A technique for delivering individualised formative problems and examples

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Abstract
Active learning plays a strong role in mathematics and statistics, and formative problems are vital for developing key problem-solving skills. To keep students engaged and help them master the fundamentals before challenging themselves further, we have developed a system for delivering problems tailored to a student’s current level of understanding. Specifically, by adapting simple methodology from clinical trials, a framework for delivering existing problems and other illustrative material has been developed, making use of macros in Excel. The problems are assigned a level of difficulty (a ‘dose’), and problems are presented to the student in an order depending on their ability, i.e. based on their performance so far on other problems. We demonstrate and discuss the application of the approach with formative examples developed for a first year course on plane coordinate geometry, and also for problems centred on the topic of chi-square tests.

Keywords
Individualised assessment, formative assessment, active learning

1. Introduction

In Higher Education it is important to foster skills that create a life-long learner. Mathematics and statistics, and indeed many other STEM disciplines, are subjects that benefit from active learning, and the usual situation is to provide regular formative problem sheets to help focus self-study activities. However, with an increasingly diverse range of student abilities, and the various issues that this raises [1], it becomes difficult to deliver formative problems that keep students engaged: the best students may find questions too easy and stop attempting them, and those who are struggling may become disheartened and give up.

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In an innovative approach to delivering formative problems or mini-tests to students, we have developed a method (implemented in Microsoft Excel) to focus on individualised sequences of problems. The approach is quite intuitive: building on simple clinical trials ‘dose-escalation’ methodology, more challenging sequences of problems are only made available to students after they have demonstrated sufficient mastery of the basics. Weaker students are assigned lower ‘doses’ (i.e. less challenging questions), with an increase if there is evidence that they can cope with them. If the student is particularly struggling, then the ‘dose’ is decreased. This helps students master the basics before moving on to higher levels of learning, i.e. it helps lead them through the beginnings of Bloom’s taxonomy [2] at a pace suitable to them. By automating the decision-making process as to when it is appropriate to move on to harder problems, students are routinely challenged to increase their higher-level understanding of the subject, but only when there is sufficient evidence that they understand the fundamentals. Crucially the ‘dose’ can de-escalate again at any point when necessary.

To ensure that the approach is generic, and can be adapted by others for use in their teaching, we have developed a set of Visual Basic macros in Microsoft Excel for making the sequences of pre-specified questions available to students. To date we have mainly focused on developing materials to go with the program for a first year course on geometry, but also on writing problems associated with the chi-square test: the chi-square problems will be made available shortly to second year pharmacy students as a trial of the program.

2. A dose acceleration procedure for formative problems

2.1 Method

In early phase clinical trials, where drugs are first being trialled in humans, a major focus is on determining a safe dose of the drug. This is typically determined by giving patients a certain dose, and then either escalating the dose if the drug is well tolerated, or de-escalating it if not. The aim is to find the target dose that is the highest one that does not cause unacceptable toxicity amongst patients. One of the simplest and common methods for identifying the optimal dose is the 3+3 design [3]. This basic design proceeds as follows: three patients are treated with a certain dose, and the following rules are applied:

- if none show toxicity, then a further three patients are treated with the next highest dose (dose escalation);

- if one shows toxicity, then a further three patients are treated with the same dose, and if none of those further three show toxicity, increase to the next highest dose, else attempt to decrease to the next lowest dose (dose de-escalation);
if two or more show toxicity, then attempt to decrease to the next lowest dose;

if six patients have been treated at the next lowest dose already when de-escalation is attempted, then stop the trial and declare the maximum tolerated dose to be the lower one;

escalation does not occur if six patients have already been treated at the higher level (with two or more showing toxicity).

Variations to this design exist, such as varying the number of patients or carrying out intra-patient dose acceleration first (whereby doses are increased within a patient until toxicity is seen) but the underlying procedure is essentially the same.

We have taken the simple design above as a starting point for our education-focused formative problems scenario. Crucially, in the education setting there is one very obvious difference. In clinical trials there is an assumption that there is a maximum tolerated dose, which is the dose that should not be exceeded in humans for safety reasons. In the educational setting, whilst one might say that such a thing may exist in students (a level of difficulty that they cannot handle), we maintain that with sufficient and repeated exposure to formative problems and examples, students will increase their understanding, and so what was once a ‘toxic’ dose, eventually becomes a well-tolerated one. Therefore, our adaptation of this approach for the educational setting has no concept of stopping, except when the problem levels have all been completed to a satisfactory standard. Its goal is instead to provide an individualised sequence of problems for the student to attempt, to help enhance student engagement and develop technical skills in the discipline.

