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Customised study companion improves student exam performance: a retrospective study in an undergraduate medicine course

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Abstract

The aims of this study were to retrospectively analyse the relationship between usage of a customised learning tool and medical student performance in an examination, and to solicit student feedback on the learning tool. Learning theories and strategies have long suggested that reducing extraneous load, e.g. by reducing learner attention to multiple information sources, could enhance learning in medicine because of more effective use of cognitive load. A customised learning tool, termed "Study Companion" (Pha1SC), was developed that integrates key analgesic pharmacology contents from several major textbooks. The entire cohort of 231 pre-clinical Medical Year 3 students was offered Pha1SC during the academic year, and 82 of them ("Users") made use of the learning tool to various extents. Overall, Users earned higher scores than Non-users on exam questions regardless of their relation to the contents of Pha1SC. However, Users were more likely to score higher in pharmacology questions than Non-users. More importantly, Users tended to fare better on the Pha1SC-related question independently, regardless of their scores on the question not related to Pha1SC. Findings in this study support the adoption and refinement of Pha1SC to enhance student learning outcomes in pharmacology.

Introduction

Pharmacology is a discipline among other foundation sciences subjects, such as physiology and biochemistry, that constitutes the core of medical education. What may make pharmacology more distinctive is that this subject is taught in typical syllabi of both pre-clinical and clinical medical education (Jefferies et al., 2010). Starting from pre-clinical years, medical students already are inundated with an enormous amount of information in pharmacology, from basic principles of drug action to mechanisms of action and adverse effects of individual drugs. Practising physicians often would recognise patterns of presenting symptoms in their patients to make diagnoses and devise treatment strategies. Seemingly, little knowledge from pre-clinical pharmacology education is explicitly applied in clinical medicine. The importance of pre-clinical pharmacology is not trivial though, since safe and effective clinical practice builds upon having prior, solid knowledge of the foundation sciences subjects. Determining the appropriate level of pre-clinical pharmacology education to prepare a medical student for clinical training and practice remains a working problem among medical educators (Achike, 2010). As Baños et al. (2002) noted in an article about pharmacology teaching in the 21st century, the great advances in drug discovery and development means "there is no realistic possibility of teaching all facts about all drugs to each student". Pharmacology educators have to juggle between which essential drugs and their mechanisms of actions to teach, and which ones to omit in the constantly updating curriculum (Karaksha, 2018).

In pre-clinical medical education, student learning is largely motivated by earning high scores on summative assessments (Jefferies et al., 2010). It is not uncommon for pharmacology teachers in pre-clinical years, who may not be clinicians themselves, to put greater emphasis on therapeutic mechanisms than clinical application (Jefferies et al., 2010; Achike & Ogle, 2000). Information overload is a less than optimal by-product of pre-clinical health sciences education, especially considering the average physicians-in-training being more of "science users" or "medical technologists" rather than "scientists" in their future careers (Dornhorst, 1981), and the challenges faced by nursing students in approaching this subject (Mauldin, 2021). Undeniably, a good number of medical students possess remarkable memory skills, but these often prove futile in the face of information overload (Cutting & Saks, 2012). Cognitive load theory has been increasingly accepted in the medical education community (Young et al., 2014). This theory states that excessive extraneous load (e.g. vast amount of details in a pharmacology textbook) will diminish the learner's ability to process the taught materials and to convert them into long-term memory to complete the learning process (Young et al., 2014). The level of learning an individual learner achieves depends on the amount of working memory, which is limited (by definition of cognitive load theory) and is reduced to a large extent when extraneous load is high (Young et al., 2014). Different teaching strategies have been described that help to lighten extraneous load, including the recognition of split attention principle in teaching (van Merriënboer & Sweller, 2010).

Split attention principle calls for the presentation of learning materials that have been integrated from separate sources by the teacher (van Merriënboer & Sweller, 2010). The learner's limited working memory would be spared from having to locate key points from different textbooks, for example. Consequently, the learner is able to make more effective use of the working memory to carry out the learning process. The split attention principle is also considered in the delivery of pharmacology contents in several pre-clinical Medical Year 3 classes at a local university. Specifically, the teacher has compiled a supplementary learning tool called "Study Companion" that is intended to be read alongside the lecture slides on analgesic pharmacology (Pha1SC). The Study Companion (Pha1SC) contains key information sourced from several major pharmacology textbooks that is deemed to be relevant to pre-clinical medical students. Information is carefully selected to minimise extraneous load on the student learner. Students can freely access Pha1SC on the university's Learning Management System (Blackboard®). The aims of this retrospective study were to examine whether Pha1SC positively impacts student performance in the year-end examination, and to solicit student feedback on the usefulness of Pha1SC.

