Milestones, Activities, and Key Performance Indicators

TIMEFRAME	MILESTONE AND ACTIVITIES	KEY PERFORMANCE INDICATORS
1 January 2016 - 15 February 2016	**Appointment of Project Team** *Project leader:* • Dr G. Woolcott (Associate Professor in Mathematics and Science Education). Time: 20 days *Project Team invitees*: • Dr W. Boyd (Professor of Environmental Sciences). Time: 10 days • Dr C. Markopoulos (Senior Lecturer, Mathematics Education). Time: 20 days • Mr A. Foster (Associate Lecturer, Mathematics Education). Time: 20 days • Dr Raina Mason (Lecturer, Computing). Time: 10 days • Project representatives invited from 5 RUN consortium partners. Time: 20 days for each	• Project Team established – Response received from each of the project team invitees • Research Assistant contracted (Dr Ouhao Chen) • Partnerships with Regional Universities • Network institutions are invited – Response received from RUN partners
	1.2 Assembling and collating from current identification processes, at each of participating RUN partners, for at- risk mathematics students	Assembling and collation of identification processes from each of the participating RUN organisations completed
	1.3 Identification and collection of data from these existing sources as to students identified as ‘at risk’.	Identification and collection of data related to the at-risk student cohort completed
	1.4 Two-phase plan of development of a library of resources and videos intended to assist target students with mathematical learning, based on cognitive load theory. Specifically, this video resource library will be constructed from examination of problems that low socioeconomic maths students frequently find difficult in the initial mathematics units that they attempt at university.	Two-phase plan of development of a library of resources and videos completed. This includes a catalogue of resources currently available that use cognitive load theory principles of instructional design in mathematical learning for first year university. It also uses a catalogue of problems that low socioeconomic maths students frequently find difficult in the initial mathematics units that they attempt.
	1.5 Design of additional data collection mechanisms and assessment criteria	• Data review and gaps analysis completed. Additional data needed is identified • Data collection mechanisms and assessment criteria established

TIMEFRAME	MILESTONE AND ACTIVITIES	KEY PERFORMANCE INDICATORS
16 February 2016 - 31 May 2016	2.1 Data collection through such processes as online assessment, surveys and interviews	Data collection from such processes as online assessment, surveys and interviews is completed
	2.2 Data analysis	Data analysis completed
	2.3 Process update on the basis of data analysis	Process is updated on the basis of data analysis
1 June 2016 - 30 September 2016	3.1 Phase one of development of library of resources and videos.	Phase one of development of library of resources and videos completed
	3.2 Data collection and analysis on Phase one of the library of resources and videos	Video resources data collection and analysis on Phase one is completed
	3.3 Online learning system development based on video library development	Five online learning system modules are developed
	3.4 Online learning system trial	Trial of interactive modules in the online learning system completed
1 September 2016 - 31 October 2016	4.1 Massive Open Online Course (MOOC) development (Phase two of the library of resources and videos)	Development of 20 interactive modules and their function as a MOOC is completed
	4.2 MOOC trial	Trial of MOOC by expert focus groups completed
1 November 2016 - 31 December 2016	5.1 Research report based on project outcomes, which identifies policy implications and recommendations for the Australian higher education sector	Research report completed
	5.2 MOOC establishment	MOOC established
	5.3 MOOC evaluation	Evaluation of MOOC by expert focus groups completed
31 January 2017	6.1 Final Report	Final report submitted to the Department of Education and Training

