A Spaced-Repetition Approach to Enhance Medical Student Learning and Engagement in Pharmacology

Dylan Jape
Monash University
Jessie Zhou
Monash University
Shane Bullock (shane.bullock@monash.edu)
Monash University

Research Article

Keywords: pharmacology, spaced-repetition, flashcards, medical education

Posted Date: July 12th, 2021

DOI: https://doi.org/10.21203/rs.3.rs-625499/v1

Abstract

Background: Pharmacology is a cornerstone of medical education as it underlies safe prescribing practices. However, medical students have reported unease regarding their perceived proficiency in clinical pharmacology. Despite the significant impetus to improve student outcomes, there is little analysis available of the techniques used by medical students to learn, retain and apply pharmacology knowledge.

Methods: A mixed methods, student-focused approach was conducted to design and refine specific resources developed to address gaps in pharmacology education. This methodology comprised an anonymised scoping survey, followed by structured focus group interviews. We developed a relevant and time efficient resource to support long-term revision for academic and clinical success. These resources were released to a cohort of 100 graduate preclinical medical students who were invited at the end of year to evaluate the intervention via a subsequent anonymous survey.

Results: The scoping survey received 103 complete responses. Surveys and focus group interviews revealed that only 50% of students engage in ongoing revision. The analysis identified in-semester revision of pharmacology as a significant predictor of strategic and deep learning methods and improved quiz performance (a 5% higher score on average), compared to superficial learning methods.

Amongst our cohort, we identified that the evidence-based technique of spaced-repetition was particularly well regarded. Hence, we developed and evaluated a bespoke resource utilising Anki™, an open-source, spaced-repetition flashcard program. A total of 1208 flashcards spanning 156 distinct classes of drugs with supplementary summary tables, diagrams and explanatory video and summary guides were created. Designed as a strategic revision tool to reinforce learning, evaluation showed students greatly appreciated the “comprehensive” and “well formatted” Anki™ resource that supported existing teaching modalities, with a global rating of 3.8 out of 5.

Conclusions: Strategic and personalised techniques for pharmacology learning that assist with in-semester revision and long-term retention are highly valued amongst students for examination preparation and preparedness for practice. Collectively, these results define a novel approach to identifying and addressing weaknesses in existing teaching methodologies in a manner that is inclusive of, and acceptable to, medical students.

Background

Competence in pharmacology is a crucial outcome in medical education as the discipline provides the rationale for therapeutic interventions and safe prescribing. However, significant challenges face medical students, such as developing expertise with the vast and ever-expanding array of medications available on the market, each with unique clinical considerations and interactions (1). Given this, it is unsurprising that many medical students express concerns regarding competence in pharmacology and prescribing,

with only 39% of Australian medical graduates perceiving that they were adequately or well prepared in clinical pharmacology (2, 3).

Thus, there is significant interest in educational reforms to improve student outcomes in pharmacology. However, it is notable that most approaches have been top-down in nature, focusing on systematic changes in curriculum, teaching and staffing (4). Hence, there is a gap in the understanding of the approaches and techniques used by medical students to study pharmacology, which could form the basis for targeted interventions to improve learning (5-8).

Of interest is how students cope with fast-paced integrated medical school curricula and whether support can be provided to encourage more efficient approaches to study (9). One technique of interest is spaced-repetition of flashcards, such as via the open-source and cross-platform digital flashcard program Anki™, which is known to improve student outcomes (10-13). This method of learning involves self-testing on flashcards that assess specific items of knowledge, which are subsequently self-rated for difficulty. The program subsequently sets intervals for re-assessment, depending upon prior difficulty ratings, establishing a personalised schedule for revision.

Spaced-repetition carries distinct advantages when considered in the context of supporting medical student education (14). Firstly, flashcard revision is a form of retrieval practice that engages students to recall items of information, an act that is known to improve long-term retention **(Figure 1)** (15). Secondly, spaced-repetition scheduling is known to improve outcomes via optimising revision to address difficult items whilst minimising repetition of easy concepts. Finally, through dividing complex concepts into discrete items of knowledge to be repeatedly assessed, flashcard revision may encourage a more deliberate and strategic approach to learning that is known to underlie attainment of proficiency (16).

In this study, we examine the perceptions and approaches of medical students to learning pharmacology, with a focus on identifying and targeting weaknesses through the development of supportive educational resources. In this way, we aim to contribute to a greater understanding of both student perspectives towards learning and possible actionable interventions to improve outcomes.

Methods

Students involved in this study were enrolled in direct or graduate entry Doctor of Medicine (MD) programs delivered by one Australian university. The direct entry degree is a five-year course, while the graduate entry degree is of four years. Each year level has approximately 350 direct entry students and 100 graduate entry students. All currently enrolled medical students were invited to participate via advertisements on online student noticeboards. Ethics approval was sought from the university's human ethics committee prior to commencement (MURHEC number: 2020-22814-44162).

To better understand medical students' approaches to pharmacology education, an anonymised scoping survey was distributed. An invitation to participate in structured focus group interviews was provided at the end of the survey, with a goal of further elucidating survey findings and to demonstrate and refine

specific resources developed. These resources were released to a cohort of graduate entry preclinical medical students who were invited at the end of year to evaluate the intervention via a subsequent anonymous survey **(Figure 2)**.

Primary survey design and data analysis

To better understand the perceptions and approaches of medical students with respect to pharmacology education, a primary survey was distributed amongst all current students within the participating MD program. The survey primarily consisted of 5-point Likert scales and free text items.

The survey consisted of four distinct sections. The first section was targeted at identifying key demographic characteristics of the survey participants such as age, sex, year level, entry stream and whether the students were domestic or international. The second section was targeted at characterising student learning approaches, based upon the validated Approach and Study Skills Inventory for Students (ASSIST) survey (17). The ASSIST survey is a 52-item inventory that quantifies the degree to which a student's learning style fits three distinct categories (deep, strategic and surface) that are predictive of academic outcomes (18, 19). To reduce the survey length and improve the response rate, a modified nine item survey was developed through selecting the nine most predictive items.

The third section of the survey was designed to identify the resources and techniques utilised by students to learn pharmacology. These characteristics were assessed with regard to three distinct time periods of learning; as first exposure to a topic, as ongoing revision and as revision prior to summative assessments. Finally, the last section of the survey involved a short pharmacology test consisting of 12 multiple-choice questions **(Appendix 1)**. The test was designed to assess core curriculum content with the primary objective of identifying the contribution of demographics to academic outcomes, with the secondary intention of ascertaining any other significant predictors of academic success.

Statistical analysis of the data was performed to identify significant associations via cross-tabulation, Pearson’s chi-squared test, linear regression and Student’s t-test using SPSS (version 26) and MS Excel.

