The self-assessment dilemma: an open-source, ethical method using Matlab to formulate multiple-choice quiz questions for online reinforcement


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The Self-Assessment Dilemma: an open-source, ethical method using Matlab to formulate multiple choice quiz questions for online reinforcement

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Abstract

INTRODUCTION: Student self-assessment using computer-based quizzes has been shown to increase subject memory and engagement. Some types of self-assessment quiz can be associated with a dilemma between 1) medical students who want the self-assessment quiz to be clearly related to upcoming summative assessments or curated by the exam-setters, and 2) university administrators and ethics committees who want clear guarantees that the self-assessment quizzes are not based on the summative assessments or made by instructors familiar with the exam bank of items. METHODS: An algorithm in Matlab was developed to formulate multiple choice questions for both ion transport proteins and pharmacology. A resulting question/item subset was uploaded to the Synap online self-quiz web platform, and 48 year 1 medical students engaged with it for 3 weeks. Anonymized engagement statistics for students were provided by the Synap platform, and a paper-based exit questionnaire with an 80% response rate (n = 44) measured satisfaction. RESULTS: Four times as many students accessed the quiz system via laptop compared to phone/tablet. Of 391 questions/items, over 11,749 attempts were made. Greater than 80% of respondents agreed with each of the positive statements (ease of use, enjoyed, engaged more, learned more, and wanted it to be extended to other modules). CONCLUSIONS: Despite simplistic questions and rote-memorization, the questions developed by this system were engaged with and received positively. Students strongly supported extending the system.

Keywords

online assessment, formative assessment, item construction, Matlab, self-regulated learning
New and Noteworthy

An open-source Matlab script is made available for formulating MCQs for online learning reinforcement. This script can be used to circumvent the ethical conflict between students who want questions relevant to the final exam and ethics committees who insist on formative questions that do not give away the content of the final exam and that are free from intellectual property issues. The questions are formulated from an easily adaptable and inspectable Excel spreadsheet.

Introduction

The sheer bulk and rate of what students are expected to learn during the first two years of medical school has hypertrophied [01; 06]. In contemporary integrated curricula, physiology educators can be expected to engage with active learning that clearly integrates physiological mechanisms with pharmacology, anatomy and other realms of biomedical sciences, which can lead to challenges in teaching [17; 08].

Student self-assessment has been proposed as the best avenue for development of strategies for improved student motivation, engagement, and learning [12]. Formative assessment is a cornerstone of self-regulated learning [13], and computerizing self-assessment methods increases the speed of feedback [10], which may improve motivation, engagement, memory and performance. Student self-assessment using computer-based quizzes has been shown to increase subject memory and engagement while decreasing mind wandering [20]. Online quizzes are popular with students, as evidenced by the number of well-known commercial enterprises that have appeared for online self-testing,
Matlab MCQs

and the use of these companies is popular with students. Many educational institutions have also developed their own in-house formative self-testing software for student learning.

Formulating Formative Quiz Items for Online Self-Assessment

The creation of the quiz questions for these educational materials is normally viewed as a necessary but acceptable educational chore. Students can be incentivized to provide instructors with these questions [18]. Many students spontaneously decide to create their own questions for these online quiz platforms, and the students who create such quizzes (that they share with friends) certainly benefit in their own learning from creating the quizzes [21]. However, many of the less enthusiastic students do not have the motivation to engage with the question-making process. On the other hand, there are countless online sources of such questions, both commercially available quizzes from publishers, as well as freely available quiz questions that can be harvested online. However, these pre-existing questions have the disadvantage that they are not tailored to the course that the instructor is leading (or that the students want to learn). Also, harvesting such questions raises intellectual property issues for course organizers.

During a focus group with medical students preceding our research into creating an online self-assessment project (Participant and Public Involvement with experimental design, PPI), a repeatedly- and strongly-voiced opinion was that the benefit and engagement with such a quiz system would be strongly determined by the curation of the questions. In particular, the students would only want questions directly related to their course, preferably designed or approved of by the course organizers/examiners. Students felt that taking random quizzes online would be wasteful of time (and unnecessarily
Matlab MCQs

discouraging), because there would be questions covering information that the students have not been taught. The students did not want to engage with quiz questions that they would not be held accountable for on the summative final knowledge test. This fits with theory on formative self-assessment, which should be criterion-referenced [02]. These demands from our students also fits within the theoretical construct that formative assessments should provide clear and specific feedback about the existing gap between the actual and desired levels of performance [14]; feedback to students remains an aspect of education that lags behind others in terms of student approval ratings [23]. In brief, taking externally formulated tests (i.e. from text book publishers), which do not directly match the assessment materials within the specific course being taught, was of no interest to our students.

