Spaced education improves the retention of clinical knowledge by medical students: a randomised controlled trial

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PURPOSE Medical knowledge learned by trainees is often quickly forgotten. How can the educational process be tailored to shift learning into longer-term memory? We investigated whether 'spaced education', consisting of weekly e-mailed case scenarios and clinical questions, could improve the retention of students' learning.

METHODS During the 2004–5 surgery clerkships, 3rd-year students completed a mandatory 1-week clinical rotation in urology and validated web-based teaching programme on 4 core urology topics. Spaced educational e-mails were constructed on all 4 topics based on a validated urology curriculum. Each consisted of a short clinically relevant question or clinical case scenario in multiple-choice question format, followed by the answer, teaching point summary and explanations of the answers. Students were randomised to receive weekly e-mailed case scenarios in only 2 of the 4 urology topics upon completion of their urology rotation. Students completed a validated 28-item test (Cronbach's $\alpha = 0.76$) on all 4 topics prior to and after the rotation and at the end of the academic year.

RESULTS A total of 95 of 133 students (71%) completed the end-of-year test. There were no significant differences in baseline characteristics between randomised cohorts. Spaced education significantly improved composite end-of-year test scores ($P < 0.001$, paired t-test). The impact of the spaced educational e-mails was largest for those students who completed their urology education 6–8 and 9–11 months previously (Cohen's effect sizes of 1.01 and 0.73, respectively).

CONCLUSION Spaced education consisting of clinical scenarios and questions distributed weekly via e-mail can significantly improve students' retention of medical knowledge.

KEYWORDS randomised controlled trial (publication type); surgery/*education; clinical clerkship/*methods; *memory; *learning; teaching/methods; urology/*education; electronic mail; cohort studies.

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INTRODUCTION

Medical knowledge learned by trainees is often quickly forgotten. This is not unexpected, as forgetting is a natural psychological phenomenon. As early as work by Ebbinghaus, published in 1885, forgetting curves (plots of memory retention over time) have been established for different types of memories, ranging from pictures of faces to names learned at a cocktail party. Ebbinghaus learned sequences of nonsense letter combinations, only to find that he repeatedly forgot more than 40% in under 5 minutes.[1,2] Memory of medical knowledge and skills is prey to these same processes of forgetting. For example, a study of retention of cardiopulmonary resuscitation (CPR) skills demonstrated a rapid, linear and substantial decay in skill in the year following training. In fact, only 2.4% of those trained 3 years earlier could perform CPR successfully.[3]

Overview

What is already known on this subject

Medical knowledge learned by trainees is often quickly forgotten. While a great deal of psychological research has investigated memory and its optimisation, little work has been conducted to implement these research findings within the pedagogy of formal medical education.

What this study adds

Utilising rigorous research methodology, this study demonstrates that spaced education consisting of clinical scenarios and questions distributed weekly via e-mail to students can significantly improve their retention of medical knowledge.

Suggestions for further research

Future investigation is indicated to determine whether the principles of spaced education can be applied online to facilitate the initial acquisition of medical knowledge, not just improve its retention.

One primary goal of medical education, and education in general, is to generate long-term learning, not just memories which decay quickly after a given lecture, conference or test. This raises the important question as to how the educational process itself might be tailored to shift learning into longer-term memory. 'Spaced education' refers to educational programmes which are constructed to take advantage of the pedagogical merits of the 'spacing effect'. Elucidated via psychological research in the 1970s and 1980s, the 'spacing effect' refers to the finding that educational encounters which are spaced and repeated over time (spaced distribution) result in more efficient learning and improved learning retention, compared to massed distribution of the educational encounters (bolus education).[4,5] While much of the research on the 'spacing effect' has focused on short- and medium-term retention on the order of hours to days, some evidence suggests that it can also generate significant improvements in longer-term retention.[6]

The problem of knowledge retention was highlighted in our recent results from a randomised controlled trial of adjuvant web-based teaching performed at 4 medical schools in the north-eastern United States.[7] Compared to controls, web-based teaching significantly increased test scores in 4 clinical topic areas at each medical school. While significant knowledge improvements persisted a median 4.8 months after completion of the web-based intervention, a substantial decline in knowledge was observed over this time period. Extrapolating this trend forward, it appeared that there would be little-to-no residual educational benefit from the web-based programme 12 months after the intervention. This disturbing finding raised the important question as to whether the educational process itself might be altered to improve the retention of knowledge by the students.

