Comparing spaced repetition algorithms for legal digital flashcards

Stephen Colbran
Central Queensland University, Australia

Wayne Jones
Central Queensland University, Australia

John Milburn
Central Queensland University, Australia

This study compares two digital flashcard spaced repetition algorithms to evaluate whether the SuperMemo 2 (SM2) algorithm produces better outcomes for law student learning as measured by assessment results than the older Leitner algorithm. Academic staff prepared hundreds of digital flashcards related to an undergraduate law unit – Introduction to law. Undergraduate law students (n=47) were randomly assigned flashcards using two variations of a software program *FlashCram*, one version of which used a simple Leitner algorithm, another version the SM2 algorithm for spaced repetition. Students completed three practical assignments, two worth 10%, one worth 20%. and a theoretical examination worth 60% of their final grade. The results confirmed SuperMemo 2 to be a superior algorithm over Leitner with respect to the theoretical examination. There was no significant difference between the algorithms for practical assessment that was skills based, not dependent on memory and not subject to any significant time pressure. The results suggest that the usefulness of spaced repetition digital flashcard systems for legal studies may depend upon the nature of the assessment task.

Introduction

This article follows a series of articles exploring the use of digital flashcards in the context of legal education (Colbran, Gilding, Oyson, Nauman, 2017; Colbran, Gilding, Marinac, Saeed, 2015; Colbran, Gilding, Colbran, 2014).

Colbran et al (2015) explored digital flashcards as a method to teach contract law. The empirical design involved three randomly selected cohorts. Two experimental groups were provided with digital flashcards and printed flashcards, respectively. The control group was not provided with flashcards. Participants were surveyed and an interview was conducted with the academic coordinator. Undergraduate law students responded positively to the use of flashcards, although the use of the flashcards made no statistically significant change in their assessment results. The 2015 research did not involve any spaced repetition system merely the absence or provision of printed or digital flashcards. There was also an absence of scaffolding. The flashcards were not integrated into the study notes nor were students given any instruction on how the cards could be used to assist with memory retention

Colbran et al (2017) considered the impact of student generated digital flashcards on student learning of constitutional law. It was anticipated that a 'learning by doing' approach (students creating their own flashcards), opportunities for collaboration (students sharing flashcards) combined with an authentic task would improve outcomes from the use of flashcards. The assessment task was one undertaken over several weeks without any need for content to be memorized. It was clear that students did not value the exercise. Students did not find their creation of flashcards assisted them with examination preparation. They found the production of flashcards to be a challenging exercise and expressed a preference for problem-based assessment rather than creating flashcards.

The above research suggests that the full potential of flashcards identified by Colbran (2014) was not being realized by law students. Several clues to this issue were evident in former studies: the usefulness of flashcards may relate to the form of assessment (assignment or skills-based versus examinations), the extent of memorization of content associated with assessment tasks, time pressure, the level of scaffolding provided, and the use of spaced repetition systems. This article sought to examine all these issues in the context of legal education.

There are several commercially and publicly available sources of flashcards for legal education; for instance, on the website www.flashcardexchange.com and *Law in a Flash* distributed by Aspen Publishing, which have now been developed into mobile phone applications. The flashcards developed in these sources are, however, generally electronic versions of old-fashioned typed or handwritten cardboard flashcards. They have not taken advantage of multimedia elements within the construction of the flashcards or spaced repetition algorithms to

assist with memory retention.

This research used a web-based product, named *FlashCram* (Colbran, 2017) to enable the development and distribution of many new types of digital flashcards for legal education. Digital flashcards extend the design of a physical two-sided printed card to incorporate further dimensions (such as hints or prompts), hyperlinks, digital media (audio and visual), data analytics and interactive exercises.

In other disciplines, the use of flashcards is more widespread and the concept of an "electronic flashcard" as a node of information, linked in flexible and creative ways into wider networks of information, has become more prevalent. Examples include diverse fields such as language studies (Dogidovic, 2013; Albers and Hoffman, 2012; Altiner, 2011; Basoglu and Akdemir, 2010), organic chemistry (Pursell, 2013), psychology (Golding, Wasarhaley & Fletcher, 2012) and air traffic controlling (Qinetiq North America, 2012).

Spaced Repetition

Many studies have concluded that spacing tests of memory recall produces superior memory retention (Carpenter et al, 2012; Delaney et al, 2010; Cepeda, 2006). Spaced repetition, a term coined by Woźniak (1990), is a memory technique which may be used with flashcards to overcome the forgetting curve identified by Ebbinghaus (1885) – figure 1. The forgetting curve suggests that memory recall falls exponentially to around 28% after two days of encoding the memory.

