# Effective Feedback with Adaptive Questions

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## Abstract

*Adaptive e-questions have been implemented for a first year electronics course that are designed to help students who answer incorrectly, by recognising the mistake made (where possible) and then providing constructive targeted feedback and another try. The questions, some choice based but mostly numeric, have been prepared for use with an assessment system that is a direct implementation of a new question-test interoperability specification. The features used are therefore likely to become more frequently available in future versions of commercial assessment systems, supporting wider use of assessment for learning. In the case reported here, the combination of targeted feedback and an immediate opportunity to apply the new information led to a rise in 'correct answer' rate from 61% to 84%.*

The work being described here is a continuation of that previously described some time ago by the author (Bacon 2005). There are a number of reasons for the delay in developments, one being that the course for which the earlier adaptive questions were developed and were being trialed had the coursework component removed to bring it in line with departmental policy of that time. Another reason was the publication of a new Question Test Interoperability specification (QTI v2.1). This directly supports adaptive questions and a number of other features that render numeric questions suitable for use in the sciences without recourse to non-standard extensions. Therefore a new assessment engine of this type was developed (SToMPII) and is now being used in place of the earlier, heavily extended QTI v1 system. Existing questions from another course have been modified to use these new standard features to provide targeted feedback and multiple tries. This paper follows on from the poster presented at this conference last year (Bacon 2010), and describes how the reporting from the engine has been modified and how the questions themselves performed.

## Marking numeric problems

Numeric questions are used widely within physics courses and are believed to help students consolidate their learning of new concepts covered in lectures and tutorials. Such problems usually require a student to recognise the context of the stated problem, to understand the relationships between the values given and the value to be obtained, and to recall and manipulate one or more formulae to obtain a solution for the final value.

In such questions there are several ways in which a student can end up with a wrong answer, ranging from the selection of inappropriate formulae through algebraic errors during expression manipulation to arithmetic errors when calculating the answer. When such problems are hand marked there is a tradition of being lenient with arithmetic errors. Providing feedback requires the marker to recognise the error (or errors) and give helpful advice about how to avoid that error in future. Recognising errors can be a difficult task due to the paucity of information provided by students, particularly the weaker students who need the help of good feedback most.

### Problems with expression entry

An earlier paper (Bacon 2005) described a method developed by the author for inviting students to enter a numeric expression for the answer, as well as the final calculated value itself. The numeric expression was required to use the values given in the question as well as constant values as needed. This expression was used if the final value was sufficiently wrong, and it was analysed in a variety of ways, including the basic form of use of the given values (e.g. A/B or B/A). The use and entry of such an expression proved perfectly acceptable for the problems being used at that time (the course was to do with radiation detection and monitoring), but was proving intractable with the electronics questions that are the subject of this paper.

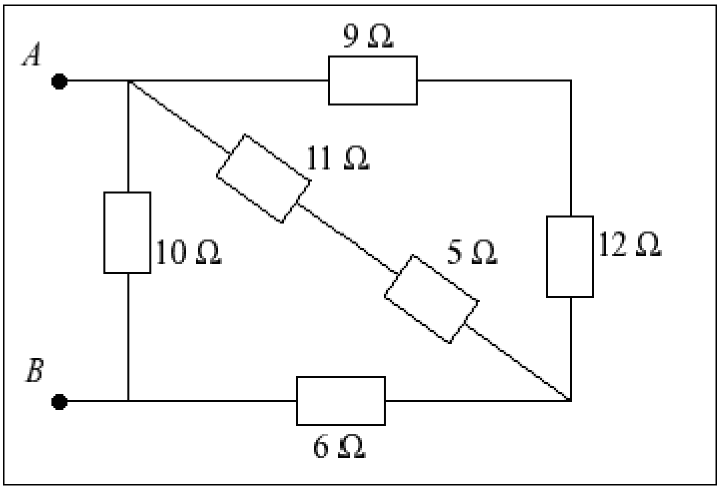



Figure 1. **Simplifying a Resistor network**

As an example, consider a question in which six resistors arranged as shown in figure 1 are to be reduced to a single equivalent resistor. Whilst the concepts are not difficult, the expression for this equivalent value is lengthy:

$$\frac{1}{\frac{1}{10}+\frac{1}{6+\frac{1}{\frac{1}{11+5}+\frac{1}{9+12}}}}$$

and when entered into a single line of text in a pseudo-computer style

1/(1/10)+1/(6+1/(1/(11+5)+1/(9+12)))

it becomes unreasonably difficult to visually check for accuracy. In order to be of use in finding students' errors it is necessary for the original values to be used in these expressions and therefore whilst the expression can be 'simplified' to just one fraction, the repetition of values makes it significantly longer:

10*(6*(9+12+11+5)+(11+5)*(9+12))/
(6*(9+12+11+5)+(11+5)*(9+12)+10*(9+12+11+5))

Both these forms are prone to error during entry and are subsequently difficult to check. Therefore, it was decided that the expression entry feature would not be appropriate for use in this type of question.

Expression entry is an area in which much progress has recently been made (MathAsses 2008), and it is hoped to revisit the use of expressions in these electronics questions in the near future.

## Diagnosing student problems

The first year electronics questions chosen for modification contain a few multiple choice style questions but are mainly numeric. These numeric questions contain randomised values, with expressions being defined within the question to calculate the correct answer value that the student is required to enter. When processing the result of each question, the student response is compared to this value in four different ways:

- exactly equal, with the requested number of significant figures = full marks.
- approximately equal and at the requested precision = full marks less 2
- exactly equal but at the wrong precision = full marks less 2
- approximately equal but at the wrong precision = full marks less 3

If a student's answer matches one of these conditions then it is assumed that they understand how to do the question and do not need any help.

In order to help students who do not obtain the correct value, a number of alternative expressions are used to obtain alternative answers, each of which is based upon a plausible mistake (or mal-rule, Greenhow & Gill 2004). For example, one such answer for the problem illustrated above assumes that the student incorrectly uses the parallel resistor expression for the resistors in series, and *vice versa*. In these questions the resultant values are checked against the student responses without checking precision and within a small range of values (usually about 5%) to cater for possible rounding errors. There are, however, several drawbacks to this approach.

One drawback is that two wrong values derived from different assumed errors can be within 5% of each other. In this case the first error value tested will be assumed to be that aimed for by the student so that the feedback message will not be appropriate. This problem might be addressed by calculating and checking the values for all possible input values (or for a closely spaced set, if floating point) and finding the volumes in the multi-dimensional randomised value space that need to be avoided.

A second drawback is that only those errors that the question author has had the imagination to consider will be explicitly addressed by feedback. This can be improved each year as new values appear in the previous year's responses, if they can be matched with further plausible mistakes. This, however, can be a time consuming and complicated task due to the randomisation of each question, and only helps later cohorts.

Another drawback is that it makes for a complicated question, particularly if the question has two or more parts, each of which has its own individual set of 'wrong' answers. Complicated questions are not a problem *per se*, but question creation clearly becomes more error prone with increasing complexity, and such questions become more difficult to validate.

## Giving further tries

One of the criteria for effective feedback (Gibbs & Simpson 2004) is that it should be applied, and within these questions this can be achieved quite simply by offering a student another try at a question if they have entered a wrong answer. If the answer they have entered matches one of the pre-defined wrong answers, then the feedback can be directed at the probable error the student made. If the answer value is not recognisable then a generic feedback message can be used, pointing out, perhaps, the principles that should be applied to obtain a correct answer.