Appendix 3: Identification of At-Risk Students at a Regional University

SCHEMA FOR IDENTIFICATION OF AT-RISK STUDENTS (SUBJECTS=UNITS, SESSION=TERM=SEMESTER)
Results from enrolment in first low-level mathematics subject attempted at university 1. an introductory maths subject at the lowest level OR 2. an introductory algebra and calculus subject
Results from processes that guide enrolment or help determine mathematics' enrolment pathways
Results from Literacy and Numeracy Test for Initial Teacher Education (LANTITE)
Previous educational experience in mathematics 1. ATAR or equivalent 2. Years since last mathematics course 3. Other at-risk factors used by each university
Pre-testing within a subject e.g., for Calculus or Linear Algebra
At one university, a novel process is being trialled that links risk factors across an undergraduate cohort (using social network analysis) and how this may be related to mathematics grades in the two lowest level subjects (Woolcott, Chamberlain & Whannell, in draft)
Course outlines for: 1. an introductory maths subject at the lowest level; OR 2. an introductory algebra and calculus subject.
Exams and solutions for: 1. an introductory maths subject at the lowest level; OR 2. an introductory algebra and calculus subject.
Frequently asked questions or other ways to identify weaknesses in student work
Survey about attitudes and mathematics experience
Case studies – in depth interviews of one or two mathematics students, or in one case of all students in a particular subject

Appendix 4: Survey Questionnaire for RUN Partners

PART 1 IDENTIFYING STUDENTS AT RISK
Q1 - What data is collected at your institution with a view to identifying students who may be at risk of early attrition or academic failure in introductory undergraduate mathematics units? (Include examples of standard data collection instruments, if available.) Q2 - How is this data collected? Q3 - When is this data collected? Q4 - Who is the data collected by? Q5 - Who conducts the analysis of the data? Q6 - How are the findings of the data analysis disseminated and who receives these findings? Q7 - What actions are taken based upon the findings of the data analysis? Q8 - What role does the academic who coordinates the first-year mathematics unit/s play in the process described above?
PART 2 INSTITUTIONAL SUPPORT FOR STUDENTS AT RISK
Q 9 – What opportunities for additional support are available to first year mathematics students at your university, e.g. Enabling program/s, mentors? Q10 - What processes are in place to inform students of how to access existing student support programs? Q11 - What percentage of students use these existing support programs? Q12 - In your view, what benefit do the existing support programs have for students who access them? Q13 - What do you think are the main limitations of the existing support programs at your university?
PART 3 PREVIOUS INSTITUTIONAL RESEARCH ON MATHEMATICS STUDENT ATTRITION/FAILURE
Q14 - What research has been conducted at your institution in relation to mathematics students' attrition/failure? Please include reference to any publications which have resulted. Q15 - What impact did this research have at your institution in relation to practices/processes for identifying and/or supporting students at risk of attrition/failure in first year mathematics units? Q16 - What research is currently in progress in relation to addressing the incidence of student attrition/failure in first year mathematics units?
FINAL COMMENT
Q 17 – What do they think the major issues are that contribute to the high rates of attrition and/or failure in first year university mathematics units?

Appendix 5: The Worked Example, Problem Completion and Modality Effects in Cognitive Load Theory

The Worked Example Effect

The worked example effect (Cooper & Sweller, 1987; Sweller & Cooper, 1985) has been shown to be effective across a number of learning situations including science (Reisslein, Atkinson, Seeling & Reisslein, 2006; Van Gog, Kester & Pass, 2011) and mathematics domains including algebra (Sweller & Cooper, 1985), statistics (Paas, 1992) and geometry (Paas & Van Merriënboer, 1994). In essence, the worked example effect states that when learners are presented with a worked example and then required to immediately solve a similar problem, learning is facilitated. The worked example provided needs to be fully elaborated. The problem is presented first, followed by the step-by-step process to its solution. When such guidance is offered and immediate problem-solving required, learning is superior to instances where no guidance is provided.

Learners work through the step-by-step explanation provided as part of the worked example. In essence, learners borrow well-structured information. When learners solve a similar, paired problem immediately after the presentation of a worked example, they draw on their newly schematised information.

On the other hand, when learners are not provided with a worked example, they need to generate a number of possible random solutions to the problem. In order to solve this problem, learners draw on the information they hold in long-term memory and generate a number of possible random solutions to the problem at hand. This is not an optimal learning situation.