This phenomenon has significant implications for education in the form of or based on the retention of knowledge. For example, in legal education, it is difficult to learn the subject civil procedure, if there is no knowledge of causes of action based on retained prior knowledge of contracts or torts.

While it is clear that testing improves memory compared with study alone (Roediger & Karpickle, 2006; Larsen, Butler & Roediger, 2013), there is a common myth that cramming (short repetition spacing) is more effective than long repetition spacing (Zechmesiter & Shaughnessy, 1980) for memory retention. The generality of the spacing effect however is not consistent across domains. Cepeda (et al, 2006, p. 355) notes:

> Moss (1996) reviewed 120 articles… conclude[ing] that longer ISIs facilitate learning of verbal information (e.g., spelling) and motor skills (e.g., mirror tracing); in each case, over 80% of studies showed a distributed practice benefit. In contrast, only one third of intellectual skill (e.g., math computation) studies showed a benefit from distributed practice, and half showed no effect from distributed practice.

Just as there are inconsistent effects of spaced repetition in some domains such as motor skills (Wulf & Shea, 2002) it is possible that spaced repetition systems will only be useful where memory retention rather than temporary acquisition is the desired learning goal. For example, law assessments based on application of skills to derive an outcome over an extended period of time have less need for memory retention, compared with theory examinations under time pressure, where application of memory to problems is of critical importance. Our current study is unique in that it examines the impact of two spaced repetition systems across skills based and memory-based assessments.

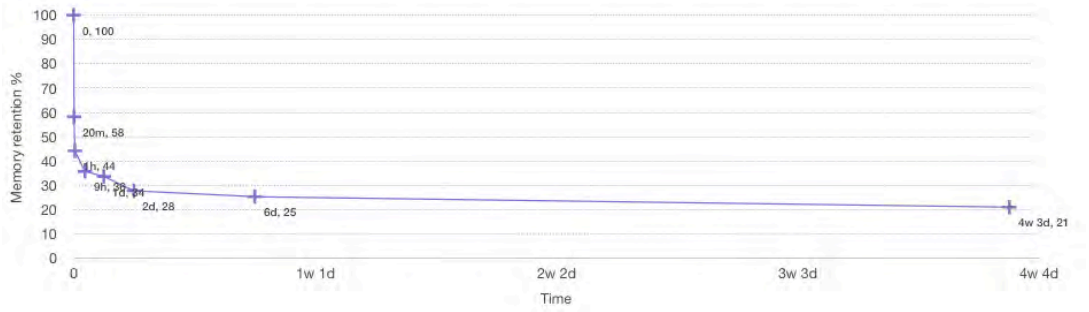

Figure 1: Ebbinghaus forgetting curve 1885

Spaced repetition affords the opportunity to retain memory by overcoming the impact of Ebbinghaus's forgetting curve - see figure 2. In essence, tentative memory in the form of neuron pathways associated with new memories are reinforced through repetition. Repeated retrieval appears to be the key to long-term retention of information (Karpicke, Roediger, 2007). A useful summary of the literature has been prepared by Gwern (2018). Regression analysis is a common methodology used in examining the effects of spaced repetition, e.g.

(Rohrer, Taylor, 2006; Seabrook et al, 2005), as is the use of ANOVAS, e.g. (Maass et al, 2015; McDaniel et al, 2013).

Apart from naming spaced repetition, Woźniak's major contribution was to study and systematize the optimum interval for spaced repetition in a series of SuperMemo algorithms implemented on paper and ultimately by computer. The history of his achievement can be found at https://www.supermemo.com/en/articles/history including the detailed description of the SuperMemo2 algorithm used in our research. The great advantage of spaced repetition systems is the ability to recall in excess of 90% of encoded information from permanent memory.