Focus group and thematic analysis

Survey respondents were also invited to participate in focus groups to further elicit qualitative information on survey findings and to evaluate several prospective study resources. Two rounds of focus group interviews with Monash medical students were performed, with a total of ten student participants.

The student participants were coded as follows:

- Focus Group A: 4 students (A1, A2, A3, A4)
- Focus Group B: 6 students (B1, B2, B3, B4, B5, B6)

Two focus-group assessors facilitated an open-ended discussion, with interviews transcribed and coded using NVivo (version 12). Principles of grounded theory were used for thematic analysis (20).

Resource design and implementation

Evaluation of the primary survey identified three potential avenues for interventions supporting pharmacology education; Anki™ flashcards, text-based summaries and diagrams. These resources were developed for initial evaluation within focus group interviews and later, a cohort of pre-clinical graduate entry medical students.

Flashcards were designed as cloze sentences, with students self-testing their ability to recall key words or phrases omitted from a pharmacological concept (**Figure 3**). Students were then given the opportunity to check their answer and rate the card difficulty, which feeds into the spaced-repetition algorithm of Anki™ to effectively schedule future revision based upon need. Anki™ flashcards were created to cover 15 core curriculum topics, spanning 156 distinct classes of drugs, resulting in a total of 1208 flashcards. Flashcards assessed a diverse range of curriculum material, including basic knowledge such as drug names, mechanisms, indications and adverse drug reactions to more complex knowledge such as clinical practice guidelines.

Traditional text and diagrammatic summaries were also developed to complement the Anki™ resource, allowing students to review the details of the broader drug class and pharmacology topics both within and independent of the Anki™ program.

Follow-up survey design and data analysis

To evaluate the effectiveness of the intervention within the population of pre-clinical graduate entry medical students, a follow-up survey was distributed via advertisements on student forums and noticeboards. Student perceptions of the pharmacology resources were elicited using 5-point Likert scales and free text items, with data subsequently analysed using MS Excel.

Results

Primary survey demographics and results

The survey received 103 complete responses from the population of enrolled students across all years of the medical course. The demographic profile of the respondents was a median age of 22 years, 69% female, 56% direct entry admission and 81% domestic students. Twenty-six per cent of respondents were in their preclinical years, 44% in their first clinical year (medical-surgical focus), 11% in their second clinical year (speciality focus) and 20% in their final year (pre-intern focus) of the course.

Student Learning Preference and Approaches

To better understand the needs of students, learning engagement and techniques were examined with respect to three distinct stages; first learning a new topic, revision during semester and revision prior to major assessments. Most participants reported significant engagement in dedicated pharmacology study to learn new material (95%) and to revise prior to exams (80%). However, only 50% of respondents reported specific pharmacology revision throughout the teaching year.

To better understand how students learn pharmacology, participants were asked about their usage of several learning techniques of interest **(Table 1).** With respect to learning new pharmacology material, students showed a significant preference towards class activities (63%), text-based notes (84%) and faculty question banks (60%). Relative to the overall level of engagement with studying during semester and prior to exams, students largely reviewed or repeated techniques utilised to learn pharmacology.

Table 1: Comparison of pharmacology study technique popularity amongst students.

This was assessed via a 5-point Likert scale, with the proportion of strong or very strong engagement responses reported

Technique	First Exposure Learning (%)	In-semester revision (%)	Exam revision (%)
Class activities or resources	63	41	56
Personal text-based notes	84	40	78
Concept maps	23	18	26
Flow chart	29	18	27
Diagrams	46	23	42
Faculty question banks	60	30	58
Flashcards	35	30	63

One notable exception was in the use of flashcards, which had a net increase in usage as in-semester review (30%) and exam revision (63%) as compared to first exposure learning (35%), despite the lower levels of student engagement at the later time points. Amongst the distinct forms of flashcard revision examined, digital flashcards with spaced-repetition scheduling (e.g. Anki™) were the most popular means of study reported.

Association between revision and predictors of student success

In the test, the mean correct score was 6.25 marks out of 12, with a standard error of 0.27. The lowest correct score was 1, while the highest score was 12. A Chi-squared test of test score over current year

level of the course was found to be statistically significant (χ^2_{33}=67.5; p < 0.001) (Fig. 4), with mean test scores increasing across year levels. Performance increased with increased knowledge and clinical learning experience.

Students who reported specific pharmacology study in-semester were associated with significant increases in the deep and strategic approaches to learning items in the modified ASSIST survey, relative to students that did not engage in in-semester revision (Table 2). By contrast, the larger group of students reporting specific exam revision was associated with significant increases in only the strategic approach to learning, as compared to students that did not engage in exam revision. Neither form of revision was associated with a statistically significant difference in test scores relative to students that did not engage in revision.

Table 2: Comparison of depth of learning approach used for revision

This was assessed via a modified ASSIST survey, and pharmacology knowledge as assessed via a 12 multiple-choice question test, between students reporting engagement or no engagement in revision in-semester or immediately prior to examinations. Student's t-test: * P < 0.05 and *** P < 0.001

Timepoint	Deep approach difference	Strategic approach difference	Superficial approach difference	Test score difference
In-semester revision	1.3**	2.0***	-0.4	0.6
Exam revision	0.5	1.6*	0.4	-0.6

Association between the digital spaced-repetition and predictors of student success

To identify any potential benefits of digital spaced-repetition, such as Anki™, for student success, statistical analysis was performed to compare students who utilised such a revision strategy to those that did not **(Table 3).** A significant association was found between the use of spaced-repetition for in-semester review and a strategic approach to learning. A similar association was found with the use of spaced-repetition for exam revision. No statistically significant differences were noted in the ASSIST survey results for deep or superficial approaches to learning, nor in the test scores, at any time point of revision.

Table 3: Comparison of depth of learning approach used for in-semester learning and revision.

This was assessed via a modified ASSIST survey, and pharmacology knowledge as assessed via a 12 multiple choice question test, between students reporting significant or occasional to no use of digital spaced-repetition (i.e. Anki™) as a learning technique at different timepoints in learning. Student's t-test: * p < 0.05 and ** p < 0.01

Timepoint	Deep approach difference	Strategic approach difference	Superficial approach difference	Quiz score difference
Spaced-repetition in-semester revision	0.8	1.2**	-0.5	0.1
Spaced-repetition exam revision	0.6	1.1*	0.1	0.4

Focus group thematic analysis

The focus group participants were 70% female, 70% direct entry medical students and 50% preclinical students. In general, pharmacology teaching by the participating medical student cohort was well received; students particularly enjoyed the clinically integrated case-based approach to learning.

Student B4 (preclinical direct entry):

"I feel like we have a good amount of clinical cases given to us. Because it is definitely easier to relate what you learn when you learn about someone who is going through that condition."