Methodology

A pharmacology study companion (Pha1SC) was offered to all 231 Medicine Year 3 students as a supplement to an two-hour analgesic pharmacology lecture. Data on student usage and feedback on Pha1SC were collected and analysed retrospective of the generation of Pha1SC. Without randomly assigning students to any specific treatment groups, all students could choose to use Pha1SC voluntarily. Thus, there was no control group in this quasi-experimental study. A null hypothesis was set before data analysis that states: Pha1SC usage did not improve performance on a related exam question, and the alternate hypothesis states that exam performance was better with Pha1SC.

Figure 1 shows the user interface and sample page layout of Pha1SC. Referring to Figure 1c which shows a sample page of Pha1SC describing the pharmacology of methadone, students are expected to know only the factual information presented on the left of the page (which shows the lecture slide). On the right of the page is the Pha1SC contents. As an example, methadone pharmacology is the topic of interest. Two "must-know" facts about methadone are: it has a long half-life, and it can be used for management of opioid dependence. To help the learner relate these two facts, Pha1SC provides some of the underlying reasons: e.g. methadone can be given by mouth (unlike other opioid painkillers); longer half-life translates to more convenient, less frequent dosing regimens. Opioid-dependent persons also suffer from withdrawal symptoms which can be alleviated by the long-acting methadone that can be given once every few days. Pha1SC presents in a more coherent manner elaborative but concise explanation and/or discussion of key points covered in the lecture slides. After the lecture, where students had been presented with the lecture slides (which were also available for view prior to the lecture), students could voluntarily log onto the university's learning management system (LMS: Blackboard®) to access

Pha1SC any time before the year-end examination. Pha1SC was created using ActivePresenter® (Atomi Systems, Inc., Hanoi Vietnam) and packaged as a Shareable Content Object Reference Model (SCORM) for user access on Blackboard®.

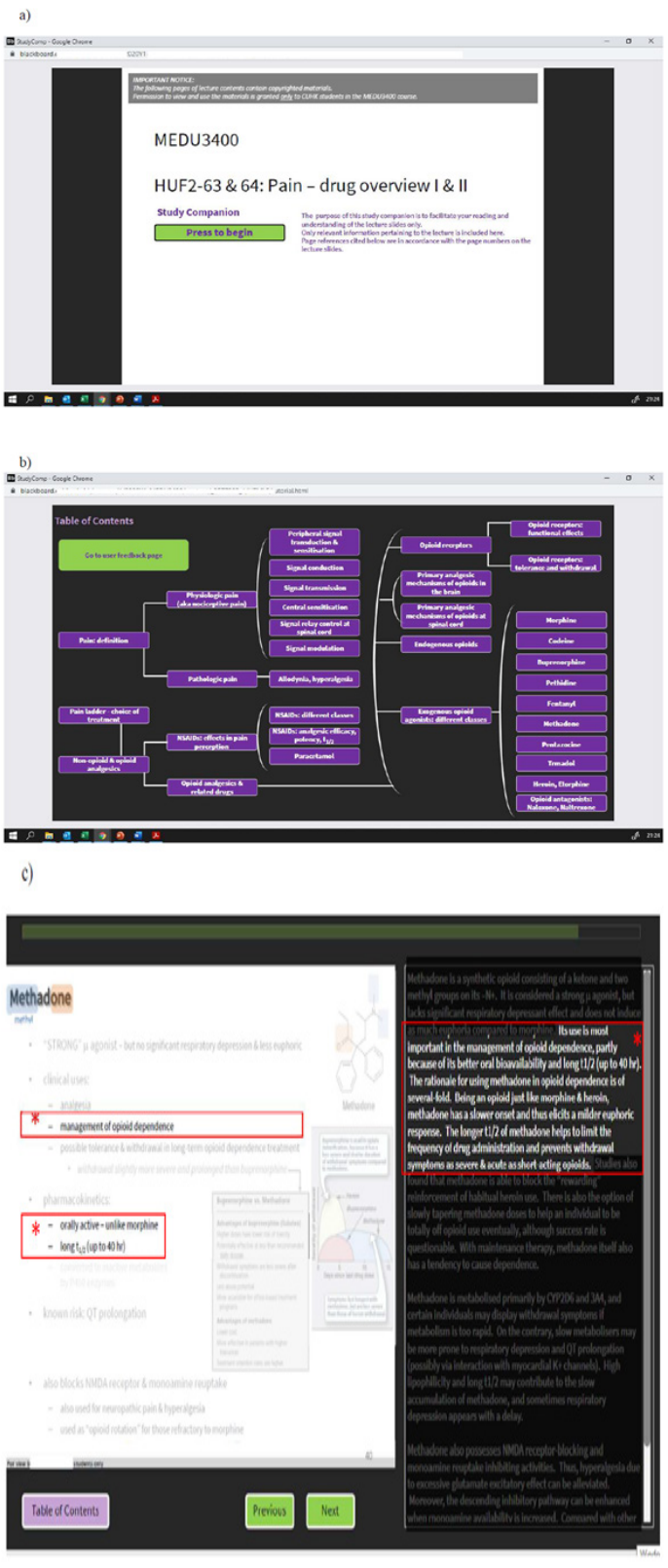


Figure 1. User interface and sample page layout of Pha1SC. a) Title page displaying lecture topic. b) Table of contents where the user can click and access a specific sub-topic of interest. c) Sample page layout showing lecture slide with alongside key points integrated from multiple sources. Refer to the boxes marked with red asterisks (*): In this example, factual points about methadone are listed on the left (showing lecture slide). These factual points are further explained with the relevant background provided on the right to help the learner understand the information better. For illustrative purposes, other parts of the sample page are shaded. Bar at the top of the page shows user progress in the lecture. d) User feedback page.