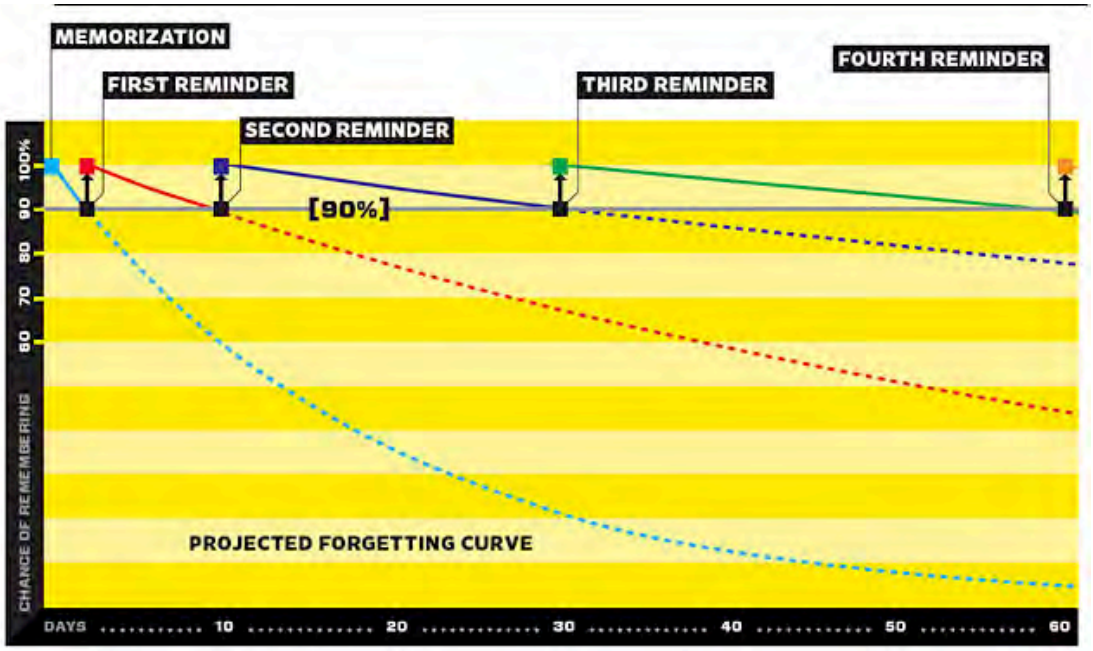

Figure 2: Projected forgetting curve
Source: http://www.gwern.net/Spaced-repetition <accessed 30 April 2018>

Our research involves exposing experimental groups with two spaced repetition algorithms: The Leitner box system and the SuperMemo 2 algorithm. The Leitner system developed by Sebastian Leitner in 1972 is a simple design to enhance memory retention. In the Leitner system, flashcards are grouped into packs of increased levels of memory retention - or current levels of knowledge. Correct answers progress a flashcard to a higher-level pack, incorrect answers revert a flashcard to the lowest level pack. Common Leitner systems have five levels of flashcard packs. The version of the Leitner box system used in this research does include fixed static intervals. Lower level packs are reviewed more often than higher level packs, e.g. pack 1 - 1-day review cycle; pack 2 - 3 days; pack 3 - 7 days; pack 4 - 15 days; pack 5 - 20 days. As the information is committed to memory and user responses to questions are accurate all flashcards move to the 5th level. The Flashcram software encoded the intervals into a bring up system based on the cycle review outlined above. Woźniak (2018) argues the original Lietner box system is a prioritization tool rather than a spaced repetition tool. Woźniak (2018) however acknowledges that 'When the Leitner box is used regularly on a small-sized collection of flashcards, it simulates the behaviour of spaced repetition.' That is the exact approach used in our study.

Progression to higher levels of memory retention reduces the inefficiency of frequently repeating information already memorized. The order of flashcards and the spacing of their display is designed to optimise memory retention by focussing attention on flashcards in which the user responses contain errors or misunderstandings. Groupings may be based on automated marking of cards – e.g. based on multi-choice or pre-set answers - or may be set by the user as they review their response to a card. A user may perceive a particular concept or task as difficult requiring more repetition to be understood and memorized. Hence the flashcard should be placed in pack 1 on a more frequent repetition cycle.

Leitner systems, while widely used and traditionally print based, have in recent times been recreated in a digital flashcard environment. Users may specify the number of flashcard boxes and also the sequencing of the spaced repetition. More complex algorithms may be implemented, that adjust to determine the optimum rate of repetition for each individual learner's memory retention.

The SuperMemo (SM2) algorithm is said to be a more advanced spaced repetition system developed by Piotr Woźniak from 1985 onwards. This system optimizes expanding spacings rather than fixed intervals associated with the version of Leitner used in this research. The SM2 algorithm is defined at http://www.supermemo.com/english/ol/sm2.htm. SM2 algorithm separated items previously grouped in pages and introduced E-Factors – an easiness factor reflecting the easiness of memorizing and retaining a given item in memory. The E-Factor was initially set at 2.5 and decreased with errors in memory recall. E-Factors could fall to 1.3 before recalculation. The quality of the repetition response was graded from 0-complete blackout to 5, a perfect response. Repetitions are continued until all items score at least 4 (correct response after hesitation). The SuperMemo system seeks to apply optimization procedures to smaller items of memory and also differentiates items based on their user's perceived difficulty. Woźniak reports long term information retention rates of 92%.