However, numerous barriers to effective pharmacology learning identified by students included time management and difficulty with long-term retention.

Student B3 (preclinical direct entry):

"Some way of keeping students somewhat accountable for not trying to cram everything at the end of the year."

Student B5 (preclinical direct entry):

"I think there should be more emphasis on learning how to learn… You could be studying a lot of hours but you might not be studying effectively."

Student B5 (preclinical direct entry):

"Actually during exams I actually knew all my Pharmacology really well, but if you were to ask me anything right now ...I wouldn't be able to answer anything. It is just not sticking in my long-term memory."

Students therefore greatly valued study techniques that prioritise time-efficiency, conciseness and knowledge retention; these became the key areas of need that the newly developed Anki™ Pharmacology resource aimed to address. Main limitations for the uptake of such a resource were the user interface which made it difficult for some students to engage with the Anki™ software.

Illustrative examples appear below.

Theme 1: Time-Efficiency

Spaced-repetition Anki™ flashcards were highly regarded by students as a time efficient method for exam revision, knowledge recall and retention.

Student A3 (pre-clinical, graduate entry):

"I just find flash cards are a much more active way to study, so in terms of efficiency, you can learn and retain the material in a shorter amount of time, which is what we're all looking for."

Theme 2: Utility as Revision Tool

Utilisation of active recall methods with Anki™ flashcards is perceived as an effective approach for forming strong long-term memories. Use of this technique along with spaced-repetition algorithms with the Anki™ software is considered a powerful method for structuring revision.

Student A3 (pre-clinical, graduate entry):

"I was excited by it, because I've used Anki™ all through my biomed degree and found it a really good way to study actively, and I also really like the structure of having cards to organise my revision."

Student A1 (clinical graduate entry):

"That long-term...knowledge would be good … and that's what Anki™'s there for … the way that you've pitched it is also quite appropriate for what it should be used for."

Theme 3: Conciseness

Clear and concise study resources are crucial for student uptake, understanding and engagement. The format of Anki™ Flashcards permits only relevant key points to be presented, making it an attractive learning tool for students.

Student B2 (clinical, direct entry):

"Flash cards would be fantastic because it is very concise …. [with] an actual real-world example that would be so much better."

Theme 4: User-friendliness

The main limitation of the Anki™ resource was that it was perceived as "intimidating", particularly for students who have not previously utilised flashcards as a study resource. Introduction of a guide and incorporating flashcards into the study workflow as a post lecture revision tool are potential strategies to enable students to fully appreciate the utility of the Anki™ resource.

Student A3 (preclinical, graduate entry):

“I talked to a couple of people who have started using it; but I think they found it quite difficult to go through without going through slides and pre-learning beforehand.”

Student B4 (clinical, direct-entry):

“There are so many cards it is a bit intimidating to try and learn them.”

Student A2 (preclinical, graduate entry):

“Write a manual ...how to use each thing, like step by step? ...Written down; so people can access it at any time.”

Follow-up survey demographics and results

The follow-up survey received 29 complete responses from a population of approximately 100 enrolled preclinical graduate entry students to whom the pharmacology resources were rolled out. Reported usage of the Anki™ resource was high at 83%, with 52% of students reporting engagement with the resource to complete all scheduled revision and 31% reporting engagement with the Anki™ resource as a traditional question bank for episodic revision. Overall, the Anki™ resource was well received, with an average rating of 3.8 out of 5. Furthermore, 66% of participants positively received the scheduling of revision by Anki™ and 76% positively rated the long-term viability of Anki™ as a study technique. Notably, 83% of students positively perceived the benefits of Anki™ as a study technique for subjects other than pharmacology. Furthermore, the accompanying summary tables and diagrammatic representations within the resource package were positively received by 79% and 83% of students respectively **(Figure 5).**

Overall thematic analysis and textual analysis based on open-ended questions in the evaluation survey *(What do you think are the strengths of the Anki™ Pharmacology resource? How could the Anki™ Pharmacology Resource be improved?)* mirrored the perspectives expressed in the previous focus groups that students regarded the Anki™ pharmacology resource as a *“great”* and *“comprehensive” “study system”* for *“continuous revision”* of key pharmacology concepts.

In free-text comments students highlighted that the resource is not only immediately valuable for their studies for revision and assessment preparation, but long-term knowledge retention in clinical years and future practice as an “*accurate resource to refer back to” that “highlights key concepts that we should know not for just this year, but for later years.”*

However, in creating a comprehensive and detailed resource for preclinical students that incorporates clinically-applied pharmacology, 45% of students expressed sentiments that *“ the sheer volume of some decks felt overwhelming”* and that some decks included information *“outside the scope”* of the preclinical pharmacology syllabus. Integration of the Anki™ resource with case examples and links to useful resources and videos for certain drugs was another suggestion for further development of the resource.

Additionally, requests for *"more visual schematics"* to be incorporated in the flashcards echoed baseline survey and focus group discussions.

Discussion

Revision and self-testing are critical acts in the process of learning, aiding students in consolidation of their knowledge and building confidence in practice (10). With the demands of modern medical school curricula, students are placed under significant pressure to remain up to date with their course content and thus, have significant time barriers impeding revision. Here, we found that whilst 95% of participants engaged in dedicated pharmacology study to learn new content and 80% revised prior to exams, only 50% revised during the semester. Qualitatively, participants reported that such revision was often superficially motivated by summative assessment deadlines, rather than for long-term competency. This is consistent with existing studies that suggest students often adopt less effective shallow strategies for learning such as rereading, highlighting and cramming (21, 22). Therefore, interventions focusing on engaging medical students in structured revision possess and active learning provides clear benefits for student outcomes (23).

Given the time pressures and high workloads of medical students, any such intervention must be time-efficient and effective (24). Here, we identified a statistically significant correlation between the use of Anki™ and a strategic approach to learning. This association may have occurred as a result of engagement with scheduled revision by Anki™, which may underlie a key benefit of this intervention as a means of supporting a more methodical and considerate approach to learning that is known to benefit students in transitioning to, and succeeding within, medical school (25, 26). Metacognitive awareness and use of spaced study plausibly supports a more methodical and considerate approach to learning, as reflected in the modified ASSIST survey results (26). In such a manner, the use of Anki™ could act to support students in developing and maintaining strategic approaches to learning that are known to improve academic outcomes (27).

Beyond requiring a learning resource to be efficacious, students have expressed concerns regarding barriers to entry to ongoing revision. Whilst focus group participants favourably perceived spaced-repetition, many expressed concerns with the initial time investment in the creation of flashcards that ultimately resulted in lesser usage of the technique. This potentially creates a undesirable situation where students that are struggling with time management are least well equipped to access and engage with more time efficient study techniques.