The amount of time that a user has logged onto Pha1SC was recorded on Blackboard®. To account for outliers, namely those users who logged onto but simply advanced through Pha1SC without reading any part of it, a "User" was regarded as such only if the usage time exceeds two minutes. Usage time of two minutes or shorter would fall under the category of "Non-users". Usage data of Pha1SC were analysed after the year-end examination, which consists of questions related to contents in Pha1SC as well as other topics. Student scores on short-answer questions, covering the following topics: analgesic pharmacology (Pha1Q), neuropharmacology (Pha2Q) and endocrine physiology (PhysQ), were subject to statistical analyses. Contents of Pha1Q were covered by Pha1SC, which is unrelated to the contents of either Pha2Q or PhysQ. Mean scores on the questions were compared between Users (defined as those who had registered usage of Pha1SC for two minutes or more) and Non-users (defined as the remainder of the cohort) by Mann Whitney tests. Median, 25th and 75th percentile scores were also qualitatively compared. Chi-square tests for trend were used to identify any relationship in the range of marks obtained in Pha1Q, Pha2Q or PhysQ (namely 0 to 19, 20-39, 40-59, 60-79, 80 and above, all in percentages) with Pha1SC usage. Correlation analysis was performed between scores on

Pha1Q and Pha2Q among Users and Non-users, followed by comparison of the correlation coefficients. All statistical analyses, with the exception of correlation coefficient comparison, were conducted in GraphPad Prism® version 5 (GraphPad Software, San Diego, CA, USA). An online calculator (http://comparingcorrelations.org) was used to determine statistical significance between correlation coefficients (Diedenhofen & Much, 2015).

Results

Scores obtained by Users and Non-users of Study Companion (Pha1SC) on a related exam question (Pha1Q) and on unrelated exam questions (Pha2Q, PhysQ)

Out of a total of 231 students, 82 (35%) of them (referred to as "Users") read the Study Companion (Pha1SC) for a meaningful duration (i.e. two. minutes or more as stated earlier). On the pharmacology question (Pha1Q) which tests on contents supplemented in Pha1SC, the mean scores were significantly higher compared to Non-users who did not register usage of the study companion for more than two minutes (Table 1). Table 1 also shows that the median, 25th and 75th percentile scores were higher among Users.

The study companion (Pha1SC) does not include contents that are tested on one other pharmacology question (Pha2Q) and one other physiology question (PhysQ). Among Users, the mean scores were significantly higher than Non-Users on both questions (Table 1). Other parameters such as median, 25th and 75th percentile scores were higher among Users as well, although the differences were smaller in the physiology question (PhysQ).

Table 1. Student scores (from a total of 231 students) on short-answer questions in a Medical Year 3 final examination.

	Users (n = 82)				Non-users (n = 149)			
	mean ± S.D.	median	25th	75th	mean ± S.D.	median	25th	75th
Pha1Q	65.24 ± 14.59 (U = 5066; P = 0.0294 vs Non-user)	70	57.5	80	58.93 ± 19.73	60	50	70
Pha2Q	72.93 ± 16.40 (U = 4744; P = 0.0048 vs Non-user)	75	60	85	64.36 ± 22.26	70	55	80
PhysQ	56.95 ± 10.03 (U = 4658; P = 0.0028 vs Non-user)	56.67	51.67	62.09	51.42 ± 12.55	51.67	43.33	60.00

Scores (mean ± S.D.) obtained by Users (defined as those who had registered usage of a customised study companion (Pha1SC) for two minutes or more) and Non-users (defined as the remainder of the student cohort) on three questions of the following topics: analgesic pharmacology (Pha1Q), neuropharmacology (Pha2Q) and endocrine physiology (PhysQ) were compared. P values smaller than 0.05 as computed from Mann Whitney tests are considered statistically significant. Abbreviation: U = Mann-Whitney U score.