From the perspective of a law student, they would view flashcards presented in the order determined by the spaced repetition system they were allocated. Students sitting side by side, each using a different algorithm, would be aware of the method by which flashcards were presented. Leitner presents a correct or incorrect solution, whereas SM2 presents six choices: 5 - perfect response, 4 - correct response after a hesitation, 3 - correct response recalled with serious difficulty, 2 - incorrect response; where the correct one seemed easy to recall, 1 - incorrect response; the correct one remembered, 0 - complete blackout. In both cases the algorithms adjust to the individual's memory performance.

Hypothesis

In this study our research hypothesis is that the SuperMemo 2 (SM2) algorithm will produce better outcomes for law student learning as measured by assessment results than the older Leitner system. The null hypothesis is that there is no significant difference between the two-spaced repetition system and that any observed difference is due to sampling or statistical error. It is anticipated that this effect will be more pronounced where memory retention is an important feature of an assessment task, such as a theoretical examination under time constraint in comparison to practical skill-based exercises without any significant time pressure.

Methodology

A set of 443 digital flashcards (See Figure 3) were created for LAWS11057 Introduction to Law and distributed electronically to 47 students in Term 3, 2015. The cohort consisted of 29 female (61.7%) and 18 male (38.3%) mature age students. Ethics approval was H15/11-260. The age profile of students in quartiles is shown in Table 1.

Table 1
Age profile of students

Range	Frequency	Percentage
16-24	12	25.5%
25-27	12	25.5%
28-33	11	23.4%
33-55	12	25.5%

LAWS11057 Introduction to Law is a first-year core unit included in an accredited undergraduate law degree leading to admission to the Australian legal profession. Both female and male students were separately randomly allocated into two groups. One group were given access to the Leitner spaced repetition system, the other group were given access to the SM2 spaced repetition system. There were two independent categorical nominal variables – Type of spaced repetition system and Gender (female vs male). The third independent variable was age in years.

