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# DESIGNING A NEW GENERATION MOOC FOR UNDERGRADUATE MATHEMATICS

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## Summary

This paper outlines the development using a design-based implementation research (DBIR) approach of a *new generation* massive open online course (ngMOOC) using two innovations: (a) a basis in the human cognitive architecture outlined in cognitive load theory; and (b) point-of-contact feedback that investigates student learning as a process. This preliminary analysis suggests that the DBIR approach supports theoretical standpoints arguing for an understanding of how design for optimal learning can utilise conditions, such as differing online or blended educational contexts, in order to be effective and scalable. The ngMOOC development outlined offers the groundwork for use of adaptive systems that cater for learner expertise and the DBIR approach offers a framework that seems especially useful in constructing and developing online learning that is both self-paced and curriculum based.

## Introduction

Massive open online courses (MOOCs) have become increasingly popular in the modern educational world, providing opportunities for learners to develop and test their own learning networks in online environments (Chen et al., 2017). There are challenges for learning design and development, however, inherent in the divergence between collaborative (cMOOC) and course-based (xMOOC) offerings, including the lack of input from learners in design and development, as well as more general factors, such as motivation, participation and study time (Hew, 2015). The quality of MOOC offerings has also been questioned with regard to learning and cognition, with calls for instructional design that is based in human cognitive architecture (Chen et al., 2017).

This article addresses some of these challenges by outlining the design and development of a new generation MOOC (ngMOOC) as a focal problem of practice for application in an instructional setting related to undergraduate mathematics. A design-based implementation research (DBIR) approach (Penuel et al., 2016) was utilised in the design and development, underscored by two important innovations: (a) a basis in the well-established human cognitive architecture outlined in cognitive load theory; and, (b) point-of-contact student feedback based in a well-tested online system dedicated to investigating student learning as a process. This follows recent MOOCs in which design-based research was used to successfully reframe MOOC construction, for example, in scaling problem-based learning (Verstegen et al., 2016).

## Study Context

### *A persistent problem in undergraduate mathematics*

An increasing number of graduates in higher education do not have the requisite mathematics knowledge and skills that the modern industrial workforce requires. There has been on-going discussion regarding the need for a rethink and redesign of mathematics teaching and learning at the university and college level in order to cater for the weak mathematics foundation of some university students (Australian Academy of Science, 2016). The ngMOOC was developed within the project, "Bite size maths: Building mathematics capability of low SES students in regional/remote Australia" (BSM), to provide online resources to support undergraduate mathematics and academic numeracy. The project established the foundations for a change in the way that online education is offered across six study universities located in regional Australia and offering online or blended education across multiple campuses. These universities, like many regional institutions, all have a substantial proportion of students with little or no mathematics background or who have completed schooling more than 10 years ago (Australian Academy of Science, 2016). The ngMOOC aimed to optimise the outcomes for students not prepared for the level of quantitative skill needed in their university program.

### *Design-Based Implementation Research (DBIR)*

The ngMOOC development can be described in terms of the principles of DBIR: four principles take up the issue of collaborative research and practice that involves multiple stakeholders in a process that aims to design, test and implement innovations through an iterative functionality (Fishman et al., 2013; p.136):

1. a focus on persistent problems of practice from multiple stakeholders' perspectives;
2. a commitment to iterative, collaborative design;
3. a concern with developing theory and knowledge related to both classroom learning and implementation through systematic inquiry; and,
4. a concern with developing capacity for sustaining change in systems.

### *Human Cognition and Student Feedback*

In combining human cognition and student feedback, the ngMOOC draws together two comprehensive research fields, human cognitive architecture and point-of-contact feedback, each field well established in its own right but rarely combined in a single learning context.