Relationship between Pha1SC usage and Ph1Q, Pha2Q and PhysQ scores

The higher mean scores on both related (Pha1Q) and unrelated (Pha2Q, PhysQ) questions among Users did not serve to determine the effectiveness of the Study Companion (Pha1SC) yet. It is conceivable that Users may be more able learners in general, who tend to perform better in an exam, with or without Pha1SC. No statistically significant relationship between usage duration and scores on any question was observed: Spearman correlation coefficients (P values in parentheses) are -0.021 (0.8483) for Pha1Q, -0.005 (0.9674) for Pha2Q, 0.1973 (0.0756) for PhysQ. On the other hand, results from Chi-square ($\chi 2$) tests reveal that Users of Pha1SC were more likely to score in the higher mark range on both Pha1Q ($\chi 2 = 5.576$; $P = 0.0182$) and Pha2Q ($\chi 2 = 5.298$; $P = 0.0214$) but not PhysQ ($\chi 2 = 1.579$; $P = 0.2089$). Figure 2 shows that higher mark ranges in Pha1Q and Pha2Q were more favoured by Pha1SC usage, which has no impact on PhysQ scores.

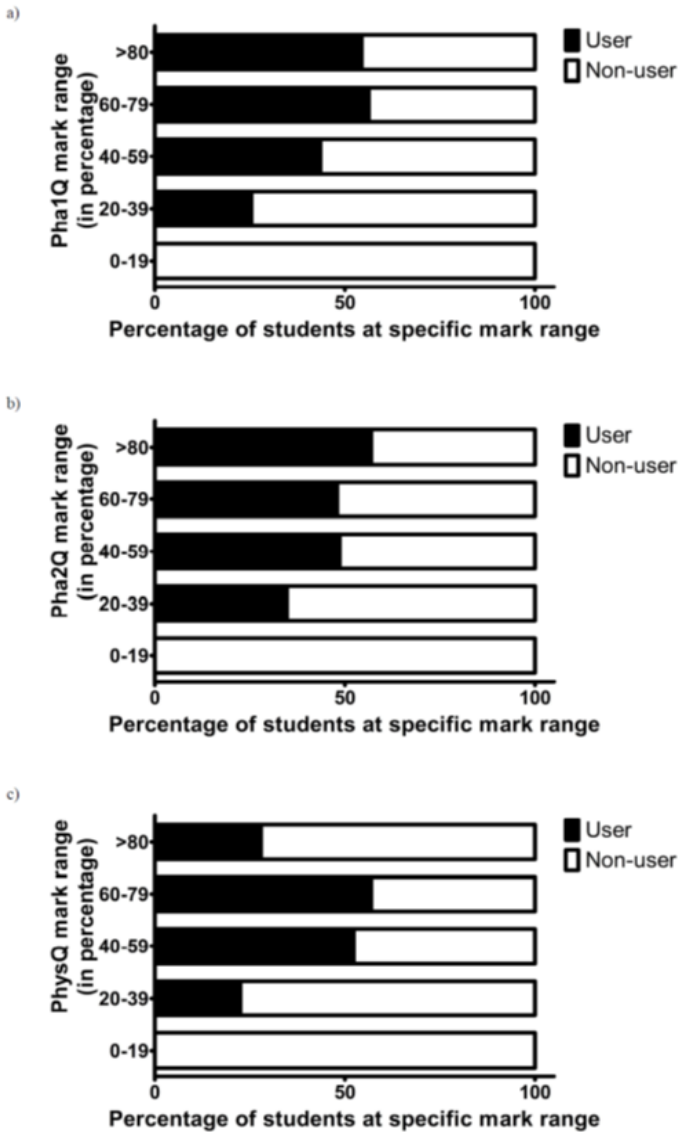


Figure 2. Stacked bar charts of scores obtained by Users and Non-users of Pha1SC. Scores are expressed as mark ranges from 0 to 19, 20 to 39, 40 to 59, 60 to 79, and 80 or greater (in percentages) on three questions related to: a) analgesic pharmacology (Pha1Q), b) neuropharmacology (Pha2Q), c) endocrine physiology (PhysQ).

Correlation differences between User and Non-user scores on the pharmacology questions (Pha1Q and Pha2Q)

The positive impact of Pha1SC usage on student performance on both pharmacology questions (one related to Pha1SC – Pha1Q; one unrelated – Pha2Q) was demonstrated. However, it remains unclear whether Pha1SC usage produced an outcome that is specific to its intended pharmacology question content only (i.e. Pha1Q). Figure 3 shows the distribution of Pha1Q and Pha2Q scores among Users and Non-users.

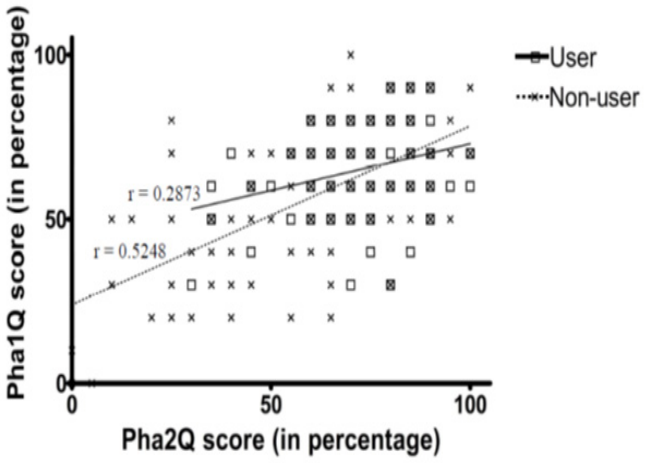


Figure 3. Correlation between scores on Pha1Q and Pha2Q obtained by Users and Non-users of Pha1SC.