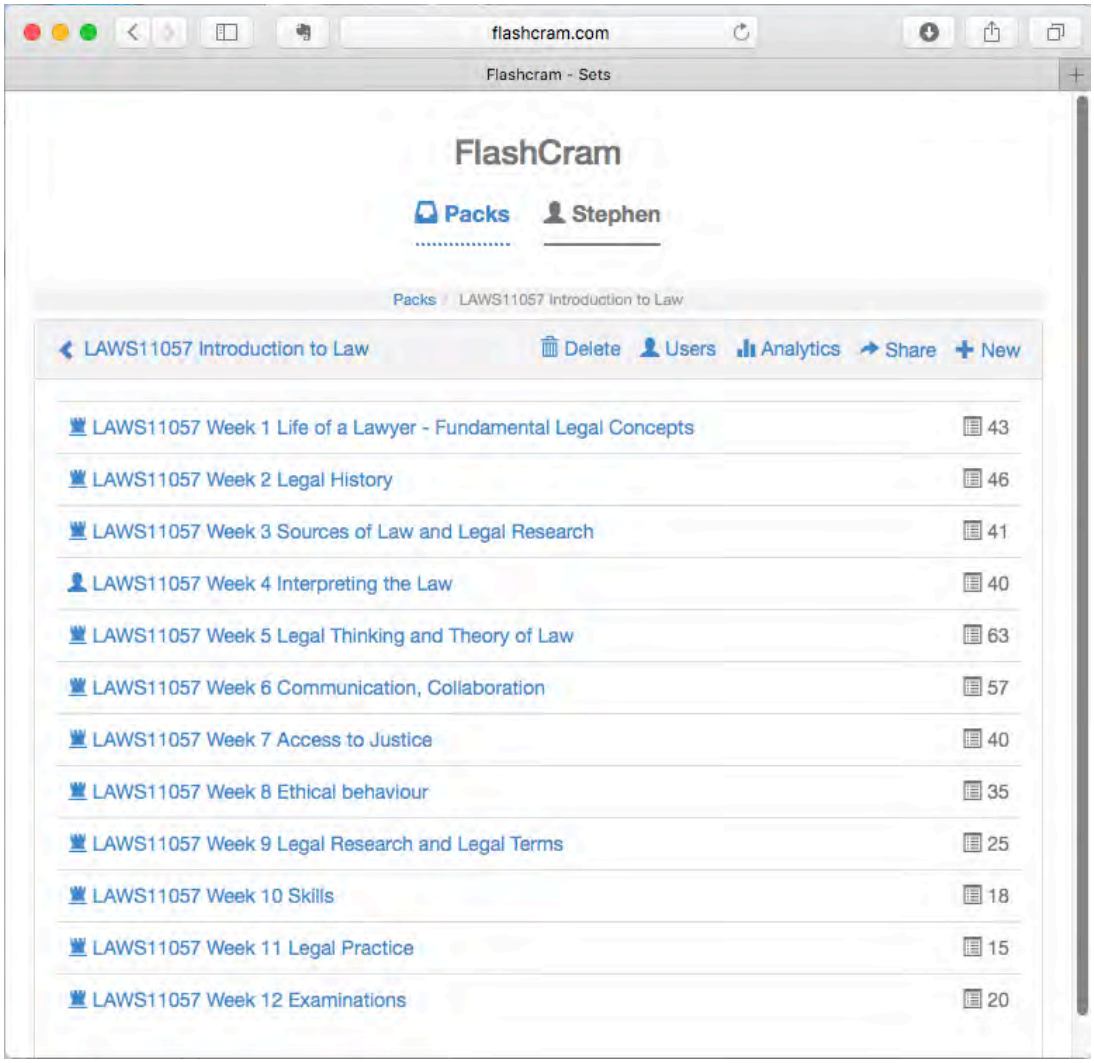

Figure 3: Topics and distribution of digital flashcards

The dependent variables were the four separate assessment items and total grade:

1. Assessment 1 (10.12.2015) 10% An exercise which required students to read one or more court cases supplied by the lecturer and then undertake some basic research to locate and read related material including the Australian Solicitors Conduct Rules and the university's policies and procedures on plagiarism. Students were then required to answer questions about the case(s) and the related materials in order to demonstrate understanding; at the same time commenting on the rationale for the court decision(s) and for the rules and procedures around plagiarism.
2. Assessment 2 (07.01.2016) 10% This exercise required students to locate a new piece of legislation meeting the description given and then answer a series of questions about the new law in order to demonstrate comprehension and an understanding of the process of law making within Australia. This exercise helped students begin to navigate around legislation sites online and forms the basis for subsequent work on statutory interpretation in Australia. Students were expected to research ancillary material including second reading speeches and explanatory memoranda to discover the purpose of the new legislation.
3. Assessment 3 (04.02.2016) 20% The third assessment task was a practical task. Students were asked to prepare a written document and also record and upload an audio-visual session that involved demonstrating legal research and referencing skills. They were required to prepare a short-written statement of up to 400 words explaining their process and the content of their video presentation. Grading focused on their technical work and communication skills.
4. Examination (15.02.2016) 60% - two-hour problem-based open book examination covering the entire unit content.
5. Unit total grade (100%) consisting of the addition of grades for all assessment items.

Results and discussion

A total of 47 students participated in the study (29 females and 18 males). The Leitner system was used by 19 students (11 females, 8 males). The SM2 system was used by 28 students (18 females, 10 males).

Pearson correlation coefficients were calculated for the variables. Type of spaced repetition system was significantly positively correlated with the final exam $r(45) = .337$, $p = .021$ and unit total $r(45) = .289$, $p = .049$. The SM2 algorithm was associated with better outcomes on the final exam and unit total than the Leitner system.

Gender was significantly negatively correlated with the final exam $r(45) = -.414$, $p = .004$ and unit total $r(45) = -.388$, $p = .007$. Males were associated with worse outcomes on both the final exam and unit total compared with females.

Assignment 1 was significantly positively correlated with assignment 2 $r(45) = .493$, $p = .000$, assignment 3 $r(45) = .671$, $p = .000$, the final exam $r(45) = .633$, $p = .000$ and unit total $r(45) = .713$, $p = .000$. People who did well on assignment 1 tended to do well on later assessment and overall unit result. The same was evident for assignments 2 and 3. Assignment 2 was significantly positively correlated with assignment 1 $r(45) = .493$, $p = .000$, assignment 3 $r(45) = .631$, $p = .000$, the final exam $r(45) = .509$, $p = .000$ and unit total $r(45) = .624$, $p = .000$. Assignment 3 was significantly positively correlated with assignment 1 $r(45) = .671$, $p = .000$, assignment 2 $r(45) = .631$, $p = .000$, the final exam $r(45) = .803$, $p = .000$ and unit total $r(45) = .896$, $p = .000$.

Exam results were positively correlated with type of spaced repetition system $r(45) = .337$, $p = .021$, assignment 1 $r(45) = .633$, $p = .000$, assignment 2 $r(45) = .509$, $p = .000$, assignment 3 $r(45) = .803$, $p = .000$ and unit total $r(45) = .979$, $p = .000$, but were negatively correlated with gender $r(45) = -.388$, $p = .007$. Final unit correlations were similar. Final unit results were positively correlated with type of spaced repetition system $r(45) = .289$, $p = .049$, assignment 1 $r(45) = .713$, $p = .000$, assignment 2 $r(45) = .624$, $p = .000$, assignment 3 $r(45) = .896$, $p = .000$ and final exam $r(45) = .979$, $p = .000$, but were negatively correlated with gender $r(45) = -.388$, $p = .007$.