When presenting this project to our local ethics committee, the committee brought to our attention a fundamental ethical conundrum arising from our focus group. While the students wanted the questions to be created (or at least curated) by the course organizers who knew the relevance of the material to the final exam, the ethics committee needed a guarantee that the course organizers were not explicitly designing the self-quizz questions. The ethics committee pointed out that the course organizers had a conflict of interest when designing such self-quizz questions, as the course organizers might be revealing the questions on the final exam to the students – possibly without meaning to. This risk of porous “walls” between the process of writing items for the self-assessment vs. the summative assessments is an ongoing dilemma for self-assessment assessment creation. We concluded that the only possible way past this apparent ethical impasse was to use a computer to design the self-assessment questions, with the input to the algorithm being information that
Matlab MCQs

was freely available to the students in the course learning materials (i.e. criterion-referenced from learning outcomes).

The project investigated year 1 undergraduate BMBS (Medical) students in a ten-week module for 133 students on "Heart, Lungs and Blood" (Module 103). This module delivers to each student just over 100 hours of requisite contact teaching in a mostly traditional (lecture-based), systems-based medical curriculum; the module is presented by over fifty instructors. The module is followed by a three-hour written summative assessment made up of short answer questions and single-best-answer multiple choice questions.

Research Goals

Our research here concerns the description of how a computer can formulate large numbers of these basic, rote-memorization, multiple choice questions; we further add a brief description of whether such questions were found to be satisfactory by students, and whether students engaged with our project. The Matlab code for making these questions is made available online (see Github address in methods), allowing for any instructor to harmonize a question set to their own curriculum. This code also allows instructors to remake their questions each year if the covered drug list on the curriculum changes (although this requires re-vetting the questions). The starting material is an Excel spreadsheet listing the individual drugs, each drug's class, its indications, and optional columns for adverse effects. The output is an Excel spreadsheet with hundreds of multiple choice questions that can be uploaded onto an appropriate online platform, after appropriate vetting of each question by educational staff or medically qualified personnel.
Matlab MCQs

We also discuss the limitations of using questions only suited to rote learning [16], and the surprising benefits to student experience of using such questions for self-testing.

Methods

Participants and Ethics

Before the study began, PPI (participant contribution to the design of the study) was conducted via a 2 hour focus group with third year medical students who had previously taken the first year module that this study relates to. The resulting study was approved by the local Research, Governance and Ethics Committee at Brighton and Sussex Medical School (BSMS); this required three submissions. Fifty-five participants (age range 18-29, 31 declared female) were recruited (via one email and an in-class announcement) from first year undergraduate medical students enrolled in a required 10-week module on heart, lungs and blood; only 133 students completed the module. The voluntary nature of participation was made clear in all announcements, and students were told that the information covered by these study materials merely repeated information that was already available in other areas of the module. All participants provided informed consent according to the Declaration of Helsinki, and it was stressed that they were free to withdraw at any time. Once students signed up (only 48 ever logged on), all data was maintained and analyzed in an anonymized form, using numerical codes for anonymous exit questionnaires and random alphabetical codes for the online engagement data; because of this double anonymization, the two sets of data could not be integrated.
Matlab MCQs

Question Design with Matlab

Two question/item building scripts in Matlab are located at:

https://github.com/harry-witchel/Ion-Channel-MCQs

https://github.com/harry-witchel/Pharmacology-MCQs

They are designed to import information from an Excel spreadsheet (using the Matlab function xlsread) and export the formulated questions into Excel format. The inputs for the ion channel MCQs are located inside the file "Ion Transport input data 2018-04-23.xls"; the pharmacology MCQs inputs are derived from an Excel file called "computer formulary 2018-04-07.xls".

Excel was chosen because of its ubiquity, its ease for inspecting and changing elements, and the fact that free alternatives are available. The input spreadsheet for MCQs about ion transport proteins has columns as listed in Table 01, and is meant to have a header in row 1. Any cell can be left empty (except drug name), and some cells support more than a single entry (separated by commas or semicolons). The category is an optional variable that is used to group both output items/questions and the selection of wrong options; this selection restriction (which can be disabled) allows you to design questions where all the options are epithelial transporters, and excludes transporters primarily in cardiac myocytes. The lecture date is an optional variable that is meant to reflect the order in which new information is presented to students. The date variable can be in a string format (yyyy-mm-dd, e.g. 2019-12-31) or as a number (e.g. a lecture number or a datenum), but it cannot be a mixture (e.g. “lecture 2b” is excluded). If this feature is enabled, the script will only select wrong options presented on the same day or previously. The output
columns are unique identifier (UID), category, lecture number, question type, correct option, and columns for wrong options (the Matlab user selects how many options). A similar table for the pharmacology questions is shown in Table 02.