Using urology as an experimental model, we investigated whether spaced education, consisting of weekly e-mailed clinical scenarios and questions, could improve the retention of students' learning from their 1-week clinical urology rotation.

METHODS

Study participants

All 156 3rd-year medical students in the 2004–5 academic year at Harvard Medical School (HMS) were invited to participate in the study. Students were recruited via e-mail announcement and an oral presentation by a faculty member (BPK). Participation was voluntary. There were no exclusion criteria. Faculty was blinded to the identities of participating students. Institutional review board approval was obtained.

Development of validated test instrument

Based on a validated urology curriculum focusing on 4 core topics in urology [prostate cancer (PC), screening with prostate-specific antigen (PSA), benign prostatic hyperplasia (BPH) and erectile dysfunction (ED)], a 28-item multiple-choice test was developed utilising the question development guidelines of the National Board of Medical Examiners.[8] Content validity of the test was established by a panel of 4 medical educators, 2 urologists (WCD, PAC) and 2 medical physicians (BAM, DDF). Construct validity was established by administration of the test to 19 urology experts.[9] Reliability of the instrument was measured by Cronbach's alpha at. 0.76,[10] and its

1-week test–retest reliability was 0.72. The identical 28-item test was used as the pre-test, the post-test and the end-of-year test in this study. In all cases, it was administered online via the HMS Mycourses™ web-based course management system. The details of the development and validation of this test instrument have been published previously.[9]

Development of validated spaced educational e-mails

Based on the validated urology curriculum, 11–13 spaced educational e-mails were constructed for each of the 4 core topics. Each consisted of a short clinically relevant question or clinical case scenario in multiple-choice question format, followed by the answer to the question, a summary of the teaching point ('take-home message'), explanations of the answers and a listing of the 'take-home message' from the previous week (Appendix 1). Each e-mail was content-validated by the panel of 4 medical educators.

Study design and organisation

During their 3-month surgery clerkship, all 3rd-year HMS students are required to complete a 1-week clinical rotation in urology and a validated web-based teaching programme on the 4 core urology topics. Both prior to and after the week, students complete the 28-item test on all 4 topics. Each week during the year, approximately 2–4 HMS students completed this urology rotation.

Randomisation and cohort assignment of eligible students were performed centrally by 1 investigator (BPK). Students were stratified by gender, hospital and date of surgery clerkship and underwent blocked randomisation[11] to 1 of 2 study arms (Fig. 1):

- Cohort A (PC/PSA) – upon completion of their urology rotation, students were sent a spaced educational e-mail each week on the topics of PSA screening and PC.
- Cohort B (BPH/ED) – upon completion of their urology rotation, students were sent a spaced educational e-mail each week on the topics of BPH and ED.

Faculties at all institutions were not informed of the students' cohort assignment. In each cohort, the 2 topics of the spaced educational e-mails alternated each week, and the bottom of each e-mail contained the 'take-home message' of the prior week. The sets of 11–13 spaced education e-mails for each topic were repeated twice over the academic year. Given the wide distribution of dates at which students completed their urology rotation during the academic year, students received the spaced educational e-mails for a duration ranging from 0 to 11 months. At the end of the academic year (June 2005), students were asked to take the 28-item urology test on all 4 core topics. Students received a $20 bookstore gift certificate for completion of the end-of-year test.

Outcomes and measurements

The primary outcome measures were the students' scores on the 28-item end-of-year test. The secondary outcome measures were the spaced education utilisation patterns reported by students. A *post-hoc* exploratory analysis was performed to investigate for systematic differences in the spaced educational e-mails utilised in each cohort.

Statistical analyses

Based on data from previous test administrations, a total of 70 students were needed in the study to achieve a 0.9 power to detect a 10% difference in test scores with a 2-sided 0.05 significance level.