Based upon these findings, we postulated that student co-development and implementation of a comprehensive Anki™ pharmacology resource, based upon the pharmacology curriculum would bear several advantages. Firstly, as a developed resource on an open source program, such an intervention would lower the major barrier to entry for students to engage in curriculum-specific pharmacology revision that is time-efficient and freely accessible (28). Secondly, such a resource could encourage more effective revision involving retrieval practice (22) and the option to study with spaced-repetition

scheduling that maximises time spent on challenging concepts to improve outcomes (13, 16). Finally, the digital nature of the flashcards allows for ease of editing, collaboration and access, thereby ensuring the sustainability of the resource in the long-term (14).

The extensive Anki™ flashcard deck was subsequently incorporated into the pharmacology program with decks of flashcards released to the participating students following traditional classes as a form of ongoing revision in accordance with Bloom's Taxonomy (29) (Fig. 6). Incorporation of Anki™ into the pedagogy, may provide reassurance for teachers that students engaging with the spaced-repetition tool are periodically reviewing delivered material, thereby enhancing their learning long-term.

Evaluation by the participating preclinical student cohort was largely positive, with use of the spaced-repetition scheduled revision being the predominant mode. Student views were largely congruent with the hypothesized benefits of the intervention; particularly of the strength of the intervention as a comprehensive, prepared resource covering their pharmacology curriculum. Notably, students largely perceived themselves engaging with the resource long-term and expressed an interest in similar resources developed for other medical course content, which potentially serves as a more accurate reflection of the overall perception of the resource potential. The prospect for long-term engagement in the resource is particularly notable as the very nature of Anki™ -based revision essentially ensures re-exposure to, and retention of, curriculum materials well into the future (22, 30).

One particular issue identified by students was a perception of excessive breadth and depth within the covered material (3). This may be exacerbated in the case of students that struggle with performing scheduled revision, where reviews may accumulate and result in distress and discouragement. Ultimately, we believe that any prepared resource should strive to be comprehensive to ensure long-term viability and for the sake of academic integrity. However, to address this issue, further support should be offered to students on how to tailor their Anki™ program to their particular needs. Examples could include providing additional flashcard metadata to categorise content based upon academic importance or further instructional material to encourage the personalisation of settings (i.e. limiting daily reviews) and how to omit cards from scheduled reviews (4, 31).

This study has limitations. Low response rates for the primary and follow-up surveys may have resulted in a significant non-respondent bias. Additionally, the assessment of students from a single medical school may have reduced the external validity of these results. Nevertheless, most findings are consistent with existing literature regarding medical school learning and the use of spaced-repetition as a technique to improve outcomes (13, 16). The replication of this study in other cohorts should be conducted to confirm these findings.

Conclusion

In this study we described a bottom-up approach to supporting medical students learn pharmacology via the investigation of student learning approaches and techniques and the design of an Anki™ spaced-

repetition flashcard resource based upon trends observed in the examined student cohort. This resource was well received by participating students, particularly with regards to addressing a significant unmet need for time-efficient strategies regarding ongoing revision of pharmacology. In this way, we believe that this approach may be broadly applied across the curriculum to improve medical student education.

Practice Points

- Medical students appear to engage minimally with ongoing in-semester revision as a result of fast-paced integrated curricula.
- Assessment of student cohort learning can lead to significant insight to guide interventions.
- Spaced-repetition flashcard resources may promote strategic approaches to learning and support long-term revision amongst medical students.
- Spaced-repetition flashcard resources are well-regarded and well-received amongst medical student cohorts.

Declarations

Ethics approval and consent to participate

Ethics approval was sought from the university's human ethics committee prior to commencement (MURHEC number: 2020-22814-44162). Consistent with the university ethic committee's guidelines, students were provided with a comprehensive explanatory statement about the study. Informed consent to participate in focus group interviews was obtained in writing, and for the survey was implied through anonymous participation and completion of the online questionnaire..

Consent for publication

Not Applicable. No private information of participants were retained within the dataset collected.

Availability of data and materials

The datasets generated and/or analysed during the current study are not publicly available due potential breach of privacy and confidentiality of participants but are available from the corresponding author on reasonable request.

Acknowledgements

Monash Rural Health, Monash University

Competing interests

There are no conflicting interests. The paper is original and has not been previously published.

Funding Details

No funding was received for this paper.

Authors' contributions

Mr DJ is a fourth-year graduate entry medical student at Monash University (Australia) with special interests regarding efficiency in medical education and student wellbeing. Having recently completed preclinical studies, he co-developed the designed pharmacology resource and coordinated the project with support from Monash University's summer research scholarship program.

ORCID: https://orcid.org/0000-0001-8309-7060

Dr JZ is a junior medical officer at Royal Melbourne Hospital, graduating last year from the graduate entry Monash Rural Health medicine program (Australia). As a registered pharmacist who is passionate about advancing medical education and technology, she co-developed the designed pharmacology resource and coordinated the project with support by the Monash University's Summer Research Scholarship program.

ORCID: https://orcid.org/0000-0002-9655-7270

Associate Professor SB is Acting Head of School of Rural Health at Monash University. He has been involved in the education of student health professionals and scientists for more than 30 years. He is the co-author of three Australian textbooks, Fundamentals of Pharmacology (in its ninth edition in Australia and in its second edition in the UK), Psychopharmacology for Health Professionals and Principles of Pathophysiology (now in its second edition). He has published a number of journal articles on health professional education, in particular with respect to pharmacology knowledge.

References

1. Gwee MC. Teaching of medical pharmacology: the need to nurture the early development of desired attitudes for safe and rational drug prescribing. Medical teacher. 2009;31(9):847-54.

2. Bullock S, Leversha A. Medical student perceptions of their knowledge and skills in pharmacology in their first and final clinical years. MedEdPublish. 2019;8.

3. Lloyd H, Hinton T, Bullock S, Babey A-M, Davis E, Fernandes L, et al. An evaluation of pharmacology curricula in Australian science and health-related degree programs. BMC Medical Education. 2013;13(1):1-15.

4. Achike FI, Ogle CW. Information overload in the teaching of pharmacology. The Journal of Clinical Pharmacology. 2000;40(2):177-83.

5. Ferguson E, James D, Madeley L. Factors associated with success in medical school: systematic review of the literature. Bmj. 2002;324(7343):952-7.

6. McManus I, Richards P, Winder B, Sproston K. Clinical experience, performance in final examinations, and learning style in medical students: prospective study. Bmj. 1998;316(7128):345-50.

7. Samarakoon L, Fernando T, Rodrigo C, Rajapakse S. Learning styles and approaches to learning among medical undergraduates and postgraduates. BMC medical education. 2013;13(1):1-6.

