THE INTEGRATION OF INTERACTIVE EXCEL TUTORIALS INTO A BRIDGING (PRE-CALCULUS) COURSE

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ABSTRACT

Inadequate mathematical skills and understanding act as a barrier to students wishing to study a variety of courses at university. At the University of Cape Town a first year course called “Effective Numeracy” is offered to such students, with the objective of supporting their study of other subjects and preparing them for mathematics courses in later years. Addressing the problem of the lack of mathematical and quantitative reasoning skills in these students is very challenging, and calls for the use of various techniques and approaches.

Excel workbooks coded with VBA have been found to be a very effective environment for creating interactive tutorials that students can use for self-paced study. The Excel tutorials constitute one third of the course (in terms of time and credit), and are very firmly integrated into the overall curriculum of the course. Although there are slight variations in timing of delivery (because the class is divided into three groups), the content of any tutorial session consolidates and enriches material covered in the classroom within the same week.

A large part of the curriculum is devoted to pre-calculus, focussing particularly on the understanding of the function concept and the idea of slope. The design of the tutorials includes a custom-built “graphing device” which can be incorporated into any Excel workbook at every point that it is required for the execution of the exercises. This means that a student can easily produce the graph of a function without leaving the context of the tutorial and interrupting the interactive “conversation” of the exercise.

This paper reports on our experiences in implementing this multimedia intervention and in attempting to answer questions about how the students experience these tutorials.

1. Introduction

At the University of Cape Town (UCT), it is recognised that many students have inadequate quantitative literacy and mathematical skills to enable them to cope with their chosen course of study (Brink, 2001). Apart from the fact that the traditional approach to teaching mathematics in schools does not develop sufficient levels of quantitative literacy (as discussed by Hughes-Hallett, 2001), in South Africa there is a legacy of educational disadvantage that still affects the majority of the population. Under Apartheid, there was an explicit policy of denying black students access to mathematical and scientific knowledge, and it will take many years to reverse the effects that this has had on the education system.

For disadvantaged students who are studying economics-related subjects in the Humanities Faculty, the Mathematics Department at UCT provides a first-year course entitled “Effective Numeracy”, which has the objective of increasing students’ level of quantitative literacy, supporting their studies in the rest of their programme and preparing them for mathematics and statistics courses in later years. The philosophy and development of this course over the last five years is outlined in papers by Brink (2001) and Frith and Prince (2001). One of the most important principles in the design of the course is to create a non-threatening co-operative environment for learning, that will allow students to develop confidence in their ability to succeed, as many of these students have a high degree of “maths-anxiety”. The very wide range of ability and prior experience, particularly in the use of computers, within the classes, poses a significant challenge to the realisation of this objective.

Currently the course consists of two semesters with slightly different objectives. In the first semester the emphasis is on developing quantitative literacy through the use of context-based applications. The second semester of the course content is closer to a more traditional pre-calculus (bridging) course.

One third of this course throughout the year (in terms of classroom time and credits) is conducted in the computer laboratory through the medium of Excel-based interactive tutorials, which are tightly integrated into the curriculum. In the first semester there is an emphasis on learning to use Excel in “real-life” contexts to perform data analysis and to represent quantitative information graphically. In the second semester the Excel tutorials are intended to support the learning of mathematical concepts, in particular, the idea of functions, graphs and gradients. This paper focuses on the use of computer tutorials in this part of the course.

2. Excel-based interactive tutorials

In designing the Effective Numeracy course, we have assumed that using computer-based tutorials in the “bridging” component of the course will enhance the students’ understanding of the mathematics concepts. There are numerous reasons to believe that properly-used computer tutorials can add value to a mathematics course, which were comprehensively reviewed by Kaput (1993). The most obvious advantages that are exploited in our course are the computational and graphical abilities of Excel, which allow more examples to be done by the student and allow the use of more realistic values in these examples. The Excel environment facilitates the understanding and representation of functions in the four different ways that the course emphasises: with a formula, with a table of values, graphically and verbally (The “Rule of Four”of Hughes-Hallett, Gleason, McCallum, et al., 1998).

The computer also makes it possible to illustrate certain concepts and processes graphically in a dynamic manner, which is difficult to achieve on paper or a blackboard, which we believe assists the students to develop the ability to produce their own mental images in situations where they are helpful. Obviously we also believe that there is an advantage in approximating the “conversation” of an individual tutorial situation where each student receives immediate feedback as they work through a computer tutorial at their own pace.