Both per protocol and intention-to-treat analyses were performed the latter of which utilised pre-test scores in place of end-of-year test scores when a student had not completed the end-of-year test. Two composite scores on the end-of-year test were calculated for each student by combining the scores in the topic areas in which the students received spaced education and those in which they did not (controls). The effect of the spaced education was evaluated by comparing the 2 composite scores via a paired *t*-test, which allowed each student to act as his or her own control. Cohen's *d* statistic, defined as the difference in means in terms of standard deviation units, was utilised to measure effect size, with 0.2 generally considered to be a small effect, 0.5 as a moderate effect and 0.8 as a large effect.[12]

To adjust for topic areas (PC/PSA versus BPH/ED) and for variables used in stratified randomisation (gender, date and site of surgery clerkship), a mixed effects model was fitted with these variables (plus intervention) as fixed effects and with student as the random effect (to account for potential correlations between each student's 2 scores). Multiple linear regression models were also fitted to analyse the end-of-year scores separately for the 2 topic areas and to analyse the score changes from post-rotation to end-of-year. A *post-hoc* exploratory analysis was performed to examine potential systematic differences in the

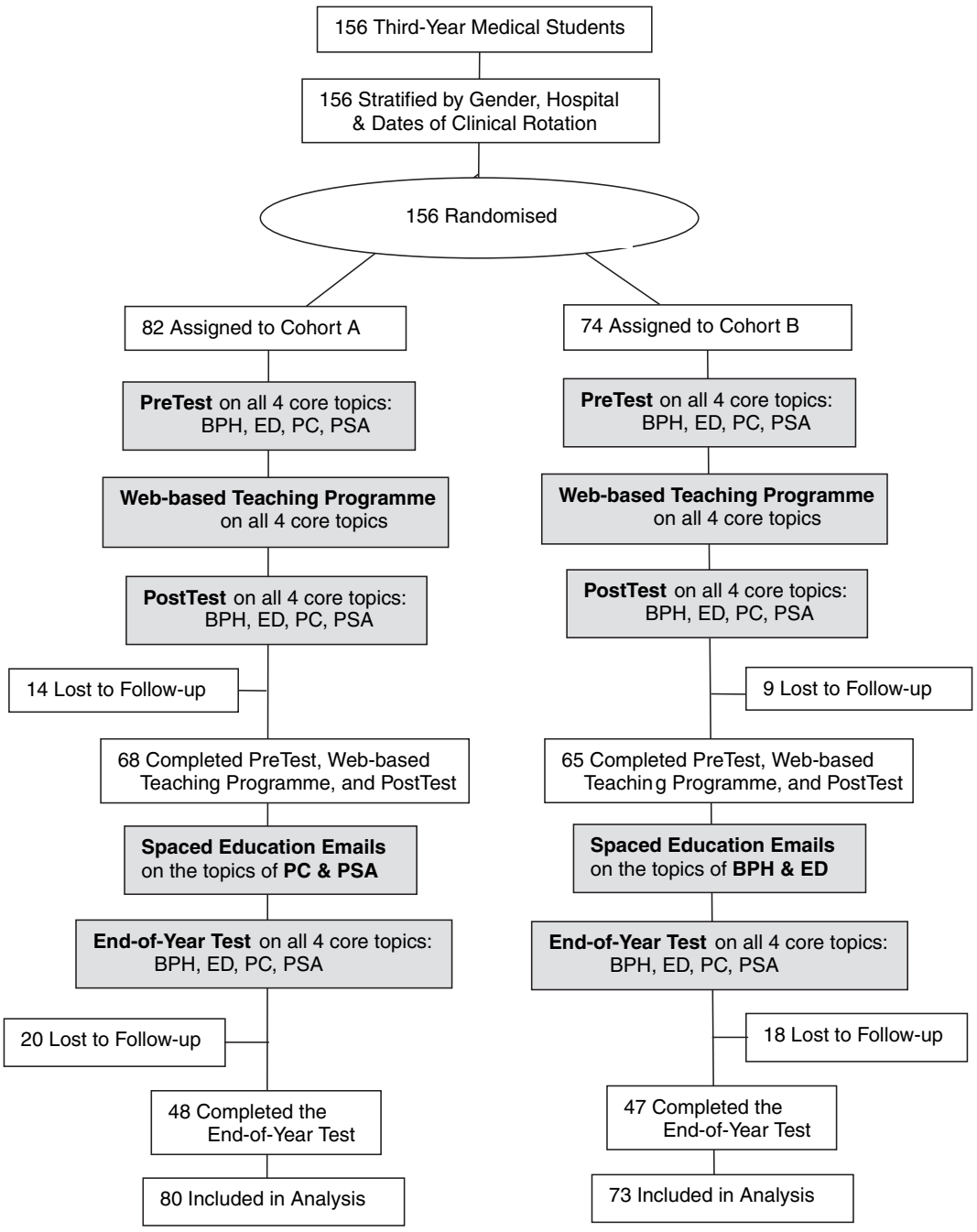

Figure 1 Flow chart of randomised controlled trial. PSA, prostate-specific antigen; PC, prostate cancer; BPH, benign prostatic hyperplasia; ED, erectile dysfunction.

spaced educational e-mails utilised in the cohorts and the potential association between e-mail utilisation and the outcomes.