The algorithms for making questions is shown in Figure 01. For each ion transporter, the algorithm loops through eight question types, so that items are produced asking both of these questions, “L-type calcium channels can be inhibited at highest affinity by:" and “Amlodipine is a high affinity inhibitor of:". The question types include matching ion transporter name to its gene, transporter name to its major physiological function, transporter gene to physiological function, and pharmacological inhibitor to transporter name. If all the wrong option restrictions are disabled, the wrong options will include all the transporters in the input data set except others that are also correct answers. The pharmacology question types include matching drug name to drug class, drug name to drug indication, drug class to indication, and adverse effects to drug name.

Note that items produced in this way will invariably have a percentage of inappropriate (or wrong) questions. All questions must be vetted before being used by students; the primary author and a qualified physician went through all the questions produced; approximately 5% of questions were rejected.

*Online Presentation of Items/Questions*

Items were uploaded onto Synap.ac. Synap is an online, content-agnostic learning platform that delivers quizzes to users in the multiple choice question format. The system runs on the user’s Internet browser and works in concert with secure data servers to mark and store quiz attempts.
Subjective Exit Questionnaire

An optional, anonymous, one-page exit questionnaire was approved by the local ethics committee. It was presented to students in a pen-and-paper format, when all the students were present, just after completion of the final examination for the module. The questionnaire included gender, age, multiple choice items for, “How often did you use the online quizzes”, and “Which type of device did you mostly use for these online quizzes with”. There were five Likert-style questions that made statements about usability of the software (see Results section), which were answered with: strongly disagree, disagree, neither agree not disagree, agree, and strongly agree. Finally, there were four open text items asking about what the student liked, what they disliked, how they would improve it, and what question type they would have preferred on the quiz (e.g. true-false vs. open text).

Analysis and Statistics

All anonymized engagement data points were outputted from the Synap system as CSV files and were read into Matlab for histogram analysis. The exit questionnaire was analyzed in Microsoft Excel.

Results

Engagement

With 391 items/questions in the system, over 11,749 attempts were made. Out of 133 first year medical students who completed the module (103: Heart, Lungs and Blood), 55 students consented for participation in the self-test project, but only 48 ever logged on. The project was launched for students three weeks before the final knowledge test, and the
Matlab MCQs

number of questions attempted by day is shown in figure 02. Sudden drops in use were observed on the day of the final exam (day 20), on the day of a summative quiz (day 11), and on Saturdays. The use of the system among students was highly variable, with 44% of the students attempting fewer than 100 items (see figure 03), although 15% of the participants attempted over 500 items; 45.8% of the students only participated on one day. The times of day for maximum participation during weekdays (see figure 04A) was just after their scheduled classes finish for the day (17:00 to 18:00), followed by just before lunch (11:00 to 12:00), and just after dinner time (19:00 to 20:00). There were dips in usage in the middle of the night when they sleep (02:00 to 07:00), during television prime time (20:00 to 21:00) and during a typical dinner time (18:00 to 19:00). There was less engagement during weekends (see figure 04B), when the peak use was during evenings, with a spike at 23:00 to midnight. There was no relationship between the number of elapsed days from the launch date vs. the number of items answered correctly (which varied between 80-95%); on inspection this may be due to the steady trickle of new users joining the project.

Subjective Feedback from Students

An optional, one-page, pen-and-paper, subjective exit questionnaire was presented immediately after the final examination to the students, and 48 students filled in the first part of the questionnaire (age, gender, primary device used, and how often they interacted with the online test); 44 students filled in the Likert ratings, and 39 students wrote some feedback in the open text boxes. We were surprised to find that 68% of the students primarily accessed the Synap system on their laptop, while only 13% primarily accessed it primarily via their phone, as an app (see Figure 05). However, among those who did access
Matlab MCQs

it by phone, some wrote very positive feedback about the ability to access the system by phone in the open text boxes.

The numerical feedback (see figure 06), based on a Likert-style questions, showed that over 80% of the respondents agreed (or strongly agreed) with the statements, “I found it easy to use the quiz software”, “I found the quiz software enjoyable to use”, “I engaged more with the study material because of the online quizzes”, and “I felt I learned more by using these quizzes”. The most positively answered numerical question was, “I would like these kinds of quizzes to be extended to other modules”, where 77% of respondents strongly agreed.