8. Abdulghani MA, Al-Naggar RA. Students' perceptions about learning pharmacology at a single private institute in Malaysia. Journal of Taibah University Medical Sciences. 2015;10(1):40-4.

9. Yeh DD, Park YS. Improving learning efficiency of factual knowledge in medical education. Journal of surgical education. 2015;72(5):882-9.

10. Augustin M. How to learn effectively in medical school: test yourself, learn actively, and repeat in intervals. The Yale journal of biology and medicine. 2014;87(2):207.

11. McHugh D, Sherban TM, Rahman SH. Digital Spaced-learning Media: a Platform to Reduce Student Anxiety and Promote Proficiency in Medical Pharmacology Education. The FASEB Journal. 2016;30:944.7-.7.

12. Rana T, Laoteppitaks C, Zhang G, Troutman G, Chandra S. An Investigation of Anki Flashcards as a Study Tool Among First Year Medical Students Learning Anatomy. The FASEB Journal. 2020;34(S1):1-.

13. Kang SH. Spaced repetition promotes efficient and effective learning: Policy implications for instruction. Policy Insights from the Behavioral and Brain Sciences. 2016;3(1):12-9.

14. Hart-Matyas M, Taylor A, Lee HJ, Maclean MA, Hui A, Macleod A. Twelve tips for medical students to establish a collaborative flashcard project. Medical teacher. 2019;41(5):505-9.

15. Tabibian B, Upadhyay U, De A, Zarezade A, Schölkopf B, Gomez-Rodriguez M. Enhancing human learning via spaced repetition optimization. Proceedings of the National Academy of Sciences. 2019;116(10):3988-93.

16. Deng F, Gluckstein JA, Larsen DP. Student-directed retrieval practice is a predictor of medical licensing examination performance. Perspectives on medical education. 2015;4(6):308-13.

17. Entwistle N, Tait H, McCune V. Patterns of response to an approaches to studying inventory across contrasting groups and contexts. European Journal of psychology of Education. 2000;15(1):33-48.

18. Bonsaksen T, Småstuen MC, Thørrisen MM, Fong K, Lim HB, Brown T. Factor analysis of the Approaches and Study Skills Inventory for Students in a cross-cultural occupational therapy undergraduate student sample. Australian Occupational Therapy Journal. 2019;66(1):33-43.

19. Brown S, White S, Wakeling L, Naiker M. Approaches and study skills inventory for students (ASSIST) in an introductory course in chemistry. 2015.

20. Charmaz K, Belgrave L. Qualitative interviewing and grounded theory analysis. The SAGE handbook of interview research: The complexity of the craft. 2012;2:347-65.

21. Glenn D. Why Cramming Doesn't Work. Chronicle of Higher Education. 2007;53(40).

22. Morin CE, Hostetter JM, Jeudy J, Kim WG, McCabe JA, Merrow AC, et al. Spaced radiology: encouraging durable memory using spaced testing in pediatric radiology. Pediatric radiology. 2019;49(8):990-9.

23. Haidet P, Morgan RO, O'malley K, Moran BJ, Richards BF. A controlled trial of active versus passive learning strategies in a large group setting. Advances in Health Sciences Education. 2004;9(1):15-27.

24. Hill MR, Goicochea S, Merlo LJ. In their own words: stressors facing medical students in the millennial generation. Medical education online. 2018;23(1):1530558.

25. Hong WH, Vadivelu J, Daniel EGS, Sim JH. Thinking about thinking: changes in first-year medical students' metacognition and its relation to performance. Medical education online. 2015;20(1):27561.

26. Turan S, Demirel O, Sayek I. Metacognitive awareness and self-regulated learning skills of medical students in different medical curricula. Medical teacher. 2009;31(10):e477-e83.

27. Abedin NFZ, Jaafar Z, Husain S, Abdullah R. The validity of ASSIST as a measurement of learning approach among MDAB students. Procedia-Social and Behavioral Sciences. 2013;90:549-57.

28. O'Hanlon R, Laynor G. Responding to a new generation of proprietary study resources in medical education. Journal of the Medical Library Association: JMLA. 2019;107(2):251.

29. Adams NE. Bloom's taxonomy of cognitive learning objectives. Journal of the Medical Library Association: JMLA. 2015;103(3):152.

30. Marín-Paz A, Casado-Arjona V, editors. DRUG LEARNING THROUGH THE SPACED REPETITION SYSTEM USING" ANKI" AND" MNEMOSYNE" SOFTWARE IN NURSING STUDENTS. EDULEARN20 Proceedings; 2020: IATED.

31. Kaylor SK. Preventing information overload: Cognitive load theory as an instructional framework for teaching pharmacology. Journal of Nursing Education. 2014;53(2):108-11.