Statistical analyses were performed with SPSS™ for Windows version 12.0 (SPSS Inc., Chicago, IL, USA) and SAS software version 9.0 (SAS Institute, Cary, NC, USA). Two-sided $P < 0.05$ denotes statistical significance.

RESULTS

Eighty-five per cent of all 3rd-year HMS students (133/156) completed the urology web-based teaching programme. Of these, 71% (95/133) completed the end-of-year test (Fig. 1). Three students were not included in the intention-to-treat analysis: they did not complete any component of the web-based

Table 1 Characteristics of the 153 students included in the intention-to-treat analyses. No statistically significant differences were present between cohorts

	Cohort A: ***prostate Ca*/PSA**	***Cohort B:*** ***BPH*/ED**	**P-*value***
Participants included in analysis	80	73	
Gender			0.55*
Male	44 (55%)	40 (55%)	
Female	36 (45%)	33 (45%)	
Dates of clerkship			0.97*
July – September 2004	20 (25%)	20 (27%)	
October – December 2004	19 (24%)	18 (25%)	
January – March 2005	20 (25%)	16 (22%)	
April – June 2005	21 (26%)	19 (26%)	
Site of clerkship			0.91*
Beth Israel Deaconess Medical	25 (31%)	24 (33%)	
Brigham & Women's Hospital	26 (33%)	25 (34%)	
Mass. General Hospital	29 (36%)	24 (33%)	
Degree programme			0.36*
MD	69 (86%)	62 (89%)	
MD/PhD	9 (11%)	6 (8%)	
No response	2 (3%)	2 (3%)	
Prior clinical rotations			
Medicine	49 (61%)	36 (49%)	0.06*
Obstetrics–gynaecology/paediatrics	40 (50%)	33 (45%)	0.28*
Radiology	23 (29%)	28 (38%)	0.16*
Prior urology experience	2 (3%)	1 (1%)	0.53*
Age (years)	Mean 26.1 (SD 2.4)	Mean 26.3 (SD 2.5)	0.61[a]
Self-assessment of prior 'knowledge base in urology' (5-point scale: 1, poor, 5, excellent)	Mean 1.8 (SD 0.7)	Mean 1.8 (SD 0.7)	0.86[a]

Statistical comparisons performed with χ^2 test* and 2-tailed *t*-test.[a]

programme, including the pre-test, and as a result their absent end-of-year test score could not be imputed by a baseline pre-test score. There were no significant differences in baseline characteristics between randomised cohorts (Table 1).

End-of-year test scores

Spaced educational e-mails significantly improved composite end-of-year test scores ($P < 0.001$, paired *t*-test, per protocol analysis, Cohen's effect size 0.50). The impact of the spaced educational e-mails was largest for those students who received these e-mails for 6–8 and 9–11 months (Cohen's effect sizes of 1.01 and 0.73, respectively, Fig. 2). Intention-to-treat analyses gave similar results.

The effect of spaced education remained significant ($P < 0.001$) after adjusting for topic (PC/PSA versus BPH/ED), gender, site of clerkship, date of clerkship, degree type and random student effect (on an intention to treat basis). We found a marginally significant interaction between spaced education and date of clerkship ($P = 0.10$); the effect in students who received e-mails for 6 months or longer was larger ($P < 0.001$) than that in students who received e-mails for less than 6 months ($P = 0.11$). No other significant interactions were indicated.

When analysing the 2 topic domains (PC/PSA versus BPH/ED) separately via multiple linear regression on an intention-to-treat basis, the composite score on PC/PSA was significantly greater in the group of students (cohort A) who received spaced educational e-mails on these topics ($P < 0.001$, Table 2). A trend towards improvement was also observed on the BPH/ED score in the group of students (cohort B) who received spaced educational e-mails on these topics ($P = 0.06$). In both topic areas, scores differed significantly with respect to the duration of time over which the e-mails were received ($P = 0.001$). No significant differences were indicated between gender, clinical sites or degree programmes.