The Problem Completion Effect

Cognitive load theory has demonstrated that instructional design can be enhanced when the worked example effect is put to effective use. Another useful tool for improving instructional design is the problem completion effect. In this instance, learners are not presented with full worked examples, but are given partially worked examples with the requirement that they fill in the gaps. Again, there is a step-by-step presentation of information, and for those steps that are elucidated, explicit information is provided. An example is given below:

$2x + 10 = 14$

$2x = 14 - 10$

$x = ?$

Research on learning by Van Merriënboer (1990) has demonstrated that for learning in computer programming, the problem completion effect has proved effective. Paas (1992) investigated three learning conditions: worked example, problem completion and conventional problem solving. Both worked example and problem completion yielded better learning outcomes than did conventional problem solving.

The Modality Effect

The modality effect suggests that learning is enhanced under certain closely-defined conditions when both visual and auditory information are presented simultaneously. Baddeley (1992) has characterised working memory as having two sub-components, the visuospatial sketchpad (relating to or denoting the visual perception of the spatial relationships of objects) and the phonological loop (represented by a brief store of mainly verbal information together with a rehearsal mechanism). Tindall-Ford, Chandler and Sweller's (1997) research determined that using both visual and audio channels produces better learning outcomes than when only a visual channel is used. The explanation may be that using both channels increases the usable capacity of working memory (Penney, 1989). Many research studies have investigated the modality effect (Kalyuga, Chandler, & Sweller, 2000; Mayer & Moreno, 1998; Tindall-Ford et al., 1997). Tindall-Ford et al. (1997) compared text presented in audio format and diagrams in visual format, to text and diagrams both presented in a visual format. They found that subsequent test scores were better for the group who were presented with the mixed format than for the group who learned via a visual format only. Similarly, Mayer and Moreno (1998) investigated the modality effect in multiple experiments where one group received narrated text and the other group was presented with only words on a screen. Results confirmed the superiority of the mixed visual and auditory format.

Appendix 6: Library Search on Cognitive Load Theory and MOOCs

Lists of free sites but couldn’t find anything at university level.
http://elearningindustry.com/over-1000-free-elearning-resources

Effective educational videos – ‘how to’
https://cft.vanderbilt.edu/guides-sub-pages/effective-educational-videos/

How to optimize students' learning? Cognitive Theory of Multimedia Learning ‘how to’
http://elearningindustry.com/over-1000-free-elearning-resources

Cognitive load theory and mathematics education
Awawdeh-Caleo, Majeda, Education, Faculty of Arts & Social Sciences, UNSW, 2008
http://www.unsworks.unsw.edu.au/primo_library/libweb/action/dlDisplay.do?vid=UNSWORKS&doc Id=unsworks_2632

ERIC and Education Research Complete
"cognitive load" AND math* AND video
"cognitive load" AND math* AND resource*

Some ‘how to’ articles but no leads to actual videos. The same as above for LearnTechLib

Khan Academy
https://www.khanacademy.org/

Nothing on cognitive load theory.

TED Ed lessons. Math in Real Life videos (directed at school age not university)
http://ed.ted.com/lessons/scott-kennedy-how-to-prove-a-mathematical-theory

Appendix 7: Various Pathways for Progress through the Mathematics MOOC

- Module pre-test (All students sit a Study Process Questionnaire point-of-contact survey prior to taking this test.)
    - Students who score 10 out of 10 move on to the next module, and
    - Students who score less than 10 out of 10, move to the snippet pre-test.
- Snippet pre-test
    - Students who score six out of six move on the next snippet within the module and sit its snippet pre-test, and
    - Students who score fewer than six out of six, progress through the snippet doing two sets of worked examples, problem solving and Cognitive Load Surveys and then sitting a post-test.
- Snippet post-test
    - Students who score one out of six receive point-of-contact feedback that advises them to go back to the snippet pre-test and, depending on their score in the snippet pre-test, they either move onto the next snippet or progress through the current snippet as described in the two sub-dot points above.
    - Students who score two, three, four or five out of six, receive point-of-contact feedback that advises them to do faded worked examples (problem completion effect) and re-sit the snippet post-test, and
    - Students who score six out of six receive point-of-contact feedback that advises them to move on to the next snippet.
- Repeated snippet post-test after faded worked examples (if required)
    - Students who score one out of six receive point-of-contact feedback that advises them to go back to the snippet pre-test. Depending on their score in the snippet pre-test, they either move onto the next snippet or progress through the current snippet in full.
    - Students who score two, three, four or five out of six, receive point-of-contact feedback that advises them to repeat the learning loop of faded worked examples and snippet post-test, and
    - Students who score six out of six receive point-of-contact feedback that advises them to move on to the next snippet.
- Once a student has completed a snippet, the process repeats itself from dot point 2 above (Snippet pre-test), with students taking a snippet pre-test for the next snippet etc., and
- When all five snippets have been successfully completed (scoring six out of six in each post-test), students take a second SPQ test. They then proceed to the next module, beginning a new learning loop at the first dot point above (Module pre-test).