The box plot of Exam by Type (see Figure 4) and an ANOVA (Sig = .021) (see Table 2) confirmed superior results for the SM2 algorithm (x = 38.11) over the Leitner algorithm (x = 28.0). The difference was 10.11% on average for the final examination.

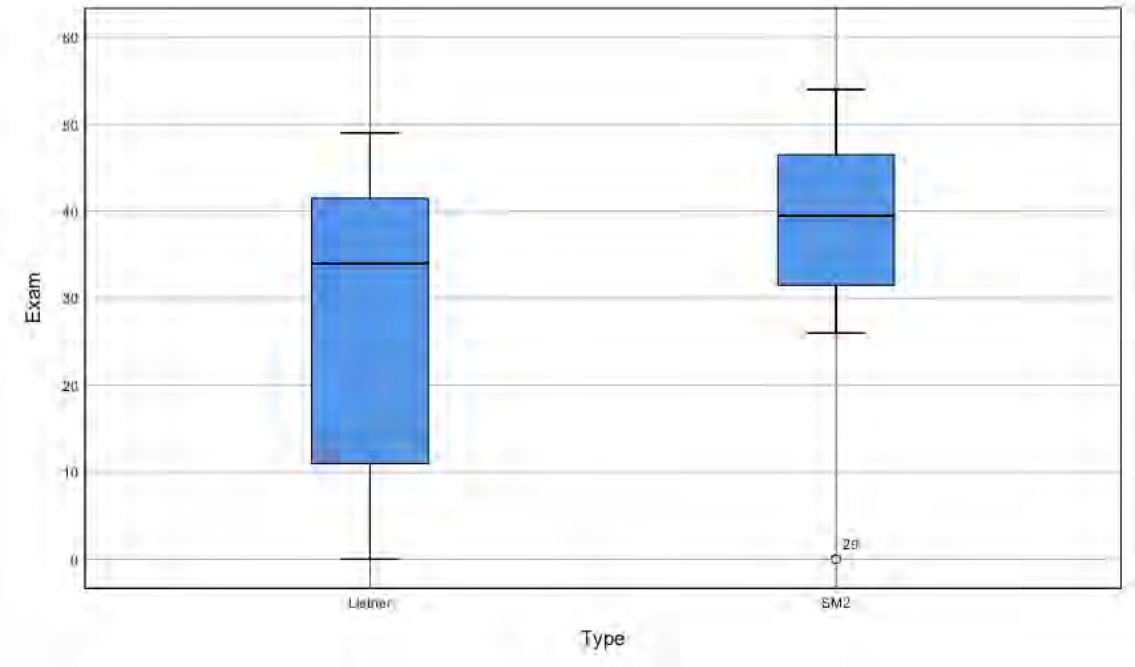

Figure 4: Exam and Type of Spaced Repetition Box plot

Table 2
Assessment and Type of Spaced Repetition ANOVA

		Sum of Squares	df	Mean Square	F	Sig.
Assignment 1	Between Groups	4.979	1	4.979	2.354	.132
	Within Groups	95.159	45	2.115		
	Total	100.138	46			
Assignment 2	Between Groups	7.677	1	7.677	2.412	.127
	Within Groups	143.238	45	3.183		
	Total	150.915	46			
Assignment 3	Between Groups	69.734	1	69.734	3.317	.075
	Within Groups	946.138	45	21.025		
	Total	1015.872	46			
Exam	Between Groups	1749.230	1	1749.230	9.302	.004
	Within Groups	8461.746	45	188.039		
	Total	10210.979	46			
Unit total	Between Groups	3044.461	1	3044.461	7.969	.007
	Within Groups	17192.018	45	382.045		
	Total	20236.479	46			

These results partially confirm the research hypothesis is that the SuperMemo 2 (SM2) algorithm will produce better outcomes for law student learning as measured by assessment results than the older Leitner system. This was only in relation to the final examination and unit total. Unit total being 60% comprised of the final examination results.

There were significant age effects as shown in the Assessment by Age ANOVA – see Table 3 - for all items of assessment apart from assignment 2. Participants in the age range 22-25 achieved relatively poor results on all assessments.

