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Mind the Gap: Exploring knowledge decay in online sequential mathematics courses

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Open access, digitally-enabled learning can provide freedom and choice for new learners − not only in how and what they study, but when. With this freedom comes risk. One potential risk lies in the timing of enrolment in courses, particularly where fundamental knowledge is built across a year and where extended gaps between sequential courses might cause knowledge decay. Mathematics may be susceptible here. Our concerns were allayed; an examination of data suggested that new students preferentially minimise gaps and found no significant evidence for knowledge decay over periods of up to 12 months. Nevertheless, to support student learning in open online learning environments, it could be important to provide resources for student self-assessment of knowledge deficiencies, and the facility to refresh and regain understanding.

Keywords: Online education, mathematics, knowledge decay, timing of courses

Introduction

More students are accessing online education, in part because of the flexibility that digitally-enabled courses allow (Mayadas, Bourne, & Bacsich, 2009). These students may be entering university studies without having had any academic experience, nor having met any academic benchmarks (Stone, 2012). Along with the ease of access to university study, there is risk; for example, students without study experience or adequate support may flounder and inefficiently use computers, materials and the online spaces available to them (Anderson, Lee, Simpson, & Stein, 2011; Marshall, 2014; Author 2 et al., 2012).

Another naivety posing a potential risk for learners is the sequence and number of courses taken at any one time. Traditionally, students are strongly encouraged to take certain courses in succession, constructing a linear learning path through a degree program. Given the flexibility in offerings of online courses, students may take a more oscillatory learning path, perhaps moving between levels of study, returning to earlier levels to refresh knowledge, building a more self-organised learning model (George Siemens, pers. comm. 2015).

The gap between sequential courses may be important. The Unified Learning Model, intended to reflect the principles of the mind's neural plasticity, supposes two memory states, with practical repetition required to transfer knowledge from short-term (working) memory to the better-retained long-term memory state (Chiriacescu, Soh, & Shell, 2013). The transfer depends on: the degree of repetition (within a number of time steps) of an idea, the motivation and emotional state of the learner, and the connectedness of the idea to already known ideas. An exponential forgetting curve (Chiriacescu et al., 2013) models decay of knowledge as a function of time and sparsity of connection, meaning that as the elapsed time since learning an idea increases, and as the number of connections between associated ideas decreases, chunks of knowledge are lost.

Knowledge decay has been studied extensively in high schools, where it is referred to as summer learning loss (Cooper, Valentine, Charlton, & Melson, 2003) and more recently in on-campus tertiary environments (Dills, Hernández-Julian, & Rotthoff, 2015). In this large, cross-discipline study, Dills and colleagues assessed knowledge decay between sequential courses, (e.g. Japanese 101 and Japanese 102) examining whether a 2 month or a 4 month gap between sequential courses had a detrimental impact on the final mark in the subsequent course. Overall, they found no evidence for knowledge decay with the longer gap, indeed they interpret their findings as evidence against the concept of summer learning loss. The exception to these findings was in language courses where a statistically significant detrimental effect was found for the longer gap.

Our study explores whether students exhibit wisdom in the design of their online study plans to minimise knowledge decay and support academic success. Any evidence would inform potential guidance to students
and input to policy regarding structured enrolment in sequential online courses.

Methodology

Data were available for two foundation level mathematics courses. These are sequential courses at the same year level with one (Course 1) as a prerequisite of the second (Course 2). Since 2012, Course 1 has been offered online 11 times and Course 2, 10 times. Course topics are dissimilar – the first course in the sequence presents basic algebra and trigonometry, the second introductory calculus - but Course 2 relies on a familiarity with the mathematical language and methods developed in Course 1. We define the gap as the time in between the teaching periods of the sequential courses. The timing of offerings and duration of teaching produces gaps which are integer multiples of 3 months. Thus a student taking the follow-on course immediately after its prerequisite ends, will experience a gap of 0 months, a student following on one study period later experiences a gap of 3 months. Rather than have a negative gap value, we denote the gap when students take both courses simultaneously as concurrent (abbreviated as cc).

Students who achieved a pass in the first course and had attempted the **second** (attempting at least one assessment) were identified. Students' final marks for Course 2 were mapped against their study gaps, with box and whisker graphs used to display the distribution of the data (Spitzer, Wildenhain, Rappsilber, & Tyers, 2014). Age and final mark in Course 2 were plotted as a series of scattergrams to represent the gaps between Course 1 and Course 2.