Appendix 8: Questions in the Interactive Module Post-Test

INTERACTIVE MODULE POST-TEST (CONTEXTUALISED)	APPROACH MEASURED
1. The module I just completed gave me a feeling of deep personal satisfaction.	Deep Motive
2. My aim was to complete the module while doing as little work as possible.	Surface Motive
3. I felt the module topic was highly interesting once I got into it.	Deep Motive
4. I did not find this module interesting so I kept my work to the minimum.	Surface Motive
5. I found that what I was learning within this module was as exciting as a good novel or movie.	Deep Motive
6. I found I got through the module by memorising key procedures rather than trying to understand them.	Surface Motive
7. I worked hard in this module because I found the material interesting.	Deep Motive
8. The module was too in depth and confused and wasted my time, when all I needed was a passing acquaintance with the topic.	Surface Motive
9. During the module, I had additional questions in mind that I want answering.	Deep Motive
10. I see no point in learning material in this module which is not likely to be in the examination.	Surface Motive

Appendix 9: Point-of-Contact Feedback Responses for Interactive Module Pre-Test

Feedback for Question 1

Literature sources used to inform feedback: Hidi and Renninger (2006); Hytti, Stenholm, Heinonen and Seikkula- Leino, (2010)
Scale: Deep Motive
Question: I find that at times studying gives me a feeling of deep personal satisfaction.

Text for each feedback:

Student response = strongly agree or agree: Your answer indicates that you are likely to be deeply motivated when it comes to study. This is a trait that is often associated with improved academic performance. Research that focuses on motivation and its relationship to achievement indicates that motivational differences between students have long-term learning implications, and are often a good predictor of learning outcomes and competencies.

Student response = strongly disagree or disagree: Your answer indicates that you may not be as deeply motivated as you could be when it comes to study. Research that focuses on motivation and its relationship to achievement indicates that motivational differences between students have long-term learning implications, and are often a good predictor of learning outcomes and competencies.

Student response = neither agree nor disagree: Your answer indicates that at times you may not be as deeply motivated as you could be when it comes to study. Research that focuses on motivation and its relationship to achievement indicates that motivational differences between students have long-term learning implications, and are often a good predictor of learning outcomes and competencies.

Feedback for Question 2

Literature sources used to inform feedback: King and Baxter-Magolda (1996)
Scale: Surface Motive
Question: My aim is to pass the course while doing as little work as possible.

Text for each feedback:

Student response = strongly agree or agree: Your answer indicates that you may have a low level of motivation towards this unit or your degree. However, often there are other reasons for this level of motivation, such as a heavy workload. Research indicates that competing events outside university study can cause distraction, thus affecting your motivation. If your main aim is to pass your course or unit, consider the implications for your learning approach, particularly if you are enrolled in a core unit that is drawn upon in other units. Perhaps consider adjusting your academic efforts by looking for ways in which you can increase your motivation levels.

Student response = strongly disagree or disagree: Your answer indicates that you are likely approaching your studies with an appropriate level of motivation. Research indicates that competing events outside university study can cause distraction, thus affecting your motivation.

Student response = neither agree nor disagree: Your answer indicates that it is unclear whether you are approaching your studies with an appropriate level of motivation. Research indicates that competing events outside university study can cause distraction, thus affecting your motivation.