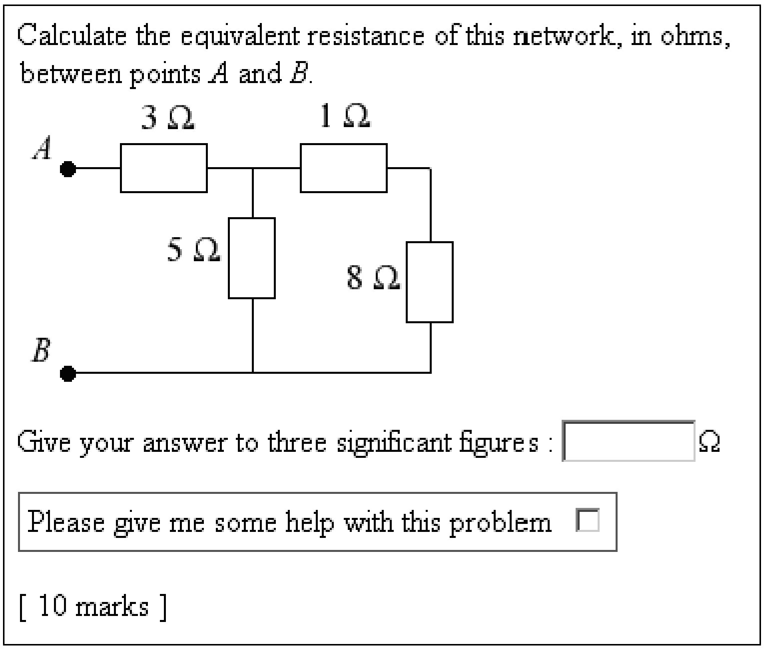



Figure 2. **Question with help being offered**

Offering another try (with reduced marks, of course) seems to act as a very strong encouragement for the student to re-think the question in the light of the feedback, and in many cases to correct the mistake. Most of the numeric questions in the two electronics tests being reported here offered up to three tries for each numeric response. If one part of a question was answered correctly and another part incorrectly, then the correct part was taken out of subsequent tries.

## Further help

Some of these numeric questions are provided with further help by the use of a check box, as shown in figure 2. If help is selected, then when the submit button is pressed the available help options are expanded as shown in figure 3. If there are fewer options they are sometimes offered directly within the question.

Would you like this help to:

| | |
|---|---|
| describe a good way to solve the problem [-1 mark] | ○ |
| show how a solution can be obtained [-2 marks] | ○ |
| split the problem into smaller parts [-4 marks] | ○ |
| OR return to the original question without help | ○ |

Figure 3. **Help options**

The first two options display additional text and possibly diagrams, together with the original question. The first option, 'describe a good way to solve the problem' details the principles involved in the solution. The second option describes the processes involved in obtaining a solution. The version for the above question is shown in figure 4. The third option presents a sequence of questions (in these questions usually two) leading to a complete solution. At each stage the student is required to enter a numeric answer that is checked by approximate value only. If the student gets it wrong then further explanation is offered, often at a simple level of showing the numeric recipe for obtaining the required value. If the student still gets this wrong then the system moves on the next part, but with a warning that the student should seek assistance if they are unable to perform simple arithmetic operations.

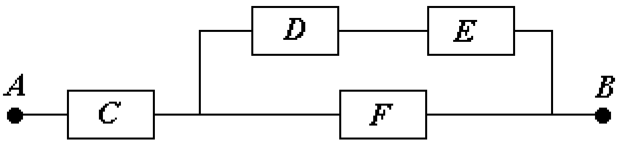
When the student has worked through the parts required in order to obtain a solution the original question is re-posed. By this time most students taking this route should have correctly carried out all the steps required to obtain a solution and should therefore be able to solve the problem.

## Choice-type questions

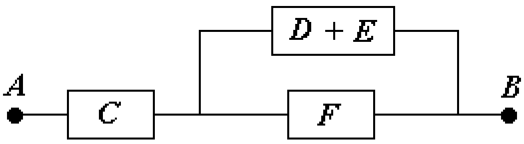
Two strategies were used to help students to the correct response in multiple selection and multiple choice questions. The first was to include a further option, ''don't know', that always came at the end of the list, even if the other choices were randomised in position. If this option was selected, then a hint was given to the student about how to approach the question, and the question was offered again. The 'don't know' option could be selected up to three times, with the hint becoming increasingly detailed each time. The last time the question was offered the 'don't know' option was omitted. The hints were carefully worded so that the assumed level of prior understanding was decreased each time, but none of the hints actually 'gave away' the solution.

The second strategy was to give students feedback tailored to their incorrect solution, and then to give them another try at the question. A potential problem with this approach is that the statistics of the situation dictate that the probability of a student getting the right answer 'by accident' becomes unacceptably large when the usual four option list is used. This was addressed by increasing the original number of options to six and by allowing only three tries, with the second try carrying 75% full marks and the third try carrying 50% full marks.

Redraw the diagram to make it clearer which resistor groups are eligible for being combined.

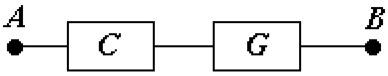



It is clear from inspection that $D$ and $E$ are the only resistors that can be combined at this stage. Resistors that are in series must have the same current passing through each resistor. Resistors that are in parallel must all be coupled across the same potential. Thus, $C$ is not in series with any single resistor, and $F$ is not in parallel with any single resistor. $D$ and $E$ are in series so they can be combined by summing their values. The diagram can therefore be redrawn as




Resistor $F$ is now in parallel with a single resistor and they can be combined as the resistor, $G$ say, where $\frac{1}{G} = \frac{1}{(D+E)} + \frac{1}{F}$.