#### *Human Cognitive Architecture and Cognitive Load Theory*

Human cognitive architecture is concerned with the organization of the structures, functions and processes that allow each person to learn, think and solve problems associated with the biologically secondary knowledge that is central to instructional design rather than the biologically primary knowledge obtained naturally and effortlessly, without instruction (Sweller et al., 2011). A key feature of human cognitive architecture is described in cognitive load theory as comprising a limited working memory, which can only deal with a small


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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 et al., 2011).

Over the past 20 years a number of researchers have undertaken research on human cognitive architecture to better understand what aspects support problem solving and learning, noting that human cognitive architecture and effective instructional design are inseparably intertwined (Sweller et al., 2011). Sweller's cognitive load theory has become one of the most cited learning theories in contemporary educational design and is critical to the success of all forms of computer-based instruction (Chen et al., 2017). Cognitive load theory has provided a set of guidelines for instructional design that are predicated on an understanding of human cognition. Comprehensive testing of these principles has given rise to cognitive load effects that can be applied in a number of different learning modalities to improve learning.

The ngMOOC discussed in this paper was designed with the principles of cognitive load theory in mind, and three cognitive load effects form the basis of the MOOC construction: the worked example effect; the modality effect; and, the problem completion effect (Sweller et al., 2011). The ngMOOC takes up reports that the use of video podcasts for learning appears to have a positive effect on student performance. However, since such reports leave open the question as to the nature of what constitutes an adequate design for interactive podcasts that are effective for student learning (Chen et al., 2017), the ngMOOC used cognitive load theory as a conceptual basis for their construction and use.

### *Point-of-contact feedback and student learning*

Point-of-contact feedback is an essential component of student learning that allows educators to make changes to unit content to better accommodate student needs. Such feedback serves to let students know about different learning approaches, providing guidance on which may be most appropriate in particular contexts, and allows feedback from the students on how well the instructional design has facilitated their learning. In recent times an updated version of the Study Process Questionnaire (SPQ) of Biggs and colleagues (Biggs et al., 2001) has been used as point-of-contact feedback to measure deep and surface learning approaches in undergraduate education contexts, demonstrating the superiority of deep learning (Lake et al., 2017). The ngMOOC utilises research showing that feedback for students about their learning approaches, motivations and strategies, as point-of-contact feedback, can be successfully embedded in online course delivery for undergraduate students (Lake et al., 2017).

## Method

The project was iterative, undertaken in two phases, with a Phase 1 pilot program undertaken in 2016 and with Phase 2 as a following through to 2019. The two Phases were examined as embedded case studies within the DBIR context using mixed methods approaches. Project partners, 24 university mathematics and education experts across the six study universities, co-created a baseline data set via a review of national database statistics on disadvantage in regional education, as well as surveys and semi-structured interviews. Several face-to-face meetings of experts at the trial university provided valuable feedback about responses to


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Phase 1, and this was used as part of co-creation and development of the ngMOOC construction and evaluation in Phase 2. Student feedback was also utilised, in both phases.

### *Phase 1: Co-Creation, Development and Evaluation of Five Online Modules*

This pilot phase was conducted using five modules in an online learning system (OLS) within a one-semester introductory mathematics subject at a single university. Volunteer participants were randomly assigned to either a treatment group or a control group on alternate modules, with the treatment group receiving two pairs of worked examples and practise tasks in a *snippet*, a total of ten pairs for the five snippets in each module. The participants in the control group were presented with two pairs of tasks that were identical to the questions in the worked examples and practise tasks of the treatment group (and of identical duration), but with no worked examples provided. The post-tests provided a total of 30 randomized multiple-choice tests for each participant in each module, allowing a determination of learning effectiveness comparable with the subject pre-test and exam. Data included: the number of participants attempting modules/snippets; the number of attempts at module/snippet completion; online cognitive load surveys in each snippet; post-tests; and, feedback from open comment boxes. The use of the OLS allowed researchers to collect data from a participant's initial attempts (ignoring those subsequent), since the modules were designed for interactivity and repeated use.

