Understanding complex calculations: Automated spreadsheets with built-in feedback

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The e-Learning team at the University of Sydney was approached to help develop a resource that would address some areas of learning difficulty that had been identified in two engineering units of study. Complex spreadsheets were developed, then automated with VBA code to provide the students with a formative assessment resource, based on scaffolded learning with immediate feedback. Twenty spreadsheets were eventually made available to second- and third-year students. Student evaluations have led to further development of the feedback features to make it clearer to students why some answers were correct or incorrect, and thus to improve their conceptual understanding of the principles behind the mathematical calculations.

Keywords: teaching and learning strategies, instructional design, personalised learning

Introduction

Engineering students need practice in applying the principles they learn in class to real life situations. They also need to be able to understand what happens when the parameters of a problem change. There was concern that students in the core subject of Fluid Mechanics were under-achieving, and six specific areas of student difficulty were identified:

- appreciation of dimensions;
- problem visualisation;
- understanding the sensitivity of output to changes of input;
- confidence in conducting routine calculations;
- logical layout;
- generic computing skills.

The USyd e-Learning team undertakes a number of strategic projects each semester, assisting and supporting academic staff to improve learning outcomes and teaching satisfaction. They were approached to assist with the development of a resource to improve the students' chances of meeting the desired outcomes of this unit of study. The aim of the project was to create a self-learning resource that would first remind the students of the basic underpinning paradigms of the problem that they had learned about in lectures and tutorials, then develop their understanding of these paradigms by allowing them to practise problems over and over with different input and parameters.

The desired outcome was that students would acquire the key concepts of Fluid Mechanics, and the strategy adopted was both teacher-learner focused and student-focused. The aim was that the students' own understandings of the concepts presented in class would be developed and deepened, following Trigwell and Prosser's (1997) Approach C and Approach D. Each of the 20 problems developed used a carefully structured approach to develop and deepen the student's understanding of and confidence with the use of the concepts.

Theory and method of development

As the generic computing skills that students need to develop include advanced use of Excel spreadsheets, a model was developed based on the work of Paul Blayney and Mark Freeman, who had created similar workbooks, with some formative feedback, for their students' summative assessment (Blayney & Freeman, 2004). However, their workbooks had different educational goals in reinforcing simple

calculations and were used for summative as well as formative assessment, requiring a much higher level of security.

The spreadsheets

A set of ten staged problems was developed in Excel workbooks for each of the two units of study (studied in years two and three of the four-year degree). These were created so that the problem seen by the student each time they opened the workbook was generated on a hidden worksheet from a set of pre-determined variables. This hidden worksheet was also used to record the correct answers. VBA code was then added so the students could both work on the problems repeatedly with different pre-determined parameters, and get immediate feedback for their answers, which the code checked against the correct ones on the hidden sheet.

Each workbook presents a reasonably complex problem in which the real-life parameters could vary widely. This might take the form of either an important theoretical concept or a real-life situation in fluid mechanics, and is usually accompanied by a diagram and/or a key equation. Examples of both a theoretical concept and a real-life problem are shown in Figures 1 and 2. The underlined text indicates variables that change every time the student attempts the problem.

Consider Eq 1 for a particular stream function, where A = <u>3</u>, B = <u>-3</u>, and C = <u>0.05</u>. Specific streamlines will be required for calculations later.

$$\psi = A \cdot \frac{y}{(x - B)^2 + (y - C)^2}$$

Eq. 1 Streamline function

Figure 1: Example of a theoretical problem
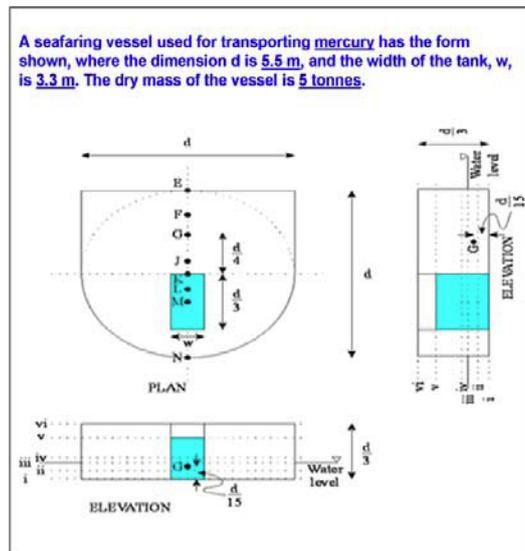
Figure 2: Example of a 'real-life' problem