Table 2 shows the results of correlation analyses, separately within Users and Non-users, between Pha1Q and Pha2Q. Correlation was significantly lower among Users, suggesting individual Users earned higher Pha1Q scores more independently of Pha2Q scores, a result more attributable to Pha1SC usage. In other words, Users who achieved higher Pha1Q scores after Pha1SC usage were no more likely than Non-Users to obtain higher Pha2Q scores. In contrast, individual Non-users' Pha1Q and Pha2Q scores were more correlated in the absence of Pha1SC intervention.

Table 2. Correlation analyses of student scores on two pharmacology questions (Pha1Q and Pha2Q) in a Medical Year 3 year-end examination.

	Users (r1)	Non-users (r2)	Comparison of r1 and r2
Pha1Q vs Pha2Q	0.2873 (P = 0.0089)	0.5248 (P < 0.0001)	P = 0.0397 (correlations are different)

Spearman correlation coefficients (r1 and r2) represent values among Users and Non-users, respectively. The two values (r1 and r2) were subject to comparison subsequently based on principles described by Diedenhofen & Much (2015). P values smaller than 0.05 are considered statistically significant.

User feedback to Pha1SC

Users may opt to fill out a survey after using part or all of Pha1SC (Figure 1d). Out of 82 Users, 26 provided their views to two statements and a few also wrote additional comments. On a 5-point Likert scale, all respondents selected either "Strongly Agree" or "Somewhat Agree" to statement 1) "You find this study companion useful in helping you understand lecture contents". To statement 2) "You find this study companion useful in explaining contents that are beyond the scope of the lecture (i.e. materials that

are non-examinable)", all respondents selected "Strongly Agree" or "Somewhat Agree", except two who selected "Neutral". Figure 4 shows the distribution of user feedback to the two statements on Pha1SC usage. Representative user feedbacks are shown in Figure 5.

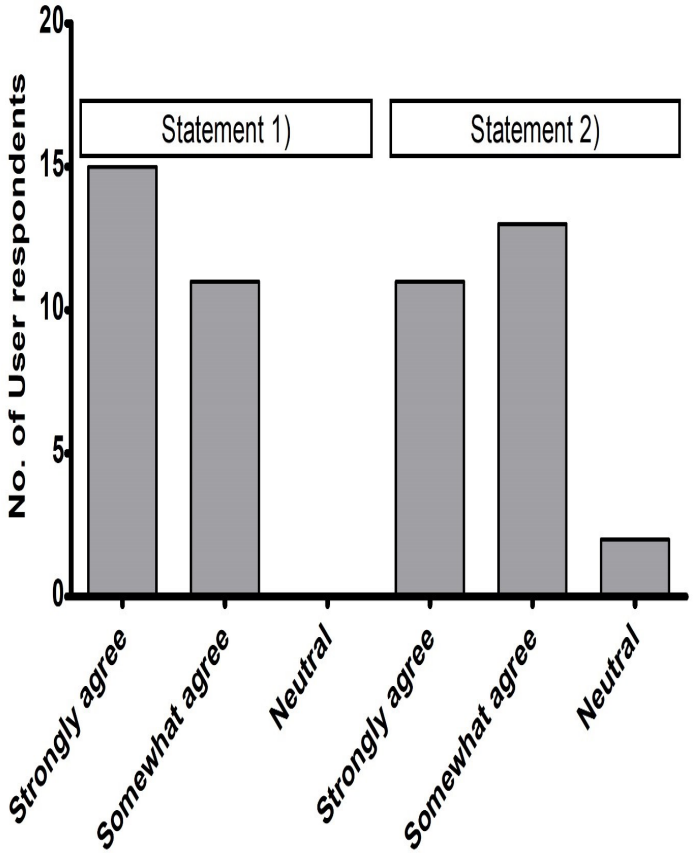


Figure 4. Users' views on usefulness of Pha1SC. 26 out of 82 Users expressed their views using a 5-point Likert scale on two statements that ask whether Pha1SC was useful in helping the understanding of lecture contents (Statement 1) and contents beyond the scope of the lecture (Statement 2). All the expressed views were accounted for in the bar graph above.