Table 3
Assessment and Age ANOVA

		Sum of Squares	df	Mean Square	F	Sig.
Assignment 1	Between Groups	72.701	22	3.305	2.891	.006
	Within Groups	27.438	24	1.143		
	Total	100.138	46			
Assignment 2	Between Groups	88.227	22	4.010	1.535	.154
	Within Groups	62.688	24	2.612		
	Total	150.915	46			
Assignment 3	Between Groups	788.122	22	35.824	3.775	.001
	Within Groups	227.750	24	9.490		
	Total	1015.872	46			
Exam	Between Groups	6921.312	22	314.605	2.295	.025
	Within Groups	3289.667	24	137.069		
	Total	10210.979	46			
Unit total	Between Groups	14704.645	22	668.393	2.900	.006
	Within Groups	5531.833	24	230.493		
	Total	20236.479	46			

The box plot of Exam by Gender (see Figure 5) plus an ANOVA $F(1, 45) = 9.3$, $p = .004$ (see Table 4) confirmed superior results for females (x = 38.83) over males (x = 26.28) in the exam. The difference was 12.55% on average. There was no significant difference on assignments 1, 2 and 3 between genders.

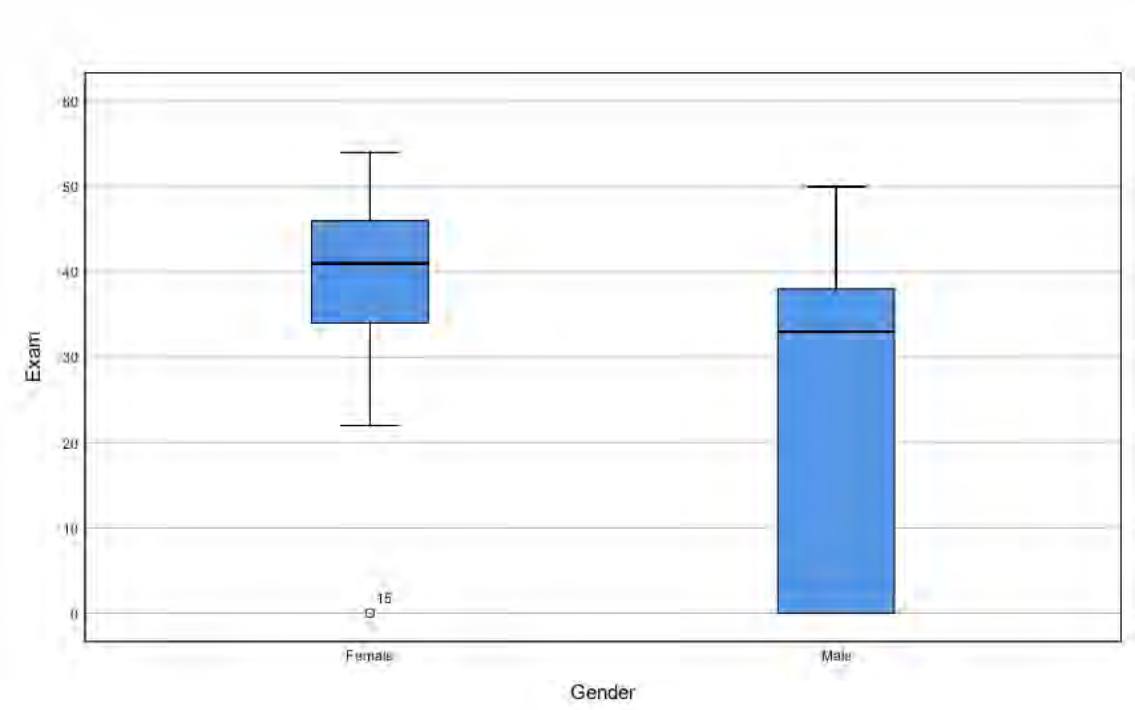

Figure 5: Exam and Gender Box Plot

Table 4
Assessment and Gender ANOVA

		Sum of Squares	df	Mean Square	F	Sig.
Assignment 1	Between Groups	4.979	1	4.979	2.354	.132
	Within Groups	95.159	45	2.115		
	Total	100.138	46			
Assignment 2	Between Groups	7.677	1	7.677	2.412	.127
	Within Groups	143.238	45	3.183		
	Total	150.915	46			
Assignment 3	Between Groups	69.734	1	69.734	3.317	.075
	Within Groups	946.138	45	21.025		
	Total	1015.872	46			
Exam	Between Groups	1749.230	1	1749.230	9.302	.004
	Within Groups	8461.749	45	188.039		
	Total	10210.979	46			
Unit total	Between Groups	3044.461	1	3044.461	7.969	.007
	Within Groups	17192.018	45	382.045		
	Total	20236.479	46			

Another way to consider the data is via linear regression – see Table 5. The previous results are confirmed.