Each workbook consists of two worksheets: 'Qx', which the students see, and 'Variables and Inputs' (V&I), which is hidden from the students, and which contains the variables that are selected to make up the problem. The hidden V&I sheet was prepared first, with the problem stated at the top and the variables generated with the LOOKUP function. The parameters of these variables varied, depending on the problem being addressed, but there were always 25 different sets of variables that could be randomly selected to create the question that was presented to the students, and that would determine the results of their calculations in the final stage of each problem.

The Qx worksheet, the one seen by the students, has the problem copied from the hidden V&I sheet at the top, often illustrated by a diagram or key formula as shown in Figs 1 and 2 above. The questions that relate to the problem are staged, usually in three steps, thus scaffolding the students' understanding.

It is not possible in this paper to go into detail about he development of the spreadsheets (which requires familiarity with the advanced functions of Excel such as VLOOKUP and INDEX), or how the VBA code was written, the principles of which are described in detail in Blayney and Freeman (2004). We will limit ourselves to a description of how the development process was aligned with the intentions and outcomes of the project, which were to address the six problems listed in the Introduction that had been identified with students' ability to visualise and solve engineering problems using the strategies described in Trigwell and Prosser (1997).

The structure of the problems

Each of these staged problems was carefully developed to test and build student understanding in a structured way, using the scaffolding steps outlined by Biggs' SOLO taxonomy (Biggs, 2003). Students are not able to enter any answers to Q2 until they have correctly answered all the questions in Q1, in which they demonstrate their understanding of the dimensions used in the problem. (There is no limit to the number of times they can try Q1.) They cannot then progress to the calculated questions in Q3 until they have completed Q2 correctly, giving them the opportunity to develop a conceptual understanding of the key factors they will need to consider in their calculations.

The first set of questions is usually a matching question that asks students to identify the units of measurement that would be used, or tests their knowledge of other basic information in a way that Biggs would classify as 'unistructural'(Biggs, 2003). This relates to the students' need to appreciate the importance of dimensions in calculations.

The next set of questions, usually multiple choice, requires the students to visualise the problem and identify the key components that would be needed to solve it. For example, in the boat question in Figure 2, students are asked questions about how they visualize the equilibrium of the vessel and location of the centre of gravity. These questions correspond to Biggs' (2003) 'multistructural' and 'relational' steps. They assist the students to develop their skills of problem visualisation.

When they have completed these preliminary questions, and thus oriented themselves to the dimensions and key issues of the problem, students are asked to solve a series of complex calculations, modelling the calculations that engineers need to be confident in making. This step is an example of Biggs' (2003) 'extended abstract', and it moves them from a detailed consideration of the parts of the problem to its solution *in toto*.

Some calculated questions appear more complex to the students, for example being presented in columns and requiring them to work out a formula, then drag to fill down. This is one of the ways that the lecturer built in challenges to enable the students to practise their basic computing skills, which they will require when practising as engineers. Others included more advanced use of Excel functions such as 'Goal seek' in the later spreadsheets.

Feedback

The VBA code was used in several ways to give the students feedback on their attempts, as we considered that immediate and detailed feedback would be appreciated by students as contributing to their understanding of basic concepts. However, the initial method of providing feedback proved inadequate for the students' needs.