The diagram can then be redrawn as




where $C$ and $G$ are in series and can therefore be combined by addition of their values. You should now be able to write down an expression for the value of this resistor in terms of $C$, $D$, $E$ and $F$. Substitute the values from the question and the result will be the value of the equivalent resistance of the original resistor network.

Figure 4. **Showing how a solution can be obtained**

## Tracking students' use of the adaptive features

It is clearly of academic significance and of practical interest in validating and improving the questions, to be able to track students' use of these features and the effect upon their ability to obtain solutions. The assessment specification upon which the SToMPII system was based, however, specified that in adaptive questions only the final state of the results (outcome variables) should be recorded (IMS 2006). This was how the first implementation was organised but it was found to have some drawbacks. One was that following an interruption of any sort, the question could not be restored to its pre-interrupted state (unless in its start-up state). Another was that the progress of a student through the adaptive steps could not be reliably reconstructed, even with the use of additional variables to store intermediate values.

The reconstruction of students' progress through the questions was fundamental to the research being carried out here, since it is conjectured that it has the potential (with a greater number of better designed questions) to better assess student ability than simply the final answers as currently used. Therefore, the restriction of saving only one set of adaptive question values was abandoned and a version of the system produced that saves the values in sequence every time the submit button is pressed. As will be shown here, this allows the desired level of tracking although poor question design can still obscure sequencing information in some situations. The new scheme has the additional advantage that an interrupted adaptive question can now be restored to its state at the time of the interruption.

## Effects of the feedback

### Numeric questions

It is assumed that the feedback has some effect in helping a student to correct a wrong answer. Results for each adaptive numeric question are shown in table 1, with three tries distributed across the columns. The three rows labelled 'try 1', 'try 2' and 'try 3' show how the progress through the tries is mapped onto the columns. Thus, the 'try 1' column shows the number of students who answered correctly at the first try. The first 'try 2' column shows those who made a 'mal-rule' mistake at the first try, received feedback directed at that particular mistake and then answered correctly at the second try. The first 'try 3' column lists those who made (hopefully different) 'mal-rule' mistakes at both the first and second try, and were then correct at the third try, and so on.

| | | try 1 | try 2 | try 3 | try 3 | try 3 | try 3 | try 2 | try 3 | try 3 | try 3 | try 3 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| try 1 | help | right | mal-rule mistake | | | | | wrong | | | | |
| try 2 | | | right | mal-rule | | wrong | | right | mal-rule | | wrong | |
| try 3 | | | | right | wrong | right | wrong | | right | wrong | right | wrong |
| q1.6 | | 31 | 6 | | | | | 2 | 1 | | 1 | |
| q1.9a | | 19 | 4 | 1 | 1 | 2 | | 2 | | 2 | | 2 |
| q1.9b | | 4 | 1 | 1 | 3 | 2 | 3 | 3 | | 4 | 3 | 6 |
| q2.1a | | 21 | | | | | | 7 | | | 3 | 1 |
| simple | 5 | 1 | | | | | | 3 | | | | 1 |
| q2.1b | | 30 | 1 | | | | | | | | | 1 |
| simple | 5 | 4 | | | | | | 1 | | | | |
| q2.2a | | 7 | | 1 | | | 1 | 9 | 2 | | 1 | 2 |
| simple | 2 | | | | | | | 2 | | | | |
| parts | 1 | | | | | | 1 | | | | | |
| q2.2b | | 18 | 1 | | | | | 4 | | | | 2 |
| simple | 2 | 2 | | | | | | | | | | |
| parts | 1 | 1 | | | | | | | | | | |
| q2.6a | | 23 | 2 | | | | | | | | 1 | 8 |
| q2.6b | | 17 | 4 | 2 | | | 1 | 5 | | | | 4 |
| q2.6c | | 14 | | 1 | | | 3 | 6 | | 1 | 2 | 5 |
| | | try 1 | try 2 | try 3 | try 3 | try 3 | try 3 | try 2 | try 3 | try 3 | try 3 | try 3 |

Table 1. **Results from individual numeric questions. See the main text for an interpretation.**

Where a question had explicit help it is shown in additional rows labelled 'simple' (for simple text help) and 'parts' (for where the problem is broken into parts). In these cases, when the original problem is re-posed, there are only two tries available. In such cases the 'mal-rule:wrong:wrong' path is in fact 'mal-rule:wrong', and 'wrong:wrong:wrong path is just 'wrong:wrong'.