Discussion

While preparing a formative, online self-assessment system for first year medical students in a module on heart, lungs and blood, our ethics committee brought to our attention a fundamental ethical dilemma for self-assessment: although the students were only interested in items/questions either written by the course organizers or relating to the final exam, the ethics committee was insistent that we provide an ironclad guarantee that the self-assessment questions would not give away the final exam, and preferably were not formulated by course organizers who knew the contents of our exam bank. One approach to this conundrum is to have a computer formulate the self-assessment questions based on tables of information that were part of the course materials given to students. We have produced a script in Matlab for performing this task, and it is available on GitHub (see methods). The a priori disadvantages of such quiz items would be that A) they would be simplistic and repetitive, B) would only be suitable for rote learning, and C) would not contribute to higher level knowledge integration. This was a disappointment, given our
Matlab MCQs

original plans for an online learning system that promoted self-regulated learning. We ran a brief research study based on these computer-derived items, and we were surprised to find that over half of the students who started interacting with the system engaged seriously with it, a small number of students used the system extensively, and nearly all the students felt strongly that this system should be rolled out elsewhere in our curriculum.

Student uptake to our question bank was relatively low compared to the whole student cohort (40% of those enrolled on the module). This could have been increased by more aggressive advertisement of our project to our students. However, given the challenges with the ethics committee, we felt a conservative approach to advertising was most appropriate.

One way our medical school has previously increased student engagement with online learning tools is with competition [09], which is also known to increase academic performance (i.e. post-test scores) [04]. This potential competitive benefit is especially important when the novelty of the new technology solutions wears off [22]; we believe that the 45.8% rate of abandoning the online system could be lowered if competition was added to the system, especially with teams (e.g. a leaderboard with teams [09]).

Formative Assessment and Self-Regulated Learning

The focus of medical education is to create self-regulated learners who can continue throughout their careers to manage their own education and training as new medical information replaces current knowledge [05]. A cornerstone of self-regulated learning is the ability to learn at higher levels such as application and evaluation by integrating one’s own knowledge, as well as promoting a deep approach to learning [19]. When our team learned
of the ethical conundrum in self-assessments, we felt that this project would be less able to achieve the feedback principles guiding self-regulated learning, and would be limited to providing (low-level) opportunities to close the gap between current and desired performance [13].

Formative assessment is meant to go beyond simply giving answers, by enhancing and reinforcing learning behaviors [10]. While the online self-test in this study may function to enhance learning (based on repetition and memory), the fact that these quizzes are independent and disjoint from other processes of learning means that they barely qualify as formative according to Black and Wiliam’s [03] more recent definition of formative: “evidence about student achievement is elicited, interpreted, and used by teachers, learners, or their peers, to make decisions about the next steps in instruction that are likely to be better”. The fact that this project was at all embraced by students is a testament to the power of computerized self-assessment. Some organizations already offer students integrative formative test questions with detailed feedback about incorrect answers, such as UWorld® in the US, and Passmed® in the UK, for example. Meanwhile, other organizations allow for students to write their own questions and feedback, such as Quizlet® or Synap®. Two clear improvements for our system would be to include feedback for wrong answers, and to extend this system to other disciplines in the same module; both of these improvements would be quite difficult to do in an automated fashion.

Limitations

There are several limitations to the study and this approach of making multiple choice questions by computer, so we have made the materials available online to expedite
research opportunities for all. While our exit questionnaire suggested surprisingly positive
feedback from students, to keep things in perspective, nearly 20% of respondents did not
agree with the statement, “I felt I learned more by using these quizzes”. Furthermore, the
positive responses may be over-represented because of the questionnaire completion rate.
Of the 133 students in the module eligible, only 55 elected to participate, and only 44 filled
in numerical questionnaire data. Presumably the 11 non-respondents were more negative
about the online system, but even if all 11 of them had answered that they had not enjoyed
the system, the number of respondents who agreed that they enjoyed the system would
have outnumbered those who did not by over 2:1.

The test items produced by this method are most suitable for rote learning, which in
Bloom’s Taxonomy only reaches the level of knowledge [07]. Assessments in physiology and
medical education are expected to stress learning at a higher cognitive level (e.g. application
or evaluation), and it is possible to design multiple choice questions at a higher level,
although doing so may be difficult using only a computer algorithm.