Specifically, we have implemented the following, making use of Excel macros

- sets of questions or examples for one topic are first graded in terms of their difficulty (i.e. each is assigned an integer ‘dose’ value) – a variation on this approach is to think of a course being delivered in a linear fashion with a monotonic increase in difficulty across the lectures, and then each section or lecture of the course becomes the assigned ‘dose’ label;

- starting at the lowest ‘dose’, three problems are presented for students to work through one by one, and their self-assessed performance is noted

  - if all are completed successfully, then the dose is escalated, and three problems are presented at the next level of difficulty;

  - if none are completed successfully, then dose de-escalation is attempted;
otherwise three further problems are presented for the current level of difficulty, and the dose is then escalated if five out of six are completed successfully, is de-escalated if fewer than four are completed successfully, else remains the same if exactly four out of six are completely successfully (in which case one further problem is presented);

- whenever fewer than three problems have been presented for the current level of difficulty, three further problems will be presented before the escalation rule will be considered, else only one further problem will be presented before the rule is considered;

- once the process has reached the stage of presenting only one problem at a time and re-evaluating the rules for escalation after each, this single problem approach will continue until there is sufficient evidence to escalate or de-escalate the ‘dose’ (pre-determined percentages of successful attempts are used as rules) – note again that there is no concept of stopping (until all ‘dose’ levels have been successfully completed).

So, although our approach has its roots in clinical trials dose-finding methodology, it should be seen as distinct from that, and in many ways can be thought of as our own ‘intra-student dose escalation 3+3+1×k design’, where k represents however many additional problems that need to be presented one by one until dose escalation or de-escalation occurs. Fundamentally, it is a simple way to determine the relevant difficulty of formative problems that a student should be presented with, tailored to their current ability. It is therefore individualised in the best sense of the word.

2.2 Program

In order to ensure that the approach identified can be readily implemented, a simple framework has been developed in Microsoft Excel, with specially written Visual Basic macros. The program (which we call autoQs below) makes use of Excel userforms, and examples/problems are presented in terms of an image on the left of the window (this approach was chosen to ensure that mathematics would be displayed appropriately), see Figure 1 for an example. On the right of the window are buttons that link to up to five different files – these files can be used for any purpose, and can be of any type provided that the user’s PC can recognise the appropriate program to open them. For example, they can be PDF files of worked solutions, input files for computing packages, screencast demonstrations, video or audio files, or any number of other pedagogic tools.
Students can work through the problem that is presented, looking at the illustrative material that is provided via the files. They are asked to declare their level of understanding for the problem (in jumps of 25%), before they move on to the next problem. The lecturer decides in advance what level of understanding counts as ‘toxic’, i.e. non-successful completion of the problem, and specifies the percentage rules for escalation and de-escalation when more than six problems have been tackled. The program checks how many of the problems so far attempted per ‘dose’ level have been completed successfully, and decides whether to present further problems for the same ‘dose’ or to attempt to escalate or de-escalate. The information is stored in a worksheet which allows for the program to be closed and progress to be continued from the last completed problem upon re-opening. Because the aim is for students to benefit from active learning, problems that have not been successfully completed earlier on will be shown again later, if the dose cannot be escalated yet due to the rule.

Specifying the images and accompanying files to make available for each problem or example is done simply by the user entering filenames into a spreadsheet in pre-determined locations (which is then hidden before the folder of materials is made available to students). Each ‘dose’ has a separate column in the worksheet, and the program can accommodate up to 25 dose levels at present (limited only to ensure that the program can be run in Excel 2003 as well as later versions). There is no limit (beyond the size of the spreadsheet) to the number of problems that can be specified for each dose level.

Where it is desirable for students to work through each problem or example sequentially, with escalation occurring only after the full set of problems have been seen, the program can be set to an “all problems” version, thereby bypassing the 3+3+1×k approach. This gives more flexibility to the lecturer in terms of how they would like to make the materials available.