Score change from rotation post-test to end-of-year test

Using an intention-to-treat multiple linear regression analysis, students who received spaced educational e-mails on prostate cancer and PSA screening

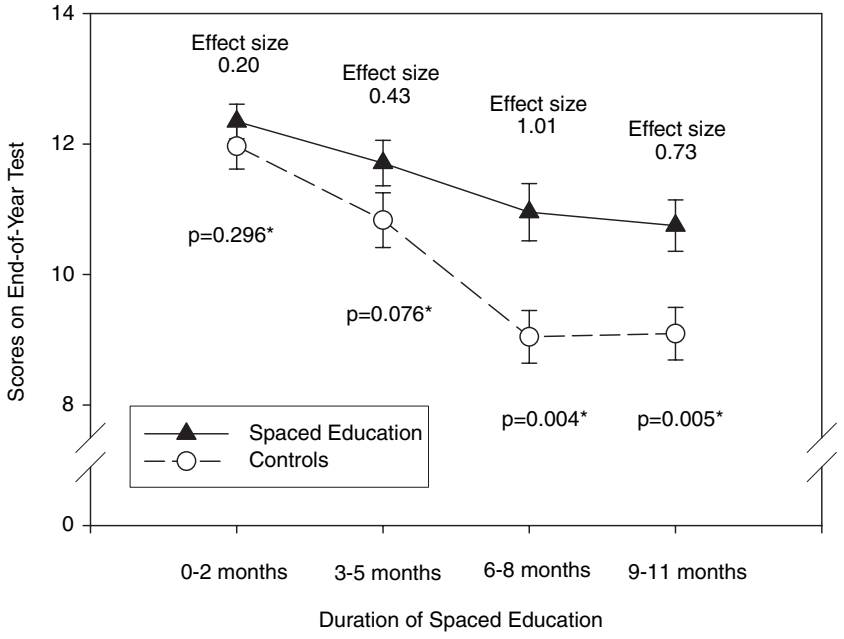

Figure 2 Composite end-of-year test scores ($n = 93$ students) as a function of the duration over which spaced educational e-mails were received. Overall, scores were significantly different between cohorts ($P < 0.001$, paired *t*-test). *To correct for multiple subgroup comparisons, the threshold for statistical significance is $P = 0.013$.

Table 2 Mean ± SD for the end-of-year test scores, under an intention-to-treat analysis

	***Test scores on PC/*PSA**		***Test scores on BPH/*ED**	
	***Intervention cohort A (PC/*PSA)**	***Control cohort B (BPH/*ED)**	***Control cohort A (PC/*PSA)**	***Intervention cohort B (BPH/*ED)**
All students	10.4 ± 3.2	9.4 ± 2.8	8.8 ± 3.1	9.5 ± 2.9
Duration since rotation				
0–2 months	11.0 ± 3.2	10.9 ± 2.8	9.9 ± 3.5	10.3 ± 3.1
3–5 months	10.3 ± 3.4	9.6 ± 2.8	9.1 ± 3.3	9.6 ± 2.6
6–8 months	9.9 ± 3.4	8.1 ± 2.7	7.8 ± 2.8	8.6 ± 2.7
9–11 months	10.4 ± 2.8	9.2 ± 2.5	8.2 ± 2.2	9.4 ± 3.0
Gender				
Male	10.3 ± 3.1	9.4 ± 2.4	8.9 ± 3.1	9.2 ± 2.7
Female	10.5 ± 3.2	9.5 ± 3.3	8.5 ± 3.0	9.8 ± 3.1
Site of clerkship				
Beth Israel Deaconess Medical	9.8 ± 3.3	10.3 ± 2.6	8.8 ± 3.5	9.6 ± 3.1
Brigham & Women's Hospital	10.9 ± 3.2	9.3 ± 3.5	9.0 ± 3.0	9.6 ± 2.7
Mass. General Hospital	10.4 ± 3.1	8.8 ± 2.2	8.6 ± 2.9	9.2 ± 2.9
Degree programme				
MD	10.5 ± 3.1	9.4 ± 2.9	8.8 ± 3.0	9.4 ± 2.9
MD/PhD	10.0 ± 4.2	9.0 ± 2.3	8.7 ± 3.6	9.5 ± 3.6