Table 5
Table of regression coefficients

Variables	B	*t*	*p*	Beta	*F*	*df*	*p*	*adj.* R^2
Assignment 1					1.785	3, 43	.164	.049
Gender	-.662	-1.524	.135	-.221				
Age	.022	.824	.414	.119				
Type	.628	1.464	.151	.211				
Assignment 2					1.206	3, 43	.319	.013
Gender	-.866	-1.593	.118	-.235				

Age	.033	.992	.327	.146				
Type	.247	.461	.647	.068				
Assignment 3					1.263	3, 43	.299	.017
Gender	-2.399	-1.704	.096	-.251				
Age	-.028	-.326	.746	-.048				
Type	.975	.701	.487	.103				
Examination					8.008	4, 42	.000	.379
Gender	-9.342	-2.558	.014*	-9.342				
Age	.085	.386	.701	.085				
Type	8.354	2.379	.022*	8.354				
Unit total					4.225	3, 43	.011*	.174
Gender	-16.181	-2.809	.007*	-.379				
Age	.222	.631	.531	.085				
Type	11.035	1.941	.059	.261				

Note.*p < .05

Conclusion

The null hypothesis that there was no significant difference between the two spaced repetition flashcard algorithms was confirmed, except in relation to the examination and overall unit results.

The research hypothesis that the SuperMemo (SM2) algorithm will produce better outcomes for student learning as measured by assessment results than the older Leitner system was confirmed in relation to the examination and overall unit results. The overall unit results were highly influenced by the final examination which constituted 60% of the overall grade.

The three earlier forms of assignment undertaken by students were practical skill-based tasks which relied less on retained memory than the final exam. It appears that memory enhancement techniques such as spaced repetition digital flashcard systems are more useful for examination scenarios requiring memory recall rather than assessments not subject to the same short time constraints and which are of a practical applied nature. It may be that spaced repetition flashcards systems assist in retaining what has been learned, rather than helping students learn the materials in the first place (Branwen, 2018). Hence flashcards can be more appropriately positioned and used in the law curriculum to ensure basic knowledge is remembered. This would be particularly important in early core units in a program of study where students need to acquire a basic stock of discipline knowledge. As part of initial teaching pedagogy students should be shown the benefits of using flashcards and how this relates to their current and future studies of law. As pointed out by Cepeda (2006, p 370) 'A primary goal of almost all education is to teach material so that it will be remembered for an extended period of time, on the order of at least months and, more often, years.' It is after all difficult to apply higher order legal analysis skills where students do not remember basic knowledge or remember basic research skills and procedures enabling them to locate such knowledge. Using spaced repetition with flashcards is a more viable option than spaced repetition through repeated assessment, which is expensive in terms of time and effort and unlikely to be implemented in a modern curriculum. Dempster (1989, p. 326) correctly notes that 'Spaced reviews and tests are underutilized in the classroom in terms of their potential for improving learning. That potential appears to be vast, although it is unlikely to be realized until those familiar with the research on spaced repetitions are willing to relate it explicitly to educational issues.'

Carpenter (2012, p. 5) again notes that 'spacing has yet to be systematically implemented in educational curricula' and this may be due to the research having 'not produced a clear set of recommendations for how it can be used in everyday instruction.' … '[I]n order to promote long-term retention of knowledge, students should receive spaced re-exposure to previously-learned information.' While this often does occur through review of concepts in subsequent instruction, tutorial problems, exams and quizzes it can also occur using flashcards combined with a spaced repetition system. This latter approach may in fact be more efficient for long term memory formation in a crowed curriculum, with textbooks wedded to a linear not spiral approach to education.

It is significant that a 10.11% improvement in examination results is apparent when the SM2 algorithm rather than the Leitner algorithm is used. This can represent a whole grade level for students, which is important for honours and competitive employment opportunities in the legal profession. The literature on spaced repetition would also suggest that such memories will be retained for the long term. In disciplines where basic retention of

knowledge is important, such as in law the SM2 algorithm has much to offer.

There are obvious limitations associated with this research. Spaced repetition flashcard systems may have different effects associated with different types of assessment. In considering intellectual skills, it may be important to distinguish between tasks involving practical skills compared with theoretical examinations, whether the examination is open or closed book, students at different stages of their law degree, as well as the influence of time pressure. Similarly, future research can compare more recent versions of SuperMemo which include more advanced algorithms, and include a control group of participants with or without digital flashcards, but no spaced repetition system. Future research could also use more sophisticated regression-based analysis to explore whether the SuperMemo 2 algorithm can predict performance in specific forms of assessment. Finally, the research could be extended to determining whether the positive effect of spaced repetition flashcard systems on examination outcomes also extends to improved performance after different retention periods. In other words, will second and third year students remember the content from their first-year introduction to law unit? And if so over what period of time?

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