Figures

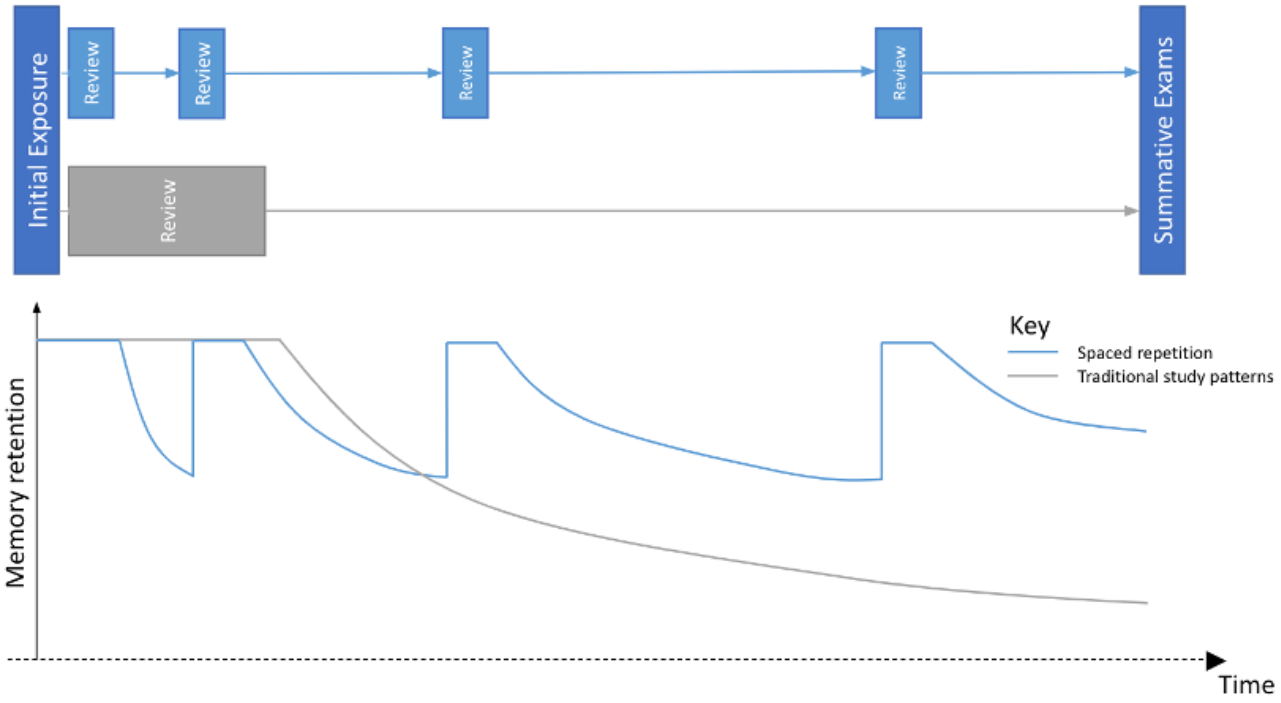

Figure 1

Comparison of exposures to a knowledge with spaced-repetition and traditional techniques. This diagram illustrates the early focus of traditional learning techniques on amassing practice, which creates an initially strong memory that ultimately decays without further revision. By comparison, spaced-repetition is known to effectively distribute meaningful practice across time to reinforce learning and slow the decay of memory, promoting long-term retention.

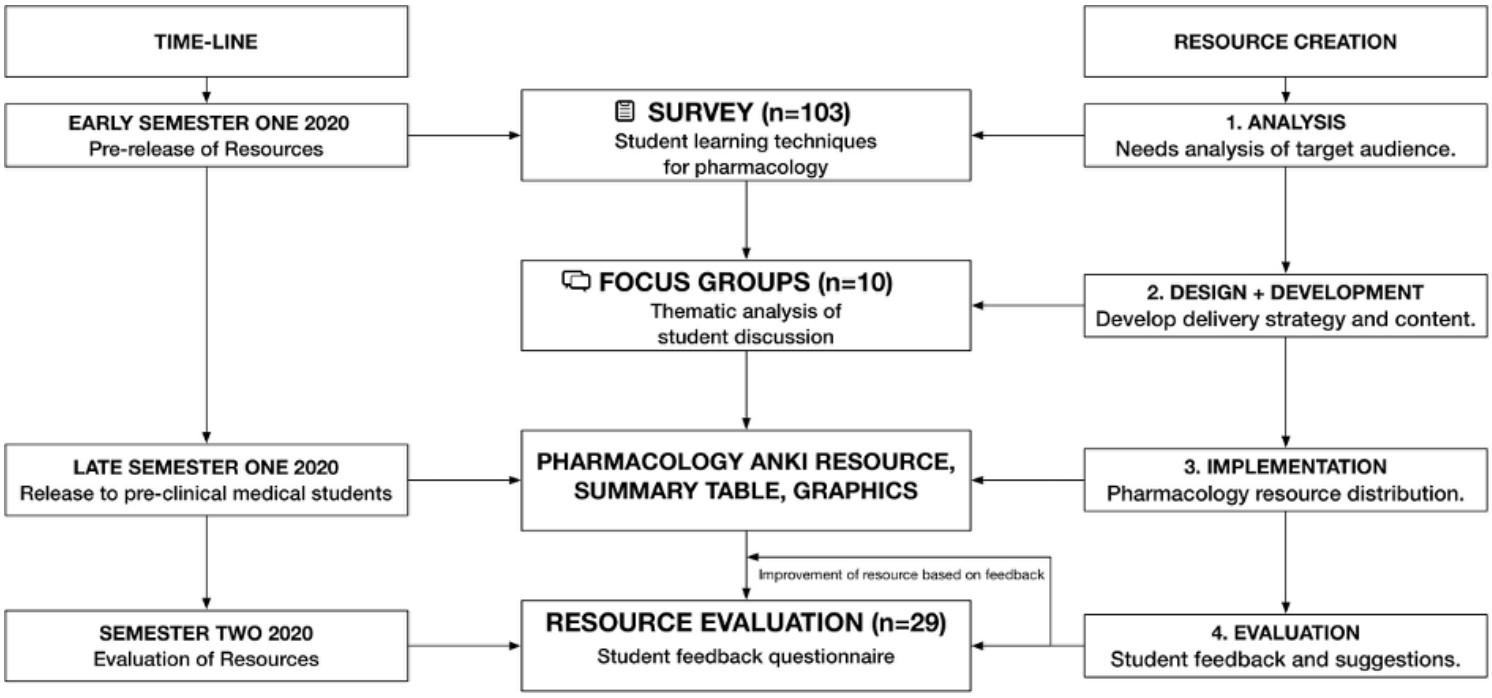

Figure 2

Flow-chart of resource development and evaluation. This diagram highlights the stepwise iterative process of resource creation. The initial scoping survey of medical students guided the design, development and implementation of bespoke pharmacology resources with evaluation and feedback processes for quality assurance and continual improvement.