Results

The observed enrolment pattern amongst the 305 students comprising our data set is shown in Table 1. Most students took Course 2 at its next available delivery, more than 90% did so within 6 months.

Table 1: Proportion of students with observed study gap (cc represents concurrent enrolments)

Gap (months)	cc	0	3	6	9	12	Other
Proportion (%)	3.3	61.6	21.0	7.9	2.6	2.3	1.3

The whiskers in the boxplots of Figure 1 represent the highest and lowest marks for Course 2 for a given gap, the dark horizontal line is the median and a rectangle shows where the central 50% of data lie. We have added a cross to show the mean value and the number of data points in each category is shown at the base of the boxplot.

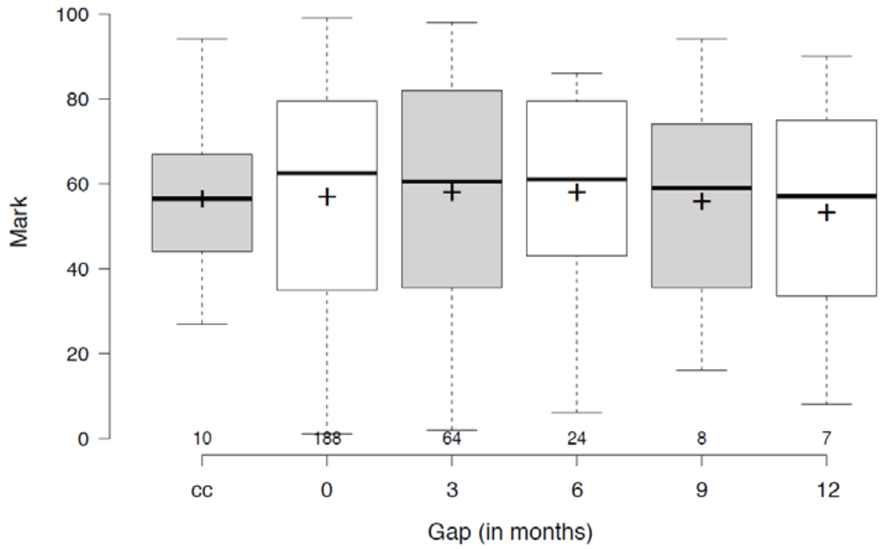

Figure 1: Course 2 marks against gap between Course 1 and Course 2.

Students selecting a gap of 0 months achieved the highest median mark. An independent-samples *t*-test was conducted to assess whether average marks obtained in Course 2 after a gap of 0 months or after a gap of 3 months are different. The two distributions are not statistically distinguishable, $t(111)= -.25$, $p = .807$. The median (and mean) mark in Course 2 appears to decline if the gap allowed is greater than 6 months. However a *t*-test to compare average mark obtained with a gap of 0 or 3 months, against marks obtained with a gap of 9 or more months, showed no significant difference in the distributions, $t(16) = .28$, $p =.393$. Our results suggest there is no discernible effect of knowledge decay for gaps of up to 12 months.

Age and Gap

In Figure 2, a series of graphs display student age on enrolment in Course 2 (horizontal axis) against final mark in Course 2 (vertical axis). The different graphs represent the gap (in units of 3 months) between starting Course 1 and Course 2. The apparent random scatter of dots indicates that students from any age group do not show a preference for gaps of a particular duration between Course 1 and Course 2, and that age does not seem to influence Course 2 mark.