### *Phase 1: Co-Creation, Development and Evaluation of the ngMOOC*

Data analysis from the Phase 1 pilot informed the development and subsequent construction of the Phase 2 ngMOOC, which comprised 20 interactive modules for use together or independently on a web hosting service. An overall aim was to be able to embed single modules, as interactive online podcasts, or embed the entire 20 modules as the ngMOOC—a novel learning approach in university mathematics programs. These 20 modules continued the Phase 1 focus on cognitive load theory's design principles, with the addition of the completion effect in the form of faded worked examples (Figure 1), but with no control groupings.

The looped pathways within modules combined with online rapid assessment allowed the introduction of several enhanced features based on Phase 1 trials, including: addition of point of contact (POC) feedback and the study process questionnaire (SPQ); addition of both module and snippet pre-tests; a repeat option for students with post-test score of less than 2; addition of faded worked examples as a *second loop* option for students with post-test test scores from 2 to 5 (to avoid imposing high level of extraneous load during subsequent learning); an out option for students with high expertise (pre-test scores of 10 for a module and 6 for a snippet) enabling those with high levels of expertise to skip modules or snippets; and, the choice to do modules in any order. Additional changes involved: print (rather than handwriting); continuation of animation in delivery; and, no duration limits within modules/snippets.


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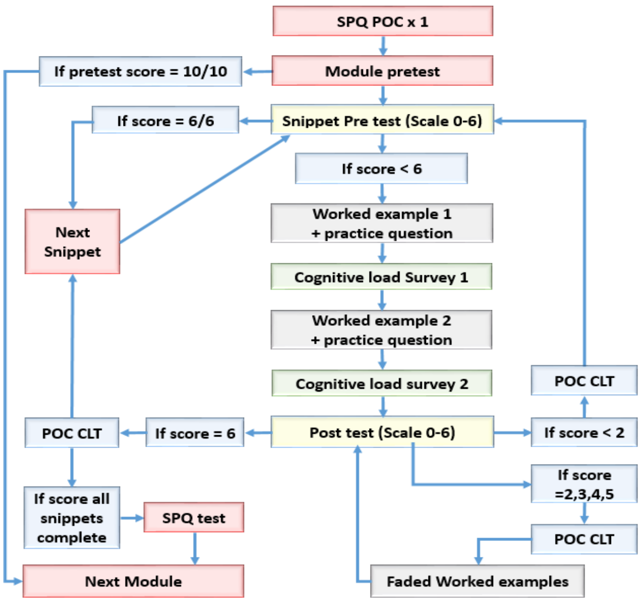


Figure 1. An outline of the common structure each module of the ngMOOC

## Results and Discussion

### *Collaboration around persistent problems of practice and multiple stakeholder perspectives*

Given the persistent problems related to undergraduate students struggling with introductory mathematics, the ngMOOC team acted in full awareness of the need for all stakeholders to have a say in how the project progressed, including via feedback at various stages of design, development and trialling. Multiple stakeholders in the university staff and student community were made aware of project goals and timelines and partner objectives localised to the needs of their own university environment (i.e., in undergraduate mathematics). As a result, the Phase 1 trial emerged from the collaborative workings of core group interactions with other stakeholders as recorded in meeting notes, journals and minutes. Phase 1 was conducted at a single university, for example, based on a collaborative team decision as a way of staying within the timeframe of the project goals. The team was able to draw on expertise from previous collaborations, and to coordinate a further focus on the persistent mathematics problem by using feedback from Phase 1 in the scaling up and refinement processes undertaken in Phase 2.