4.
(Attempt 1 of 1)
Grade Previous Item
Grade Next Item
LEARNING OBJECT INTERACTIONS

Learning Object Name	Total Time	Status	Scaled Score	Learner Response	Result
Study Companion for Analgesics	1 hour, 43 minutes, 51.42 seconds	N/A	N/A	N/A	N/A
StudyComp	1 hour, 43 minutes, 51.42 seconds	N/A	N/A	N/A	N/A

51.
(Attempt 1 of 1)
Grade Previous Item
Grade Next Item
LEARNING OBJECT INTERACTIONS

Learning Object Name	Total Time	Status	Scaled Score	Learner Response	Result
Study Companion for Analgesics	1 hour, 39 minutes, 9.78 seconds	complete	0%	N/A	N/A
StudyComp	1 hour, 39 minutes, 9.78 seconds	complete	0%	N/A	N/A
studyCompLikert_0	N/A	N/A	N/A	5	5
studyCompLikert_1	N/A	N/A	N/A	5	5
63_30	N/A	N/A	N/A	good for revision	good for revision

29.
(Attempt 1 of 1)
Grade Previous Item
Grade Next Item
LEARNING OBJECT INTERACTIONS

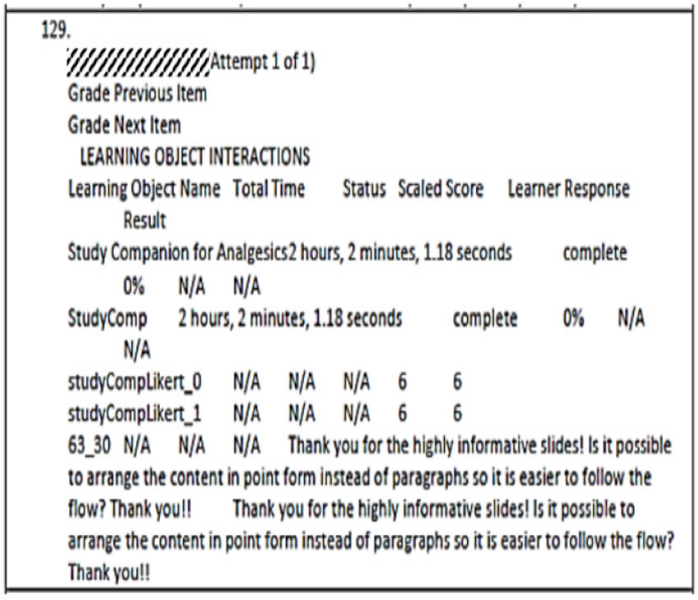
Learning Object Name	Total Time	Status	Scaled Score	Learner Response	Result
Study Companion for Analgesics	1 hour, 23 minutes, 1.6 seconds	complete	0%	N/A	N/A
StudyComp	1 hour, 23 minutes, 1.6 seconds	complete	0%	N/A	N/A
studyCompLikert_0	N/A	N/A	N/A	6	6
studyCompLikert_1	N/A	N/A	N/A	6	6

88.
(Attempt 1 of 1)
Grade Previous Item
Grade Next Item
LEARNING OBJECT INTERACTIONS

Learning Object Name	Total Time	Status	Scaled Score	Learner Response	Result
Study Companion for Analgesics	5 hours, 34 minutes, 28.74 seconds	complete	0%	N/A	N/A
StudyComp	5 hours, 34 minutes, 28.74 seconds	complete	0%	N/A	N/A
studyCompLikert_0	N/A	N/A	N/A	6	6
studyCompLikert_1	N/A	N/A	N/A	6	6
63_30	N/A	N/A	N/A	Could not copy the words inside this study companion, better if the pdf file is also provided	Could not copy the words inside this study companion, better if the pdf file is also provided

90.
(Attempt 1 of 1)
Grade Previous Item
Grade Next Item
LEARNING OBJECT INTERACTIONS

Learning Object Name	Total Time	Status	Scaled Score	Learner Response	Result
Study Companion for Analgesics	6 hours, 11 minutes, 26.2 seconds	complete	0%	N/A	N/A
StudyComp	6 hours, 11 minutes, 26.2 seconds	complete	0%	N/A	N/A
studyCompLikert_0	N/A	N/A	N/A	6	6
studyCompLikert_1	N/A	N/A	N/A	6	6
63_30	N/A	N/A	N/A	thank you!	thank you!


129.

//////////////Attempt 1 of 1)

Grade Previous Item

Grade Next Item

LEARNING OBJECT INTERACTIONS

Learning Object Name	Total Time	Status	Scaled Score	Learner Response	Result
Study Companion for Analgesics	2 hours, 2 minutes, 1.18 seconds	complete	0%	N/A	N/A
StudyComp	2 hours, 2 minutes, 1.18 seconds	complete	0%	N/A	N/A
studyCompLikert_0	N/A	N/A	N/A	6	6
studyCompLikert_1	N/A	N/A	N/A	6	6
63_30	N/A	N/A	N/A	Thank you for the highly informative slides! Is it possible to arrange the content in point form instead of paragraphs so it is easier to follow the flow? Thank you!!	Thank you for the highly informative slides! Is it possible to arrange the content in point form instead of paragraphs so it is easier to follow the flow? Thank you!!