(cohort A) demonstrated significantly greater retention (composite post-test score minus composite end-of-year test score) in these topics compared to controls ($P = 0.03$). Similarly, students who received spaced educational e-mails on BPH and erectile dysfunction (cohort B) demonstrated significantly greater retention in these topics compared to controls ($P = 0.004$). The score change differed marginally with respect to duration ($P = 0.05$ and 0.06 for PC/PSA and BPH/ED, respectively); no significant differences in retention were observed between gender, clinical sites or degree programmes.

Utilisation patterns, e-mail: structure and student feedback

Students in cohort A (PC/PSA) reported reading a median 90% (mean 79%, SD 25%) of the spaced educational e-mails they received, while those in cohort B (BPH/ED) reported reading 60% (mean 62%, SD 33%), a significant difference ($P = 0.01$, Mann–Whitney *U*-test, Table 3). Other parameters of e-mail utilisation were similar between the cohorts (Table 3). A *post-hoc* analysis of the e-mail structure indicated that the e-mails for cohort A were

Table 3 Utilisation characteristics of spaced educational e-mails reported by students. Median is listed, with interquartile range (IQR) posted in parentheses

	Cohort A	*Cohort B*	*P-value*
What percentage of the weekly 'spaced education in urology' e-mails did you read on the topics to which you were randomised?	90% (65–100)	60% (25–100)	0.01
What percentage of the weekly 'spaced education in urology' e-mails did you read on the topics to which you were *not* randomised?	0% (0–65)	5% (0–50)	0.53
Please rate whether or not you feel the 'spaced education in urology' e-mails were effective educational tools? (5-point Likert scale: 1, not effective, 5, very effective)	4.0 (4.0–5.0)	4.0 (2.8–5.0)	0.13
On average, how many e-mails do you receive each day?	15 (10–25)	15 (10–20)	0.42
How often do you check your e-mail account(s) for new messages? (times per day)	3.0 (1.0–5.0)	3.0 (1.4–5.0)	0.84
If multiple specialties besides urology started spaced education e-mail programmes, what would be the maximum total number of these e-mails that you would want to receive each week?	5.0 (3.0–7.0)	4.0 (2.8–5.0)	0.06

Statistical comparisons performed with Mann–Whitney *U*-test.

significantly shorter than those e-mails sent to the students in cohort B (mean 218 versus 290 words, respectively, $P < 0.001$, 2-sample *t*-test). However, these e-mail utilisation variables were not associated significantly with the test scores (mixed effect model analysis, adjusting for covariates). Limited cross-over between cohorts was reported by students (Table 3).

Students reported that the spaced educational e-mails were effective educational tools (median 4.0, mean 3.9, SD 1.0 on a 5-point scale: 1, not effective, 5, very effective). If spaced education programmes were started in other specialties, 96% of students indicated that they would want at least 1 spaced educational e-mail per week. Overall, students reported that 5 e-mails a week (median 5.0, mean 5.0, SD 3.7) would be the maximum that they would want to receive.

DISCUSSION

This randomised controlled trial demonstrates that spaced education consisting of case scenarios and clinical questions distributed weekly via e-mail can significantly improve students' retention of medical knowledge. These retention improvements were topic-specific and increased with the duration over which spaced educational e-mails were received. In addition, students perceived the e-mails to be effective educational tools, with almost all students indicating that they would want to receive spaced educational e-mails in the future.

These results are not surprising: repeated reinforcement of learning would be expected to improve its retention over time, consistent with previous psychological research.[1,6,13–15] Even so, this study is novel in that it demonstrates that principles of spaced education can be applied to a large dispersed student population via the distributive power of e-mail and the internet, resulting in significant improvements in retention of clinical knowledge. This pedagogical model for improving retention of knowledge may have a broad application in medical education and in education in general. For instance, 1 repeated criticism at our institution is that students arrive at their 3rd-year surgery clerkship with a dearth of anatomic knowledge, in spite of an intensive course in human anatomy in their 1st year. A spaced educational programme in human anatomy administered between the 1st and 3rd years may be able to halt this decline in anatomical knowledge.