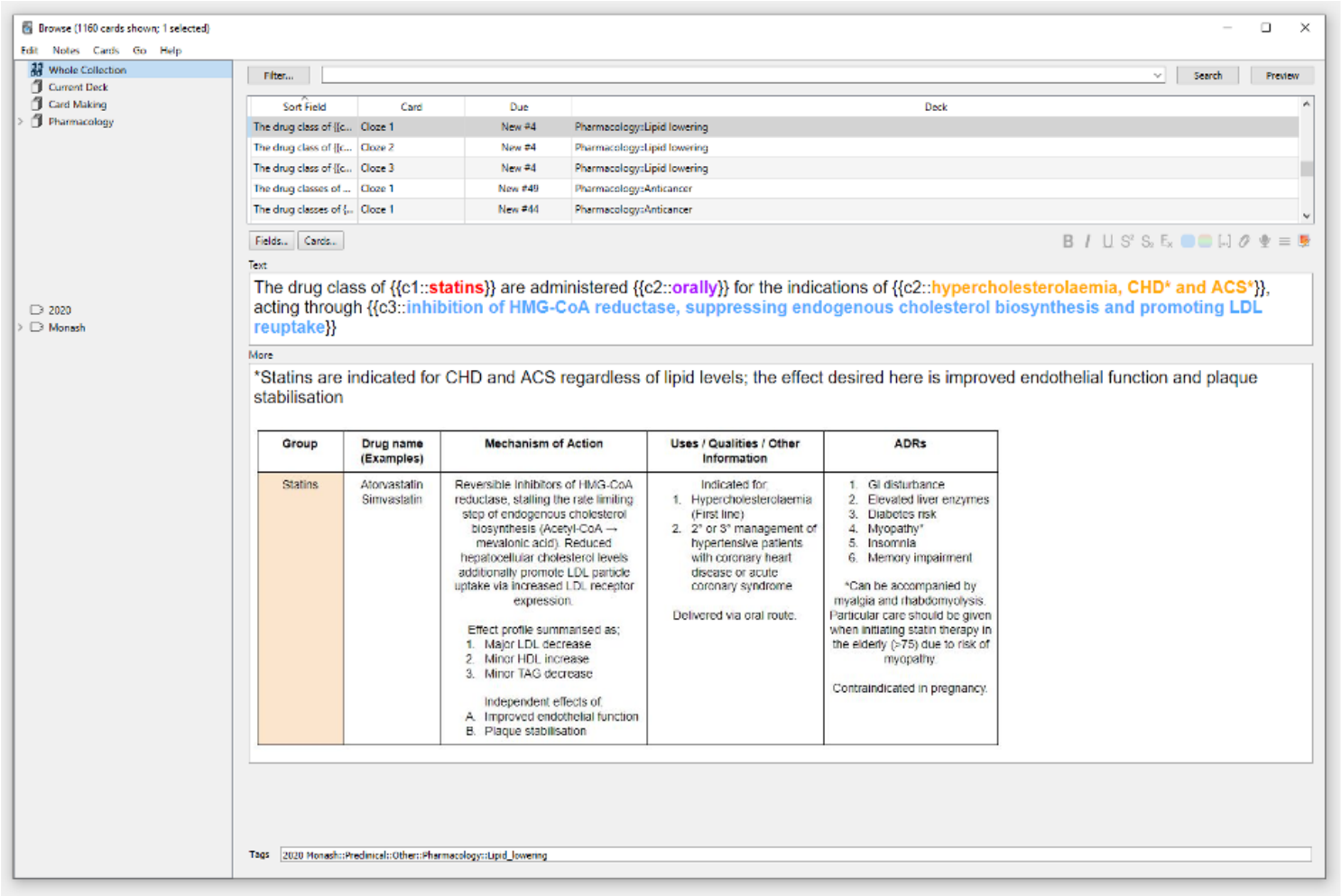

Figure 3

Example design of Anki™ pharmacology flashcards. This view shows the back-end editing view of Anki™ flashcards, demonstrating the use of three distinct clozes within a single note to produce three distinct flashcards that assess distinct items of knowledge. When reviewing, the students will be given the text section with a single cloze left out. Once answered, the program will flip the card to show the answer and the more information section of the flashcard.

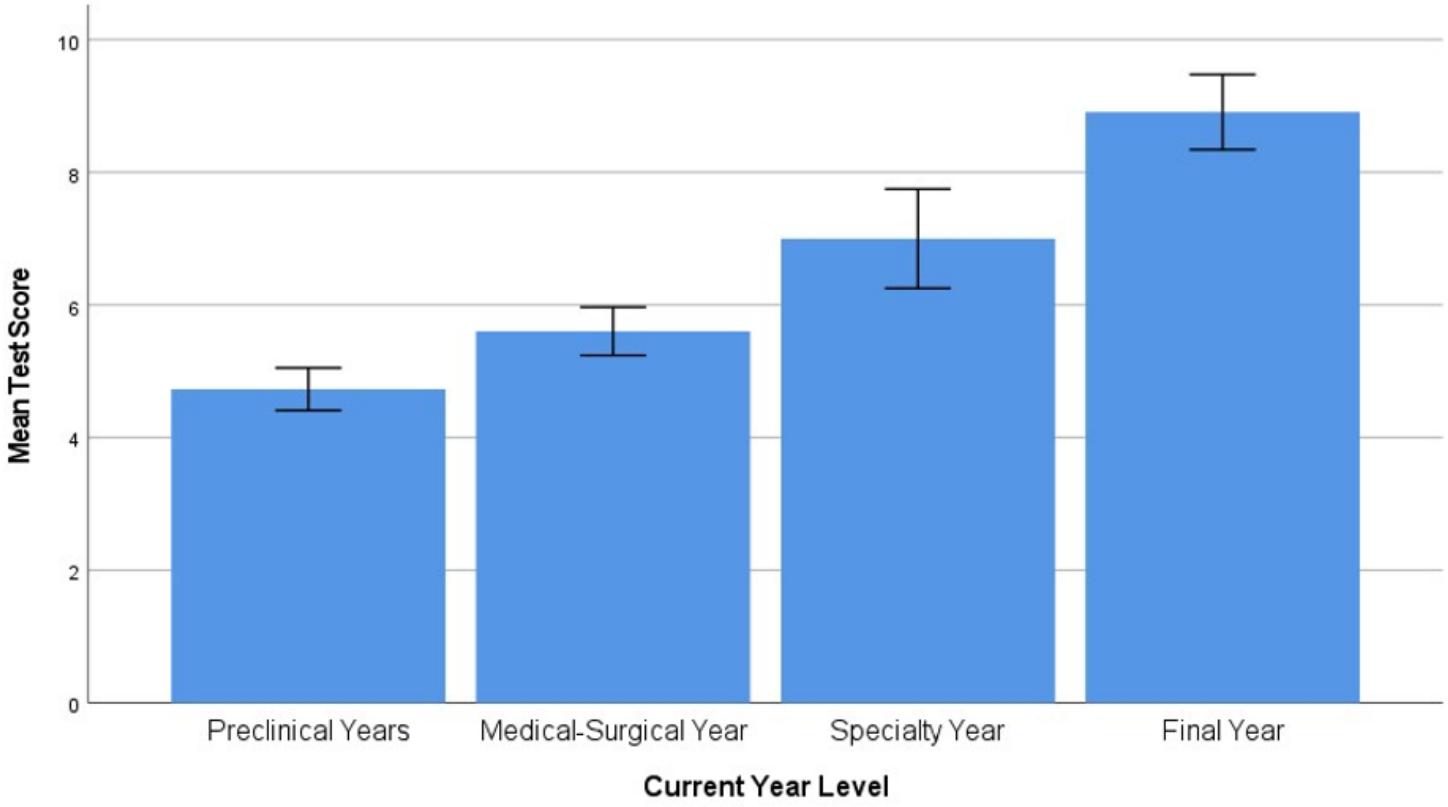

Figure 4

Test scores of the pharmacology test (Appendix 1) across course year levels. Graph data is expressed as mean score + standard error.