Figure 5. Representative user feedbacks of Pha1SC. User identities are redacted. The headings "studyCompLikert_0" and "studyCompLikert_1" refer to statements 1) and 2) as stated in the text, respectively. The statements aim at determining user satisfaction on contents covered in class as well as contents that fall outside the scope of the course. Users opted in to give a 5-point rating ranging from "Strongly Disagree" (denoted by a system-built-in numerical value of "2") to "Strongly Agree" (denoted by a system-built-in numerical value of "6") to the statements.

Discussion

A number of teaching methods have been proposed to tackle the problem of information overload in medical education, especially in the area of pharmacology education. More recently with reference to cognitive load theory, strategies designed to reduce extraneous load and to improve intrinsic load presentation are put into use so that germane load on the learner is optimised for learning (van Merriënboer & Sweller, 2010). An ideal medical curriculum should help a student to build a solid knowledge base (Achike and Ogle, 2000) for the sake of enhanced patient safety, considering that one in five medication errors could potentially be attributed to poor understanding of the pharmacological properties of drugs (Rubaiy, 2021). Pharmacology educators are tasked to select an appropriate breadth and depth of contents for teaching, to enhance student learning and yet to prevent information overload. Reducing extraneous load with reference to split attention principle represents one way to free up the learner's working memory to accommodate other cognitive loads to effect the learning process (van Merriënboer & Sweller, 2010).

Extraneous load experienced by the pre-clinical Medical Year 3 students in this study was reduced by the availability of a customised analgesic pharmacology Study Companion (Pha1SC) that integrates information from multiple sources. Students' learning efforts need not be expended on locating useful information from textbooks, but rather to focus on the essential contents as presented in the lecture instead. A similar practice in nursing pharmacology education was reported elsewhere. Kaylor (2014) described the use of annotated lecture slides in the Notes section of Powerpoint® presentations, which were well-received by the students as reflected in qualitative feedbacks (Kaylor, 2014). User feedback in the present study was also overwhelmingly positive. Furthermore, findings in this study suggest greater correlation between exam performance and Pha1SC usage. As pre-clinical students are more driven by assessment performances in their learning (Jefferies et al., 2010), a comprehensive, yet concise, Study Companion (Pha1SC) that provides the learner a "one-stop" source of information would likely appeal to students. Considering its non-mandatory nature, the fact that over one-third of all students opted to use Pha1SC to various extents represents a reasonable value of this learning tool. While the Users might be more self-directed learners as reflected in their overall better performance on questions not related to Pha1SC, their scores on the related pharmacology question (Pha1Q) indicate a less significant relationship with their individual ability. Scores of Non-users of Pha1SC on Pha1Q (related to Pha1SC) and Pha2Q (unrelated to Pha1SC) were more strongly correlated, as shown by the findings in this study. One of the "Twelve Tips" for health professions education by Gooding et al. (2016) states that to reduce extraneous load, the essential material (text and graphics) should be presented together. The present Pha1SC, as well as the method described by Kaylor (2014), did exactly as suggested (Gooding et al., 2016) and demonstrated promising results. The use of enrichment tools to improve student learning outputs has been in long practice across many disciplines. In medical education, animations and narrated videos play crucial roles in illustrating pharmacological and physiological concepts (Karaksha et al., 2011; Young et al., 2014) and in demonstrating surgical techniques (Bernado et al., 2004). Interestingly though, animations may not be preferable over traditional lecture slides (van Wyk, 2018), as long as extraneous cognitive load is minimal, e.g. by integrating contents from multiple sources, or by combining different modes of information delivery (Mauldin, 2018). Cognitive load of the student learner can be optimised when these learning tools are designed and used appropriately. In spite of technological advances, one traditional learning tool – textbook – remains an important information source for the learner. Medical textbooks are often voluminous, and plenty of valuable information is contained in them. For a student learner, deciding on a single textbook as a major reference is already a challenging endeavour. Even more frustrating is the enormous task of selecting which of the textbook contents should a student be more concerned with. In an article on the overload of pharmacology information, it is said that the goal of teaching pharmacology to medical students is to equip them with a basic knowledge of drugs in order to prescribe them wisely (Achike and Ogle, 2000). Thus, the pharmacology teacher bears the responsibility to provide a succinct yet credible source of the most important contents to prevent overloading students who are in the early phase of undergraduate studies. The current Pha1SC shares similar features of the nursing pharmacology lecture notes (Kaylor, 2014) but also has marked differences in serving distinct student populations. Instead of showing bullet-point items, Pha1SC contents are presented in prose so the learner may better appreciate the logics behind interlinking concepts, as exemplified in Figure 1c) and

described in the Methods section. Timing the release of the lecture slides and Pha1SC for student access may also be significant in further reducing the extraneous load. Pha1SC was only available to students after they have viewed the lecture slides, which already could be accessed prior to the lecture. The learner would have the opportunity to scan through the lecture slides before learning these contents in class. After the lecture, the learner would be able to consult Pha1SC directly with the accompanying lecture slides. This sequential release of contents in Pha1SC may also help the learner in managing intrinsic load. Key facts about a topic (e.g. properties of a drug) are presented first in point form in lecture slides, followed by Pha1SC which connect these facts together (e.g. how individual properties of a drug contribute to its preferred usage). The contents of Pha1SC then serve as a stimulus in forming a germane load to effect learning as a constituent of the intrinsic load (Young et al., 2014).