The program (without any course-specific accompanying files) can be freely downloaded from http://www.personal.reading.ac.uk/~sns99kla/

3. Application to geometry and statistics

3.1 A first year course on geometry

Whilst developing the autoQs program, we focused on how it could be used to support a first year course on plane coordinate geometry. For this course there are many examples and problems to tackle, and because of student engagement with a teaching and learning placement scheme in the Department [4], we have available many Geogebra files for demonstrating the solution to these examples and problems, as well as PDF files and screencasts with voiceovers. The need to make available a number of different files that could aid students in their understanding guided the eventual appearance and structure of
autoQs. Figure 1 shows a screenshot of the autoQs program for implementation in the Geometry course.

Figure 1: Screenshot of autoQs program for a first year Geometry course

A clear benefit of using autoQs to deliver the various illustrative materials is being able to tailor the level of skill and mathematical maturity required for a specific problem to the successes on previous, related problems. The range of questions associated with the course is very wide. Some questions require basic algebra and trigonometry, while related questions may require more advanced algebra, or complex/obscure trigonometric formulae, or possibly just more stamina. Others require more lateral thinking, or some subtleties which increase as the ‘dose’ increases. In all cases, confidence gained at lower ‘doses’ enables later problems to be less daunting and challenging than they would otherwise be without the systematic escalation of difficulty that the method affords. One example of a problem at the higher end is shown in Figure 1. This would be near the end of a range of problems on loci, starting with ones which are routine, through to more challenging ones, and culminating in ones of this type, which may well require the student to use a range of approaches, each of which has been met individually in the preceding problems with lower dose levels.

While considerable resources have been created so far, further materials are required to be able to implement this fully in the delivery of the course. The program and the files would also be useful at the end of the course, for revision purposes, providing students with a structured way to progress through the materials and problems, or as a self-study course.
3.2 A service course in statistics for pharmacy students

In order to trial the program in a different way, where problems are focused on a single topic only (i.e. one lecture), with different levels of difficulty determined by how many hints are provided, a set of 120 questions focused on the chi-square test of independence for contingency tables was produced. These were divided into 10 levels of difficulty, starting from questions where expected counts were also provided for 2×2 contingency tables, along with the relevant formulae and critical value, up to r×c tables where the data were provided in the text rather than in tabular form, with no other details given. Here the accompanying files provided to students will include statistical tables, a PDF of the worked solution and data files and screencasts for a software package. The theme of the questions produced is medicine/health, since the audience is mainly second year pharmacy students who have studied statistics in the previous term. The program and questions will be released to the students at the end of the Spring term, and their feedback will be sought with respect to general comments and suggestions for improvement.

4. Discussion

All STEM subjects benefit from active learning through completion of formative problems. Although the work we have done so far on producing an individualised sequence of problems has been focused on geometry and statistics, the Excel macros that have been developed are generic, and thus are relevant more widely. If problems and supporting files, e.g. worked solutions, screencasts, animations or online tests exist, then they (or a link) can be put into the program and the problems delivered in an order so as to ensure struggling students get repeated exposure to the basics before moving on to more challenging problems. Indeed, we are in the process of investigating how to make use of mini-tests (consisting of a small number of questions) in Maple T.A.™ with the autoQs program: essentially this would involve assigning each mini-test an identification code, and directing the student to the relevant code depending on their current level of understanding.

An issue not yet discussed is how to assign levels (i.e. ‘doses’ in the terminology used above) to problems or examples. Input from a student working on one of our teaching and learning projects suggested a graduated sequence of hints and reminder of formulae could assist in distinguishing levels. This will be context dependent of course, and is in itself a useful area for future research. Indeed, it is something which would be good to discuss with the end users, the students for whom these problems are developed. To date our feedback on the approach is limited, but we hope that the chi-square test trial will attract some useful comments. Our intention is to release further materials in the future, and to gather the views of students in order to evaluate the program and the approach in general.
As a final note, completion of formative problems that require self-assessment are obviously subject to the honesty of the student, and the autoQs program will always be dependent on this. Students need to accurately declare their understanding in order to get the most appropriate sequence of problems delivered to them in a useful order. To help ensure that the approach that we have outlined here reaps maximum benefit, it is important to explain the purpose of individualised formative problems to students, and how they should structure their studies in order to address any weaknesses they identify. As with all teaching and learning initiatives, engaging students at an early stage can help avoid problems later on, and we would certainly encourage those who wish to use this system to discuss fully with their students how it can be implemented in the most effective way.

5. References


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