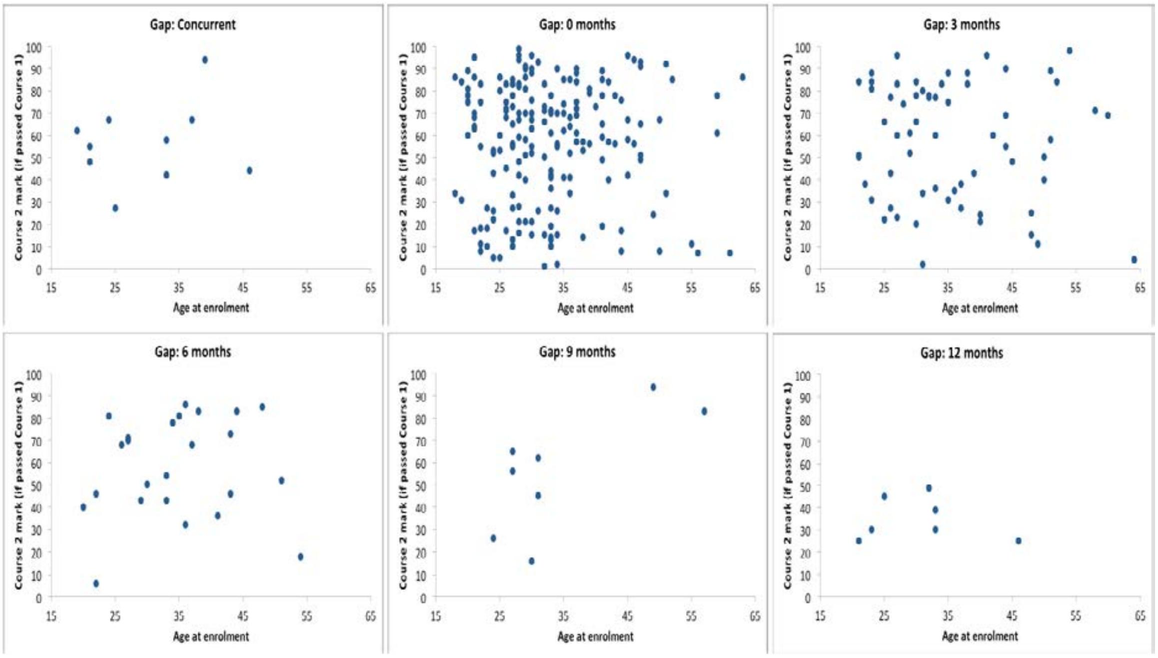

Figure 2: Relationships between Course 2 final mark, age and gap between Course 1 and Course 2.

Discussion

Knowledge decay has been an argument used to promote a change in high school calendars from 9 to 12 months (Cooper et al., 2003). Studies at tertiary level show evidence of knowledge decay in a few disciplines (Deslauriers & Wieman, 2011; Dills et al., 2015). In this study we explore whether knowledge decay plays a role in the success of online mathematics students of various ages who are free to determine their own gap between successive courses.

To focus on knowledge decay, rather than online learning capabilities, we limited our study to those students who had a successful online mathematics experience (defined as passing Course 1). We excluded from the data set a population of students who enrol and pay their fees but never log in to the course web site (here third parties often finance enrolment). Only those students who submitted an assessment were included in the analysis. In examining data from 3 years of deliveries of sequential foundational mathematics courses, we found no definite support for evidence of knowledge decay across gaps of up to 12 months. Many students selected minimal gaps in their pattern of enrolments; perhaps they do not require direct guidance on this issue.

Online students exhibit considerable age diversity but this apparently does not affect course outcome or the gap selected by students. However many of the online students report as being new to university study. Perhaps a detectable knowledge decay experienced across a sizeable gap is confounded with the effect of new students becoming more effective in their learning.

Variables known to impact on mathematical knowledge retention include learning approaches (De Smedt et al., 2010), teaching method (Deslauriers & Wieman, 2011), structure (Thiel, Peterman, & Brown, 2008) and emotion (Kim, Park, & Cozart, 2014). Digitally-enabled courses can support knowledge retention and regaining in ways that may not be easily available in traditional learning environments. For example, an extensive quiz can be used to identify deficiencies in students' current knowledge and direct students to modules where they can re-learn and review specific concepts. In this way students' brains may be able to quickly rebuild the neural connections despite the time between the original and new learning (Chiriacescu et al., 2013).
We speculated that the older students in our cohort might possess some academic wisdom concerning the potential effect of interrupted practice of their mathematics knowledge, and would therefore preferentially select shorter gaps between sequential courses. Such a pattern was not demonstrated in our data but neither was there a discernable impact on study success. It may be that online learners, being largely self-directed learners, recognise the potential effect of a considerable

gap and make use of resources provided to refresh their knowledge before resuming study. While knowledge decay is not evident amongst these students, the university should continue to develop resources so that students can self-assess their incoming knowledge and be directed to materials specifically chosen to suit the level and topics relevant to courses they will study.

Conclusion

A university has obligations to provide students with accurate and complete advice in order to help them achieve success in their studies. However online students assembling programs of study in reference to their perceived needs, are able to make wise choices about the length of time to allow between sequential courses. Knowledge decay seems less of an issue in tertiary environments and for online students compared to high school environments. Available self-assessment tools and resources to promote recall and revision are possibly important components of open online learning environments for supporting students in overcoming any knowledge decay that may occur between sequential courses.

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