First iteration

Direct feedback for **incorrect** answers to the conceptual questions (the second level of questions in the worksheets) was provided in the first iteration by the Microsoft message box provided by the Visual Basic command 'msgbox'. These included hints, extra information, and pointers to pages in the course texts for further assistance. However, this box proved to be limited in its application for this mathematical exercise, as it wasn't possible to express exponents, Greek letters or other basic mathematical symbols. Also, the box that provided the feedback disappeared as soon as the "OK' button was pressed, so there was nothing left on the screen for the students to consider. Figure 3 shows text from two of the feedback message boxes.

Figure 3: Text of two message boxes

At this point it was considered unnecessary to create feedback for **correct** questions, partly for time constraints on the project. However there were other kinds of feedback used in this first iteration. For some of the calculation questions equations became visible to students as a clue after they had attempted the problem themselves, and sometimes extension activities were revealed after the correct answers were completed. These took various forms, such as further diagrams or equations, or tables in which the students could change variables and see the result of these changes on output demonstrated in dynamic graphs in Excel.

Changes in the second iteration

At the end of each semester the students evaluated the worksheets were evaluated by a voluntary questionnaire (Scott & Ward, 2006). This revealed that the students had found the multiple choice (conceptual) section of the worksheets to be of limited usefulness, because they sometimes didn't know why their lucky guess was correct, or their unlucky guess wrong. This meant that they had to keep changing their answers and clicking the 'assess question' button until they hit the jackpot, and, has already been explained, it also meant that they couldn't move on until they had found that lucky combination. It also meant they had no idea why their answer was correct nor the desire to read the notes to find out for themselves.

So in the second iteration textboxes were added, coded blue for correct or red for incorrect, that are hidden when the worksheet is opened, but that appear after the student has pressed the 'Assess Question' button in direct relation to the answers provided. These provide detailed feedback on each answer in the second section of questions – the section that tests and builds conceptual understanding. Now the students have the chance to develop a good understanding of the concepts that underlie the problems before they apply their understanding by attempting the calculations that make up the third part of the problem rather than just trying out answers until they get them all correct. If their answer is wrong they can read the feedback that is staged according to how many attempts they have made, and make a more educated attempt at the multiple choice the second time. This feature is currently being trialled with a new cohort of students, and has yet to be evaluated.

Conclusion

The target audience for these problems was initially students who were keen enough to make some effort and realise that practice might be beneficial; it was staged formative assessment for students to work on in their own time and at their own pace. We were realistic enough to appreciate that many students will only do the minimum necessary to pass the unit of study, with some motivated enough to do some extra work. However, the completion of two of these problems has become mandatory for all students enrolled in the units of study, as many of the students admitted in the evaluation that they had not used the sheets as they 'were too lazy' and 'didn't have time'. It will be interesting to see in the future if the evaluations change over time if students are mandated to attempt at least some of these worksheets.

These worksheets are initially time-consuming to develop but not especially difficult to set up, and the first workbook developed forms a template. They may lack something in presentation (the Microsoft message box is a particularly unattractive object, not easily customised), but they provide a practical framework for students to extend in a carefully scaffolded way the work presented in lectures and reinforced in tutorials, especially the more complex concepts, and get immediate detailed feedback for their efforts.

Only one cohort of students has completed both the second- and third-year units of study, but there is some evidence indicating a slight correlation between an individual's availing themselves of the opportunity to complete some of these worksheets and a trend from fail to pass in examination results (Scott, Ward, & Wood, 2006). Qualitative and anecdotal feedback also indicates that some students

appreciate the learning opportunity this resource has provided. The problems provide a model of a logical layout, and give students the opportunity to learn generic computing skills that they will use when they begin their professional lives. Students can see how to model a conceptual problem mathematically, they learn the importance of dimensions, and they can gain confidence in doing calculations that will become routine to them. They can also repeat the problems as many times as they choose with different variables, and see how the changes in input affect output.

Student responses recorded in the initial evaluation of the spreadsheets and in their informal discussions with the lecturer have led to the development of the textbox feedback, and a new cohort of students, who will be mandated to attempt these problems, will be re-evaluated for their reaction to the textbox feedback over several semesters in order to continue to improve the spreadsheets and make better use of them as a teaching tool.

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Acknowledgements

Bionotes

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