There is a great deal of experience of and knowledge about using Spreadsheets to enhance learning in mathematics, some of which can be accessed through a website at Vienna University (Neuwirth, 2001). Some practitioners have also used extensive Visual Basic for Applications (VBA) code to create Excel-based tools and environments that can be used to enhance learning (for example Carr, 2000). Our approach is to make use of VBA code within an Excel workbook, to program self-contained “tutorial-simulations” (Laurillard, 1993) that can be used semi-independently by the students without the support of any other materials.

Thus a typical tutorial will consist of several electronic Excel worksheets, one stating objectives, some containing the interactive presentation of relevant mathematics content, and others comprising examples and exercises, many of which make use of a custom-built “graphics tool”. This allows the student to produce the graph of a function (as they would with a separate graphics package), but at the relevant place within the worksheet and without interrupting the interactive conversation that comprises the tutorial.

Some of the advantages of using Excel as an authoring environment are that the students are familiar with it, that all the functionality of Excel remains accessible to the students throughout the tutorial, and that Excel is so commonly used that the tutorials become extremely portable. In addition it is very easy in this environment to change the content, for instance to modify an example or introduce different data. It is also relatively easy to program fairly sophisticated interactions and animations using the in-built VBA macro language, and to record students answers to a database for automated processing.

3. Integration of tutorials into the course

Every week the students spend one 2-hour session in the computer laboratory, and two 2-hour periods in the workshop-lecture environment. The actual mathematical material dealt with in the computer tutorial for any particular week is always covered in the classroom within that same week, and the lecturers concerned are encouraged to make the links between the laboratory and the classroom materials explicit.

There is a critical relationship between assessment practices and the nature of student learning (Luckett and Sutherland, 2000) which means that planning the assessment structure and practices is an integral part of the curriculum design for computer interventions as well. The continuous assessment process built into the design of the entire course (which has both a formative and a summative purpose) is also applied to the computer component. To assist with this process a system has been developed whereby students’ responses to questions in the tutorials and assessment can be recorded automatically to a database, where they can be processed to produce feedback to individual students about their misconceptions, and to the tutors about the class’s performance in general. This system also can be used to automate some of the burden of marking that the regular evaluation schedule generates.

Every third week there is a “computer evaluation” in which students complete a computer tutorial that is submitted for marking and counts towards their class record. As pointed out by

Laurillard (1993), use of computer learning material "must be integrated with other methods, the teacher must build on the work done and follow it through, and most important, the work students do on the material must be assessed." One third of the final examination for this course is also conducted in the computer laboratory through the medium of an Excel workbook similar to the tutorials, but without feedback.

In section 2 above, the ability of the computer-based tutorial to provide the student with immediate feedback (and a "conversational" tutorial environment), is stressed as one of the main motivations for using this type of intervention. In the Excel tutorials, in almost every case where a student provides and answer to a question, they will immediately receive explanatory feedback (see Figure 1). Ideally this feedback would be "adaptive", allowing the tasks presented to the student to be tailored to their particular needs, as manifested by their performance on questions in the tutorial (Laurillard, 1993). This level of interactivity is not built into our Excel workbooks, but is made available through the presence of the lecturers and tutors in the laboratory sessions. All students perform the same tasks on the computer, (although they can control the order), and more advanced optional tasks are also made available. Students who need additional support, can get almost immediate assistance from a tutor, of whom there are 3 present in each class of less than 30 students. It is not our intention that these tutorials be used for independent study, but rather to support the learning of material that is also dealt with in workshop-lectures.

As mentioned before, the Effective Numeracy course concentrates on quantitative literacy in the first semester and on pre-calculus in the second. During this semester, students explore the properties of different functions and use the graphical capabilities of Excel to solve "word-problems" graphically. Rather than draw up a table of values for every function they wish to represent, or change to another environment such as a graphics calculator, they are provided with a pre-programmed "graphics tool", which allows them to create up to five graphs simultaneously merely by typing in the formulae. A separate instance of this tool is placed at the appropriate place in the tutorial, wherever it is needed, so that producing a graph can be done in a manner that creates the least distraction to the student's train of thought while working through the tutorial. An example of an instance of the Graphics tool in context is shown in figure 1.