Question q1.9 is the six resistor mesh shown above. The first part asks for the equivalent resistance to be calculated. The second part asks for the current flowing down the central oblique arm for a given applied potential. This is a little more complicated than the first part and this is reflected by the fact that only four got it right first time. Of the 14 who did not get the first part right first try, the majority were helped by the directed or general feedback to get it right in a subsequent try. In the second part, however, of the 26 who did not get it right first try, the majority were not helped by the feedback and ended up with all three tries incorrect in one way or another. Clearly, the feedback for the second part needs to be re-visited. Additionally, the results seem to show that there is a further mal-rule used by eight students that has not yet been identified and addressed with specific feedback.

The questions offering explicit help were q2.1 and q2.2, and the result for those student who chose to look at the help are quite encouraging. Following the 16 instances of help being selected, there were only two instances of the final answer being wrong. Since students would presumably only ask for the help if they really needed it (because of the mark penalty) this implies that the feedback was effective.

### Choice based questions

The first two adaptive multiple choice questions offered a 'don't know' option, but no student selected it. The third was a multiple selection question with six options (three correct) plus a 'don't know' option. Results were 28 right, nine part right, three wrong and one selected the 'don't know' option and then got it wrong.

The fourth choice question had six options with just one correct, but no 'don't know' option. Incorrect responses were given directed feedback and offered up to two further tries. Here 31 students were correct on their first try, five correct on their second try, and two correct and three incorrect on their third try.

## Conclusions

It is worth pointing out that in a well designed numerical problem of the kind used here, good conceptual understanding is a necessary pre-requisite for a correct solution. The problems are sufficiently complex that there is negligible chance that a student could guess a correct answer, although a good approximation can often be obtained by mental calculation. Numerical accuracy itself can be critically important professionally, as occasionally highlighted by expensive or fatal consequences of the alternative. Students therefore clearly need to be trained to accept the need for accuracy. Most of the feedback in the questions discussed here is directed primarily at the concepts and how to shape the problem to help the learner recognise them.

The numbers of students and questions involved in this study are too small to draw any statistically significant conclusions. It can be seen, however, that the adaptive features are being used by the students, and that they are undoubtedly of benefit to some of them. Over all students and adaptive numeric questions, after first getting the question wrong, 45% of those given directed feedback (62 instances) and 41% of those given general feedback (143 instances) obtained a correct answer. It is obviously unclear whether or not the directed feedback derived from the recognised mal-rule answers contributed much to the student learning experience.

In the one MCQ that offered multiple tries after feedback, of those who did not get it right first time 70% were helped to a correct answer by the adaptive features of the question together with the directed feedback.

All the numeric questions in these two electronics tests had randomised numeric values (except, by error, q1.9), and whilst students were able to work together at developing solutions to the problems it was likely that they obtained their own solutions. The multiple choice questions were randomised in other ways to a similar effect. The conclusion that can be drawn with some confidence, therefore, is that in the 12 questions (or part questions) analysed here, of the 424 student-answers, 165 were incorrect at the first attempt but 97 of them were corrected after one or two further tries following feedback. Without the stimulus of the feedback and the further attempts being offered, it is unlikely that the students involved would have learnt anything from their failing experience.

## References

Bacon R. (2005) "Discriminative Marking of Numeric Problems" CAA Loughborough.

Bacon R. (2010) "The SToMPII QTI v2.1 assessment system and its use within the sciences" CAA Southampton.

Greenhow M. & Gill M. (2004) "Setting Objective Tests in Mathematics using QM Perception" CAA, Loughborough,

Gibbs G. &Simpson C. (2004) "Conditions Under Which Assessment Supports Students' Learning" Learning and Teaching in Higher Education, Issue 1

Maths Asses project (2008) http://mathassess.ecs.soton.ac.uk/

IMS (2005) "*IMS Question & Test Interoperability Specification*" http://www.imsglobal.org/question/