In future versions of Pha1SC, other teaching methods may also be considered in order to further enhance students' learning experiences. Cutting and Saks (2012) wrote on tips to support medical education (Cutting & Saks, 2012). One of the tips describes the integration of learning contents provided by the teacher that serves as triggers to students to compare and contrast related topics (Cutting & Saks, 2012). The learner will be required to re-organise information that is provided and which fosters deeper learning in the process. As such, open-ended questions may be included in a newer version of Pha1SC that allows user responses to be recorded and feedback to be provided via the LMS platform. As another tip suggested by Cutting & Saks (2012), these in-depth questions with instructor feedback should enhance the ability of the learner to monitor their own learning. Presently, Users of Pha1SC could already monitor their own progress of the analgesic pharmacology lecture by referring to a progress bar at the top of the user interface (Figure 1c). Nevertheless, the learner will certainly benefit more with the inclusion of interactivity elements (e.g. open-ended questions or simpler recall-of-facts questions), which offer ideas in the development of an upgraded, enhanced version of Pha1SC.

A good balance needs to be struck in creating learning tools, such as the said study companion, with desirable difficulty levels (Cutting & Saks, 2012; Gooding et al., 2016) that the learner can choose according to their proficiency on the topic. Presentation of contents that are too difficult inevitably overwhelms the learner's intrinsic load and consequently exhausts the total cognitive load available for learning. There are also concerns of expertise reversal effect when more able learners may be disengaged from learning the content if it is presented at an excessively elementary level (van Merriënboer & Sweller, 2010). Therefore, it is the responsibility of the teacher to design learning tools wisely and to guide learners of varying abilities in the knowledge acquisition process. Ideally, a refined version of the study companion (Pha1SC) will cater to the learning preferences and needs of the entire student cohort universally. Future versions of the study companion can be improved by categorising information into "must-knows", "explanation of the must-knows", and "extras". "Extras" of a Study Companion are to be read by students who want to explore further on the topic. This "extra" reading may be done before or after course assessments. "Explanation of the must-knows", sometimes encompassing advanced pharmacological concepts or drug mechanisms could pose a great challenge to both the teacher and the student. In a review article, Engels (2018) emphasises on the importance of pedagogical content knowledge (PCK) in teaching pharmacology, where the teacher should be an expert not only in the subject content, but also in the range of teaching methods to deliver the content to students (Engels, 2018). Mnemonics represent an aspect of PCK a teacher frequently uses to target novice learners in medicine (Young et al., 2014). An future, upgraded version of Pha1SC (or other Study Companions in general) will require a more advanced comprehension and application of PCK, with a broader variety of assessments that allow more precise measurement of student understanding of different pharmacology topics. The teacher bears the responsibility to load the student learner with the appropriate amount of subject contents and at the appropriate difficulty level. As stated earlier, suggested improvements of an existing study companion may combine the introduction of open-ended questions and categorisation of contents to engage and encourage the student learner to gradually adapt to an active learning behaviour. One of the tips on the science of learning refers to the creation of retrieval exercises where the learner needs to generate answers to questions, rather than choosing from a range of options (Gooding et al., 2014). Moreover, provision of regular feedback serves to enhance learning further (Gooding et al., 2014). A more advanced design of Pha1SC (and similar study companions in general) may support near real-time feedback by the teacher who may be alerted at a given time every day whenever a student works on the retrieval exercise. Where "must-knows" contents are distinguished from "extra" ones, students are invited to transform into active learners. The learner can assume control on the rate and depth of learning while the bare minimum of content knowledge is maintained. A transformation from a teacher-centred to a student-centred approach of learning can occur with a mixture of the traditional mode of content delivery and retrieval exercises with feedback to the learner. The learning tool described and evaluated in this study has the potential to be further promoted in other subject areas, noting that a number of these have also invested into the student-centred approach of learning (Wright, 2011).

Teaching the right amount of information at an appropriate level of difficulty remains an ongoing challenge in medical education. Data from this retrospective study provide solid evidence of improving learning outcomes with the reduction of extraneous load in pharmacology. An indigenous learning tool (a Study Companion) that integrates key information from multiple sources resulted in better student performance in a summative assessment of a medical course. Higher scores on questions were attributed to the specific area of content coverage in the Study Companion. It is envisaged that further developments based on this tool and others will serve as practical means to optimise the cognitive load in facilitating learning in medicine and other disciplines.

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