A further advantage of the "in-situ" graphics tool, is that, when marking a student's work, the lecturer can see the graph(s) that the student actually plotted. This allows for partial credit being given for partly correct work, and allows the lecturer to develop an understanding of students' difficulties and misconceptions. If students were using a graphics package or calculator "on the side", one would only have access to their final answers for evaluation purposes.

4. Students' response to the tutorials

There are several questions we would like to be able to answer about the way students' respond to the computer tutorials used in this part of the course, and to which we have so far received partial answers, which will be outlined below:

1. *Do the students believe the tutorials helped them to understand the mathematics content of the course?*

The students in the Effective Numeracy course every year, complete a comprehensive course evaluation questionnaire at the end of the first and the second semester of the course. In addition a randomly selected sample of students are interviewed about their reactions to the course at the end of the year.

The course evaluation results obtained in 2001 are representative. In response to the questions on forms filled in by about three quarters of the class at the end of the 2001 course, 70% of the respondents claimed to have found the explanations contained in the tutorials useful, while 82% were positive about the usefulness of the feedback in improving their understanding. These results are illustrated in Figure 2. The aspect of the tutorials that many students "particularly liked" was the automated drawing of graphs. Others mentioned the feedback, the visualisation of concepts, and the fact that they were "doing maths" on computers.

In 2001, extensive interviews were carried out with 11 students, chosen at random, in which one of the questions asked was: "Did the laboratory tutorials contribute to your understanding of the maths?". These were some of representative responses:

- “Yes, definitely. The class and labs helped each other. For example the labs helped with understanding graphing and the class dealt with the equations, which were needed in order to do the labs and so on. Both helped each other.”
- "Yes, if you don't understand in class, it comes together in the labs. The feedback is very useful. It shows how the lecturer would answer the same questions... (The labs) really brought about a greater understanding. What we did in class we would get immediate practice in the labs."
- "Labs were very visual. You can actually see how things work. In class you have to imagine for yourself what things look like – in the labs you can see it clearly before your very eyes, it is easier to understand. They are helpful, they show more than you see in class – especially the graphics package (I explored more than the tut told me to)"
- “Ja, it did, but mostly to computer skills… Labs gave direction for solving word sums, helped for doing similar ones again later.”
- "The good thing about the labs is that even if you don't want to ask questions, you still get feedback. There are lots of exercises and real-life examples. They helped you through the problems and helped you to understand how to integrate concepts."
- “Yes, they provide reinforcement to what was done in class, step-by-step. I liked learning how to use the computer.”

Seven of the eleven students felt strongly that the computer tutorials had helped them to understand the mathematics content of the course, and there were also seven who remarked on the interdependence of the laboratory and classroom material. However there was a tendency to see the laboratories as reinforcing work done in the classroom, rather than the other way around. This is consistent with the observation that students prefer to see new ideas first in the classroom. Two of the students specifically referred to the feedback as being helpful with learning the mathematics and two remarked on the usefulness of the step-by-step approach utilised in the tutorials for solving “word sums”. It is interesting that one of the students saw the visual (graphical) nature of the tutorials as making the greatest contribution to her understanding.

2. Do the tutorials have any effect on students’ attitudes to learning mathematics?

This is a difficult question to answer because of the close integration of the tutorials into the course. Any recorded attitude changes cannot be ascribed to any particular component of the course. However there are indications from the course evaluation results, that there was a general improvement in students' feelings of confidence in doing mathematics (and in using computers). These results are illustrated in Figure 3. However, to study attitude changes more thoroughly, will involve the use of properly validated scales, such as those described by Cretchley et al (2000).

3. *Does the timing of the delivery of a computer tutorial relative to the related classroom sessions have an effect on the learning?*

Since there are three lecture groups who attend the laboratories on different days of the week, there is variation in the experience of the students in different groups as far as the timing of the computer tutorials is concerned. Some students will encounter a new idea for the first time in the laboratory and then have it reinforced in the classroom, while others see the same idea for the first time in the classroom, (and then have it reinforced in the laboratory).

Our observations and students' comments indicate that some students in our course are more comfortable when they encounter new knowledge on paper first, and then apply that knowledge in the computer tutorials. It is possible that it is easier to assimilate new ideas (and transfer them to other contexts) when they are first introduced in a medium that is familiar.