### *A commitment to iterative, collaborative design*

In the early design and development of trial modules, the team decided that an iterative design provided effective teaching and learning values of the *usable tool* through efficiency in use of resourcing on a limited budget. Coincidentally, the ngMOOC and module structures were also iterated internally for construction efficiency and to allow for incremental learning capability. Collecting evidence during and after process iteration is typical of the DBIR process, but in this case included the enhanced capability provided by feedback from the Phase 1 trials. Iterative design is not necessarily a good option for single use MOOCs, but in both Phases, designers and learners engaged in co-designed and co-created research-practice


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partnerships involving people in the design of their own learning, fully consistent with an application of DBIR in the MOOC context (Penuel et al., 2016). Within iterations, the collaborative partnerships drew on considerable in-kind support in terms of commitment to group meetings, review of processes and materials, and semi-structured interviews and surveys, allowing the budget to be directed to script writing and online production with a few dedicated staff. Module design was taken back to partners at workshops and focus groups to ensure that the modular process trialled in Phase 1 could be scaled up as the ngMOOC of Phase 2. This stakeholder feedback ensured also that the content of the online modules was fit for purpose and graduated for the incremental learning necessary for long-term memory gains (Hew, 2015).

### *A concern with developing theory and knowledge related to both learning and implementation through systematic inquiry*

The combination of theories in the ngMOOC required a systematic approach in order to first determine the effectiveness of the key cognitive load effects being implemented, primarily the worked example and modality effects, and then to include the point-of-contact feedback in combination with these and the problem completion effect. The project strategy, therefore, was to first trial five modules to ascertain how the well-studied worked example effect could inform module design in interactive online podcasts. Phase 1 trial analysis favoured the worked example effect, although there was insufficient data for a significant treatment effect to be proven (due to confounding of zero scores and post-test non-completions). Phase 2 was informed by the high dropout rates in Phase 1, characteristic of MOOCs, suggesting a larger student samples in Phase 2 trials. Greater content coverage was also indicated since Phase 1 subject results (and not the modules) were inconclusive in determining the effect of the five trial modules. Feedback from Phase 1 trials indicated also that system delivery needed to be fully automated and accessible through a widely accessible internet portal (as instituted in Phase 2) rather than an internal university OLS.

Both the SPQ and POC have been trialled previously at the study university and were shown to enhance the student experience while at the same time providing research data from students about learning approaches that had not previously been utilised by university teachers (Lake et al., 2017). In Phase 2 the SPQ was placed in the course introduction and at the end of each module. Although this was to provide comparative data to researchers as to whether the student motives (deep or surface) had altered during the module, students thus far have been reluctant to engage with the post-trial SPQ. Of those students who attempted the initial SPQ, surface learning processes predominated and these students did not feel that the modules were going to be of benefit for deep learning. Further data collection may give a clearer picture of how the SPQ and other POC is contributing to student learning processes.

### *A concern with developing capacity for sustaining change in systems*

Sustainable system change was not an obvious goal in initial planning or in Phase 1. This phase did, however, rely on team members who, as individual implementers, brought significant skills and expert knowledge to the project, in terms of discipline content, awareness


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of regional student education, professional expertise, mentoring ability and project management. In the BSM project, therefore, people worked together on common goals, building on a network of prior relationships, as well as drawing upon the elements of cohesion and mutual respect available from newer team members, as attributes of interdisciplinary teams. As a result, there were clear flows of communication and systematic and structured approaches that were mentored by experienced researcher who understood their own capabilities and those of their research partners. In the longer term, the Phase 2 project may influence system change through its novel approaches within a human cognitive architecture as well as through its initiation of sustainable feedback. This, in turn, will enable individuals and teams working in introductory university mathematics units to contribute to development of this new learning system, while at the same time increasing their own capabilities in online mathematics learning. In order for this to happen, each university may benefit from supporting collaborative involvement of both teachers and learners in sustainable system development.

## Conclusion

MOOCs continue to offer universities a way to provide educational outcomes that are based in learner needs while remaining within a prescribed curriculum. The ngMOOC development outlined here is a beginning for the adoption of a cognitive architecture in conjunction with feedback systems that offers the groundwork for use of adaptive systems that cater for learner expertise. DBIR offers a framework that seems especially useful in constructing and developing online learning that is self-paced and curriculum based.

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