As expected, formulating questions by computer will lead to some potentially
nonsensical or wrong questions. This means that all questions need to be vetted before
posting. The most consistent problem was that there were automated items where there
was more than one potentially correct answer; this was particularly true for questions about
drug indications. For example, in our table of drugs, aspirin was listed as a treatment for
infarct prophylaxis, but not for pulmonary embolism. The algorithm produced the following
question: stem -- "The class of antiplatelet drugs is used in the treatment of" -- correct
answer (in our formulary): "ischemic heart disease (infarct prophylaxis)", incorrect options:
"angina", "pulmonary embolism". While aspirin should not be considered a first-line
Conclusions

We conclude that, while this strategy is certainly not a perfect study method for self-regulated learning, it is a satisficing solution that can be used to address ethical challenges of the self-assessment dilemma [15]. From an ethical perspective, the process of automated question formulation provides genuine arm’s-length distance between the summative question bank and the self-assessment questions. Furthermore, this method can be extended to other topics in the medical curriculum such as topographic anatomy, as well as allowing for rapid updates and harmonizing to different curricula.

Acknowledgements

We gratefully acknowledge Kevin Davies and the BSMS RGE Committee for frank discussion about our methods. We acknowledge the original idea and research from Darrell Evans demonstrating the utility and importance of online formative testing at BSMS. We are grateful to the five participants in our initial focus group. We acknowledge the secretarial assistance of Terri Desmonds. We are especially grateful to Omair Vaiyani and James Gupta at Synap.ac, who made an isolated platform for our medical school, uploaded our question set, and outputted the extensive data for us.
Grants

We thank the University of Brighton’s Centre for Learning and Teaching for a Learning and Teaching Scholarship (to HJW and CS), and the University of Sussex’s Excellence in Teaching Awards for funding.

Disclosures

The authors have no financial interests in this project to disclose.

Contributions of Authors

HJW: exp design, funding, focus group, ethics prep, Matlab, collaboration set up, question sets, data entry, stats, first draft

CS: exp design, funding, question sets, editorial

JHG: focus group, question sets, editing the final draft

References


**Figure and Table Legends/Captions**

Table 01. Columns of input spreadsheet for ion transport proteins. “>1 Entry” refers to columns that can support more than a single option in each cell; multiple options are separated by commas or semicolons.

Table 02. Columns of input spreadsheet for pharmacology. “>1 Entry” refers to columns that can support more than a single option in each cell; multiple options are separated by commas or semicolons.

Figure 01. Schematics of the question-building process in Matlab are shown: the ion transporter algorithm is on the left and the pharmacology algorithm is on the right.

Figure 02. Items attempted on the online system are plotted against the days elapsed from beginning of the experiment. The final exam was on the afternoon of day 20. The day of the week is listed as one-letter abbreviations (e.g. Monday = “M”).

Figure 03. A histogram of the number of items/questions attempted by our student cohort is shown.

Figure 04. Items attempted on the online system are plotted against the time of day. The engagement with the system was greater during weekdays (panel A, left) than during weekends (panel B, right); note that the Y-axes have different scales.

Figure 05. This compares the primary device used to access online self-test. The data is based on self-report.

Figure 06. Subjective Likert-style responses to statements about how students responded to or felt about the self-assessment system (see Results text for precise statements). Each line represents one subjectively-answered item from the exit
Matlab MCQs

questionnaire. 1 = strongly disagree, 2 = disagree, 3 = neither agree nor disagree, 4 = agree, 5 = strongly agree.
### Table 01 (UU4X)
columns in input excel for Ion Transporters

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<th>Variable Type</th>
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<td>Internal Admin</td>
<td>Any (not used)</td>
<td>—</td>
</tr>
<tr>
<td>2</td>
<td>Category</td>
<td>Character String</td>
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</tr>
<tr>
<td>3</td>
<td>Lecture Date</td>
<td>Number or String</td>
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<td>4</td>
<td>Ion Transporter Name</td>
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Table 02 (KEV4)
Table KEV4 Pharmacology Columns in Input Spreadsheet

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</tr>
<tr>
<td>9</td>
<td>Extra Adverse Effects</td>
<td>Character String</td>
<td>Yes</td>
</tr>
</tbody>
</table>
Loop through: Select transporter and question type

Collect relevant lists: Transporter Names, Transporter Genes, Functions, Inhibitors

Select Wrong Options: Not correct, By Lecture Date, By Category

Output List: Into Excel

Loop through: Select drug and question type

Collect relevant lists: Drugs, Classes, Indications, Adverse Effects

Select Wrong Options: Not correct, By Lecture Date, By Category

Output List: Into Excel
Histogram of Items Attempted per Student

Percent of Participating Students

Number of Questions Attempted

Fig 83325
Post-Project Feedback

Percentage of Participants

Likert Rating ("strongly disagree" to "strongly agree")

- Easy
- Enjoyable
- Engaged More
- Learned More
- Extend Project