An attempt was made to gain insight into whether the timing of delivery of the computer tutorials has an effect on the learning, by performing pre- and post-tests on the function concept in the class where the concept was first introduced in the laboratory and in the classes where it was first encountered in the classroom. The intention was to explore whether it is possible to observe differences in the effectiveness of the learning between the classes who experienced the different learning environments in a different order.

The results were inconclusive, but provided a great deal of insight into the requirements for the design of such an experiment, (which we intend to repeat in the second semester of 2002). The most noteworthy result was that the medium in which the pre-test was delivered had a very significant effect on the students' performance. Since the students were assigned to the different classes at random, and there was no significant difference in their performance throughout the year, it was justified to assume that the three classes should all achieve similar results for the same questions in a pre-test conducted in all classes at the same time.

It was found however that the class who performed the pre-test in the medium of an Excel tutorial performed significantly better. This could be because the students were more inclined to engage seriously with the pre-test presented to them as part of an Excel tutorial than as a paper-based test. This effect highlights the need to present pre- and post-tests to all groups in exactly the same way (even if the questions are identical in content) and also to ensure that the students engage with the questions in a manner that truly reflects their knowledge.

4. *How do the students interact with a typical tutorial? Which features contribute best to their learning?*

This is a very broad question and should be the subject of a whole investigation in its own right. However, close observations of students interacting with the tutorial dealing with functions and their graphs yielded some very useful insights into the learning processes that take place while a student is engaged in working through a computer tutorial. These insights were sufficient to convince us of the need to conduct more extensive observations more frequently. These should lead to a much greater understanding of the nature of students' misconceptions, which types of activities in the tutorials lead to better understandings, and consequently how to design better tutorials that are more effective in meeting the students' needs .

5. The way forward

The results of observations, course evaluation questionnaires and student interviews indicate that in general the use of interactive Excel-based tutorials for supporting the learning of mathematics concepts is well-received by the students in the Effective Numeracy course. They appear to have a positive opinion of the value of the computer tutorials in contributing to their learning.

The incorporation of a custom-designed graphics tool that can be included within an Excel workbook wherever it is needed has enhanced the design of the tutorials used in the pre-calculus part of the course, and a system for recording student responses to a database has allowed for some of the assessment to be automated. We will continue to refine both these initiatives.

As the ability to learn mathematics is strongly influenced by affective factors, especially confidence and anxiety, we explicitly try to address these factors in our curriculum design. Thus, we plan to carry out a more systematic study of the effect of the course, and the computer component in particular, on students' attitudes towards and feelings about learning mathematics and using computers.

A study of the effect of the timing of the delivery of the computer tutorials (relative to the classroom materials) will be continued in 2002, making use of pre- and post-testing of students' understanding of concepts, and detailed observations of students interacting with the computer tutorials. These observations will provide further insights that will inform the design of computer tutorials that more effectively meet the needs of students in the Effective Numeracy and other courses in the future.