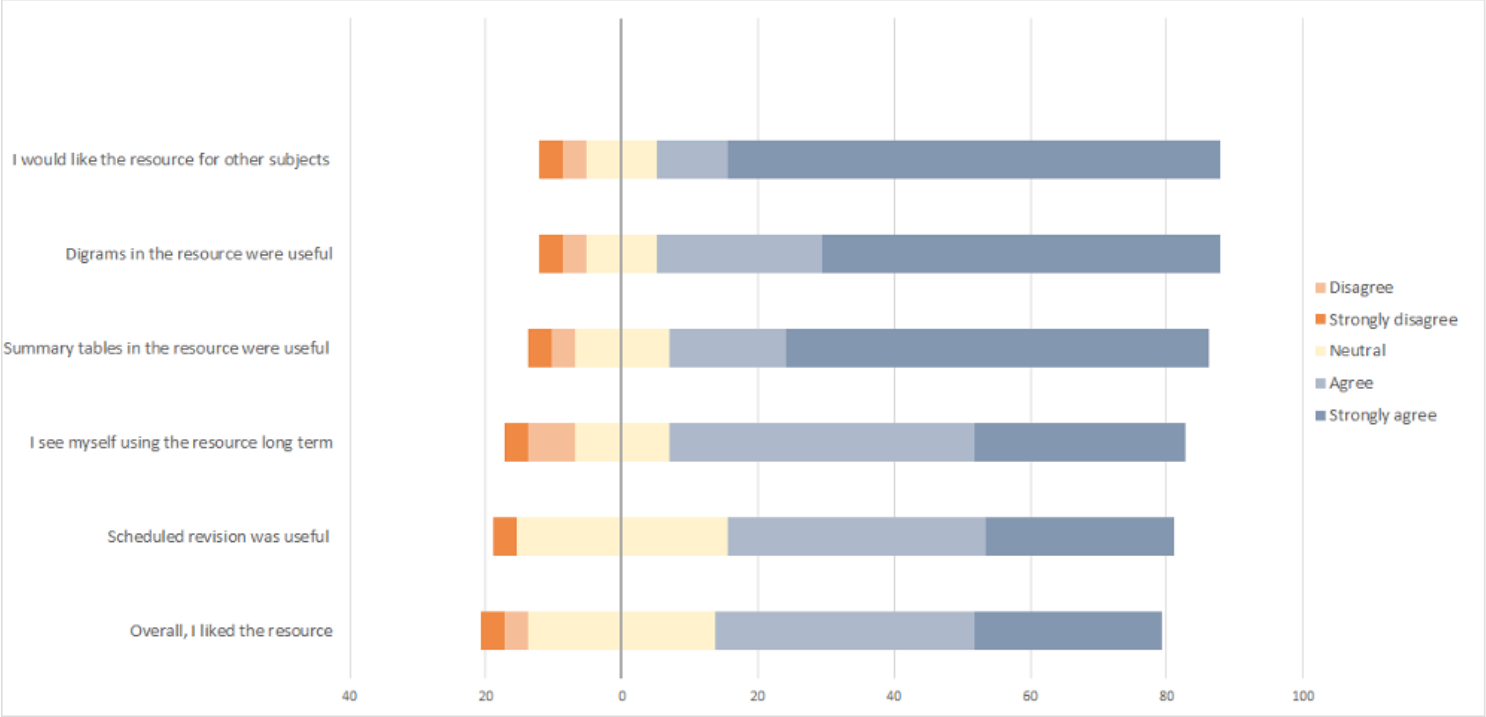

Figure 5

Likert scale rating of student-guided learning interventions. This graph demonstrates the proportion of different student responses to a 5 point Likert scale evaluating the Anki™ resource developed and implemented from insights gained via the primary survey. Students additionally evaluated supplemental resources provided alongside the Anki™ resource, which were provided in the more information section of flashcards as a means of quickly reviewing a topic.

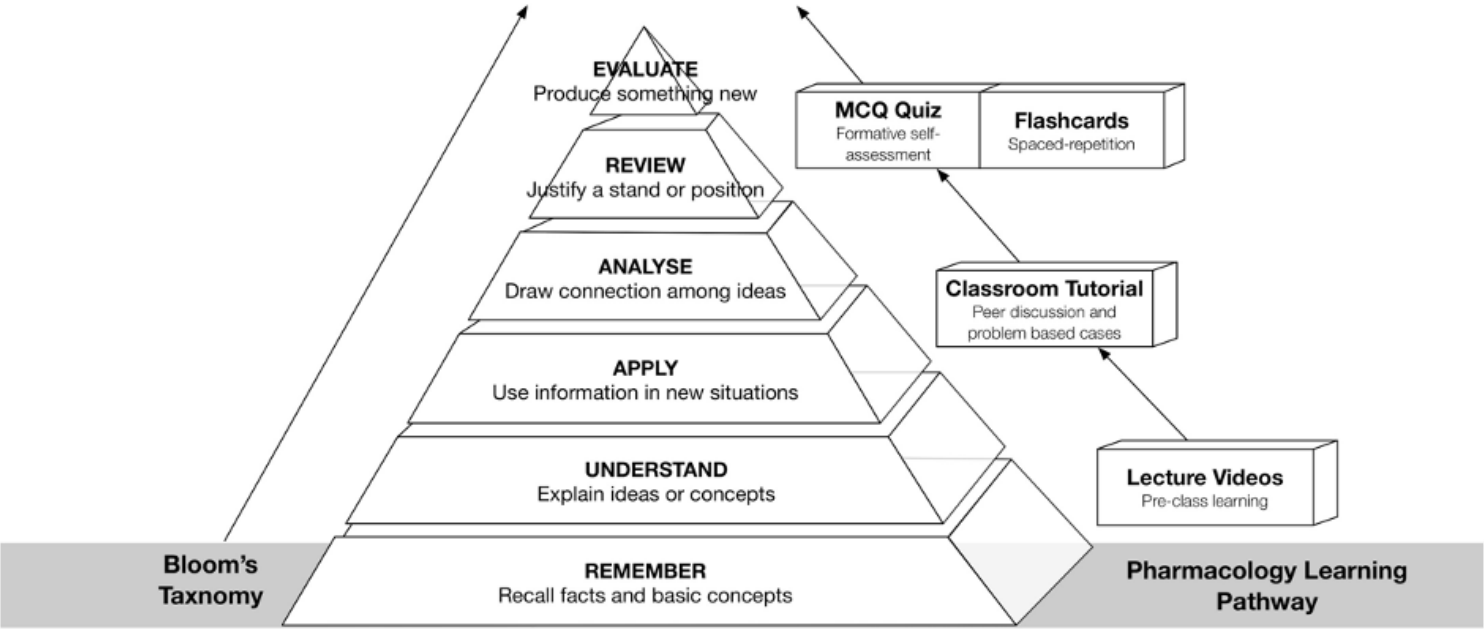

Figure 6

Incorporation of AnkiTM Spaced-repetition flashcards into pharmacology teaching articulating with Bloom's Taxonomy framework for learning. This diagram demonstrates how resources such as our intervention that assists with review of materials complements traditional methods of teaching and helps to develop a higher level of learning.

Supplementary Files

This is a list of supplementary files associated with this preprint. Click to download.

- PharmacologyAppendix1Final1.docx