Feedback for Question 3

Literature sources used to inform feedback: Hidi and Renninger (2006)
Scale: Deep Motive
Question: I feel that virtually any topic can be highly interesting once I get into it.

Text for each feedback:

Student response = strongly agree or agree: Your answer indicates that you are likely highly motivated. Keep in mind that the level of a person's situational interest has been found to influence learning.

Student response strongly disagree or disagree: Your answer indicates that at times you may not be motivated by a broad range of topics. If you are not interested in the units of study you are currently undertaking at university, consider doing units that spark interest. Keep in mind that the level of a person's situational interest has been found to influence learning.

Student response = neither agree nor disagree: Your answer indicates that at times, you are likely highly motivated. Keep in mind that the level of a person's situational interest has been found to influence learning.

Feedback for Question 4

Literature sources used to inform feedback: Biggs et al. (2001); Hidi and Renninger (2006)
Scale: Surface Motive
Question: I do not find my course very interesting so I keep my work to the minimum.

Text for each feedback:

Student response = strongly agree or agree: Your answer to this question may indicate that you are adopting a surface approach to parts of your learning. In the future try to research unit outlines ahead of time so that you choose (if possible) topics that align with your intrinsic motives.

Student response = strongly disagree or disagree: Your answer indicates that you are motivated in terms of your learning approach. To help maintain this motivation, in the future try to research unit outlines ahead of time so that you choose (if possible) topics that align with your intrinsic motives.

Student response = neither agree nor disagree: Your answer indicates that at times you are motivated in terms of your learning approach. To help maintain this motivation, in the future try to research unit outlines ahead of time so that you choose (if possible) topics that align with your intrinsic motives.

Feedback for Question 5

Literature sources used to inform feedback: Hidi and Renninger (2006)
Scale: Deep Motive
Question: I find that studying academic topics can at times be as exciting as a good novel or movie.

Text for each feedback:

Student response = strongly agree or agree: Your answer indicates that you are likely to be highly motivated and excited by academic topics. One of the most powerful factors influencing learning is the level of a person's interest. As an indicator of a deep approach to learning, it appears likely that you are undertaking units or a degree which you find interesting.

Student response = strongly disagree or disagree: Your answer indicates that you are not as motivated or excited by academic topics. One of the most powerful factors influencing learning is the level of a person's interest. As an indicator of a deep approach to learning, perhaps consider researching future units in which you wish to enrol and consider choosing subjects that interest you.

Student response = neither agree nor disagree: Your answer indicates that at times, you are not as motivated or excited by academic topics. One of the most powerful factors influencing learning is the level of a person's interest. As an indicator of a deep approach to learning, perhaps consider researching future units in which you wish to enrol in and consider choosing subjects that interest you.

Feedback for Question 6

Literature sources used to inform feedback: Biggs et al. (2001)
Scale: Surface Motive
Question: I find I can get by in most assessments by memorising key sections rather than trying to understand them.

Text for each feedback:

Student response = strongly agree or agree: Your answer indicates that by relying substantially on memorization you are likely using a strategy that is commonly associated with a surface approach to learning. In order to gain a deeper understanding of course content, consider studying the linkages to other course concepts and how that could aid your understanding of core concepts that could be used later in the unit or in other units of study.

Student response = strongly disagree or disagree: Your answer indicates that by not relying substantially on memorization, you are likely to be avoiding a strategy that is commonly associated with a surface approach to learning. In order to gain a deeper understanding of course content, consider studying the linkages to other course concepts and how that could aid your understanding of core concepts that could be used later in the unit or in other units of study.

Student response = neither agree nor disagree: Your answer indicates that at times, you are likely avoiding a strategy that is commonly associated with a surface approach to learning.

In order to gain a deeper understanding of course content, consider studying the linkages to other course concepts and how that could aid your understanding of core concepts that could be used later in the unit or in other units of study.

Feedback for Question 7

Literature sources used to inform feedback: Eccles and Wigfield (2002)
Scale: Deep Motive
Question: I work hard at my studies because I find the material interesting.