The results of this study also directly challenge the value of an extremely common outcomes measure in educational research, namely short-term learning as measured by a post-test taken closely following an educational intervention. There is an assumption that short-term learning gains are maintained, but the forgetting curves demonstrated in this paper argue strongly against such an assumption. This study emphasises the value of knowledge retention (longer-term learning) as an important outcomes variable by which educational interventions should be judged.

There are several limitations to this study, including the moderate participation rates and the narrow subspecialty focus of the educational intervention. In addition, the study design did not control for the differences in time that students spent learning the specific urology topics. It remains to be demonstrated whether this pedagogical model can be generalised to other topics and to other students at various points in their training. While the study demonstrated

statistically significant score differences between cohorts, it is reasonable to ask whether these seemingly small score differences are educationally significant. Ultimately, this is a question of validity: does the test assess a construct which is clinically meaningful, such that a difference of 1–2 points actually matters? The rigorous methodology we followed in constructing a validated test and validated spaced educational e-mails argues that such a score difference does reflect a real knowledge difference of clinical and educational import.

Strengths of this study include its randomised controlled design and the rigorous methodology followed in the development of the test and educational interventions. By analysing the results of the randomised students and not just those who completed the end-of-year test, an intention-to-treat analysis eliminates any potential bias in favour of a positive result that may result from non-random attrition of students. In addition, the intention-to-treat analysis (which imputes end-of-year test score by pre-test score for students who did not complete the end-of-year test) is inherently conservative. Under such a method of analysis, the impact of the spaced education intervention is purposely diluted by the inclusion of these non-completers who, by definition, have made no improvement from their pre-test scores. The fact that the results remain statistically significant under such a conservative approach and with such a high percentage of imputed data (38%) is testament to the robustness and generalisability of the findings.

Many questions about spaced education remain: what are the optimal spacing patterns to facilitate retention and learning, what is the optimal structure for the educational materials, what is the optimal frequency of spaced educational e-mails, etc. Another important question is whether the principles of spaced education can be applied online to facilitate the initial learning of educational material, not just improve its retention. While studies in the psychological literature suggest that this is the case, this research has largely been conducted in controlled settings with a relatively small number of subjects and over relatively short durations.[5,15,16] Two multi-institutional randomised trials are currently under way to test this hypothesis.

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APPENDIX 1

Example of spaced educational e-mail

Spaced education in urology: erectile dysfunction

A 63-year-old-male comes into your office concerned that his love of Barry Manilow songs might be contributing to his development of erectile dysfunction (ED). Using all your patient–doctor skills, you reassure him that Barry Manilow is an unlikely cause of his ED, but recommend that he listen to Barry White. You take a full history addressing risk factors for ED and then move to the physical examination. What components of a GU examination are important in the work-up of this patient's erectile dysfunction? (please select all the answers which are correct)

(a) prostate – assessing for tenderness
(b) penis – assessing for scarring
(c) lower abdomen – assessing for surgical scars
(d) digital rectal examination – assessing for anal tone and perineal sensation
(e) feet – assessing for pedal pulses

Scroll down for the answer…

Correct answers: B, C, D, and E (not A)

Take-home message:

The primary aetiologies for ED are vascular, neurogenic and iatrogenic, so your physical examination should look for evidence for each: reduced pedal pulse can indicate peripheral vascular disease, reduced anal tone or perineal sensation can raise suspicion of a neurological component, and lower abdominal scars may indicate pelvic surgery which may have disrupted the nerve supply to the penis (cavernous nerves). A detailed examination of the penis should also be performed because, for instance, scarring of the corpora cavernosa can lead to severe curvature of the erect penis (Peyronie's disease).

Explanation of incorrect answers:

(a) While it is important to do a prostate examination as part of a thorough GU examination, disorders of the prostate are not typical causes of ED.

Take-home message from last week: BPH

There are 7 basic BPH-related symptoms which fall under the mnemonic WISE FUN:

W: weak urinary stream
I: intermittency of urinary stream
S: straining to urinate
E: incomplete emptying

F: frequency of urination
U: urgency of urination
N: nocturia (frequency of urination at night)

The WISE symptoms are obstructive in nature, while the FUN symptoms are irritative in nature. These symptoms form the basis of the validated International Prostate Symptom Score (IPSS), which is used to quantitate and follow change in severity of BPH-related symptoms.

Reference: *J. Urol* 2001; **166**:1011.