Text for each feedback:

Student response = strongly agree or agree: Your answer indicates that you are interested in materials that relate to your studies. Studies indicate that 'interest' is an important factor in the 'quality of learning', and is affected by both individual and situational interest. Importantly, the level of interest, but more specifically deep- level learning, is strongly related to the improved ability to recall main ideas, as well as the ability to respond to deeper comprehension questions.

Student response = strongly disagree or disagree: Your answer indicates that you may not be as interested in materials that relate to your studies. However, studies indicate that 'interest' is an important factor in the 'quality of learning', and is affected by both individual and situational interest. Importantly, the level of interest, but more specifically deep-level learning, is strongly related to the improved ability to recall main ideas, as well as the ability to respond to deeper comprehension questions.

Student response = neither agree nor disagree: Your answer indicates that at times, you may not be as interested in materials that relate to your studies. However, studies indicate that 'interest' is an important factor in the 'quality of learning', and is affected by both individual and situational interest. Importantly, the level of interest, but more specifically deep-level learning, is strongly related to the improved ability to recall main ideas, as well as the ability to respond to deeper comprehension questions.

Feedback for Question 8

Literature sources used to inform feedback: Biggs et al. (2001)
Scale: Surface Motive
Question: I find it is not helpful to study topics in depth. It confuses and wastes time, when all you need is a passing acquaintance with topics.

Text for each feedback:

Student response = strongly agree or agree: Your answer indicates that you tend not to study topics in depth and believe that it is a waste your time to do so. Consider carefully whether a passing acquaintance will be adequate for understanding core content at a deeper level. Keep in mind that core concepts will often require a greater effort to understand and therefore a passing acquaintance may not be sufficient to open up a portal to new concepts presented in other units.

Student response = strongly disagree or disagree: Your answer indicates that you may tend to study topics in depth and believe that the extra time involved is not time wasted. Remember that core concepts will often require a greater effort to understand and therefore a passing acquaintance may not be sufficient to open up a portal to new concepts presented in other units.

Student response = neither agree nor disagree: Your answer indicates that you tend not to study topics in depth and believe that it is a waste your time to do so. Consider carefully whether a passing acquaintance will be adequate for understanding core content at a deeper level. Keep in mind that core concepts will often require a greater effort to understand and therefore a passing acquaintance may not be sufficient to open up a portal to new concepts presented in other units.

Feedback for Question 9

Literature sources used to inform feedback: Hidi and Renninger (2006)
Scale: Deep Motive
Question: I come to most classes with questions in mind that I want answering.

Text for each feedback:

Student response = strongly agree or agree: Your answer indicates that you are likely motivated in your learning to seek answers from your teachers. This approach is an indicator of a deep approach to learning.

Student response = strongly disagree or disagree: Your answer indicates that you are not motivated to seek answers to concepts with which you are struggling. Although there are very likely good reasons for this, such as fear of asking a stupid question, failure to ask questions could impact on your academic outcomes.

Student response = neither agree nor disagree: Your answer to this question may indicate that at times, you are not motivated to seek answers to concepts with which you are struggling. Although there are very likely good reasons for this, such as fear of asking a stupid question, failure to ask questions could impact on your academic outcomes.

Feedback for Question 10

Literature sources used to inform feedback: Hidi and Renninger (2006)
Scale: Surface Motive
Question: I see no point in learning material which is not likely to be in the examination.

Text for each feedback:

Student response = strongly agree or agree: Your answer indicates that your motivation regarding your learning of material is not optimal on this particular measure. Consider the importance of learning other material not covered in an exam, such as concepts that might be relevant to future units you study or useful in a work situation.

Student response = strongly disagree or disagree: Your answer indicates that your motivation regarding your learning of material is good on this particular measure. Perhaps you have considered the importance of learning other material not covered in an exam, such as concepts that might be relevant to future units you study or useful in a work situation.

Student response = neither agree nor disagree: Your answer to this question appears to indicate that at times, your motivation regarding your learning of material is not optimal on this particular measure. Consider the importance of learning other material not covered in an exam, such as concepts that might be relevant to future units you study or useful in a work situation.