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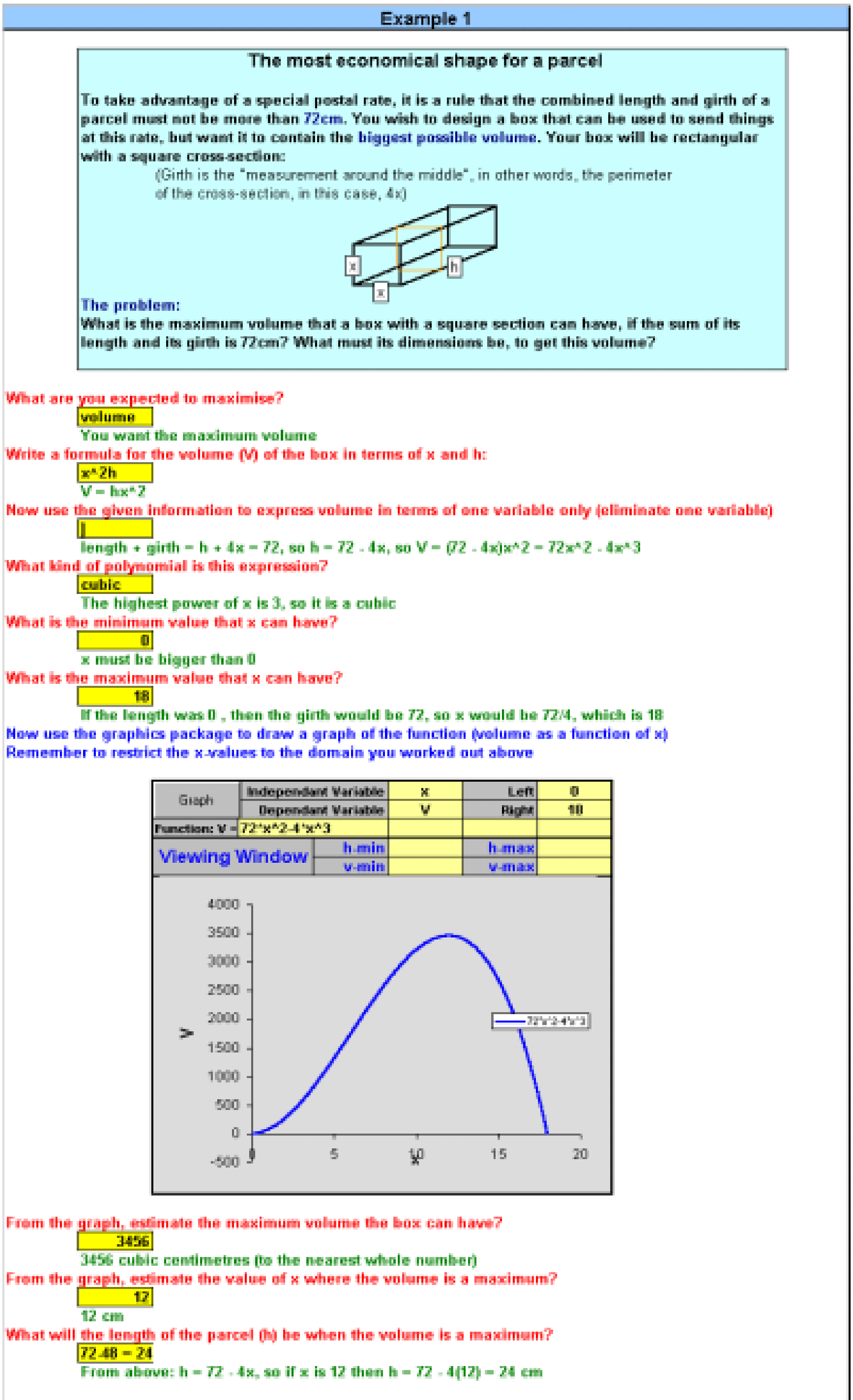
Example 1

The most economical shape for a parcel

To take advantage of a special postal rate, it is a rule that the combined length and girth of a parcel must not be more than 72cm. You wish to design a box that can be used to send things at this rate, but want it to contain the biggest possible volume. Your box will be rectangular with a square cross-section:

(Girth is the "measurement around the middle", in other words, the perimeter of the cross-section, in this case, 4x)

The problem:
What is the maximum volume that a box with a square section can have, if the sum of its length and its girth is 72cm? What must its dimensions be, to get this volume?

What are you expected to maximise?
volume
You want the maximum volume
Write a formula for the volume (V) of the box in terms of x and h:
x^2h
V = hx^2
Now use the given information to express volume in terms of one variable only (eliminate one variable)
length + girth = h + 4x = 72, so h = 72 - 4x, so V = (72 - 4x)x^2 = 72x^2 - 4x^3
What kind of polynomial is this expression?
cubic
The highest power of x is 3, so it is a cubic
What is the minimum value that x can have?
0
x must be bigger than 0
What is the maximum value that x can have?
18
If the length was 0 , then the girth would be 72, so x would be 72/4, which is 18
Now use the graphics package to draw a graph of the function (volume as a function of x)
Remember to restrict the x-values to the domain you worked out above

Graph	Independant Variable	x	Left	0
	Dependant Variable	V	Right	18
Function: V =	72*x^2-4*x^3			
Viewing Window	h-min		h-max	
	v-min		v-max	

From the graph, estimate the maximum volume the box can have?
3456
3456 cubic centimetres (to the nearest whole number)
From the graph, estimate the value of x where the volume is a maximum?
12
12 cm
What will the length of the parcel (h) be when the volume is a maximum?
72-48 = 24
From above: h = 72 - 4x, so if x is 12 then h = 72 - 4(12) = 24 cm

Figure 1: An instance of the "graphics tool" in the context of an exercise on the graph of a function (with student responses filled in). Note that the feedback is all-visible in this view, but only becomes visible to students after they have attempted an answer.

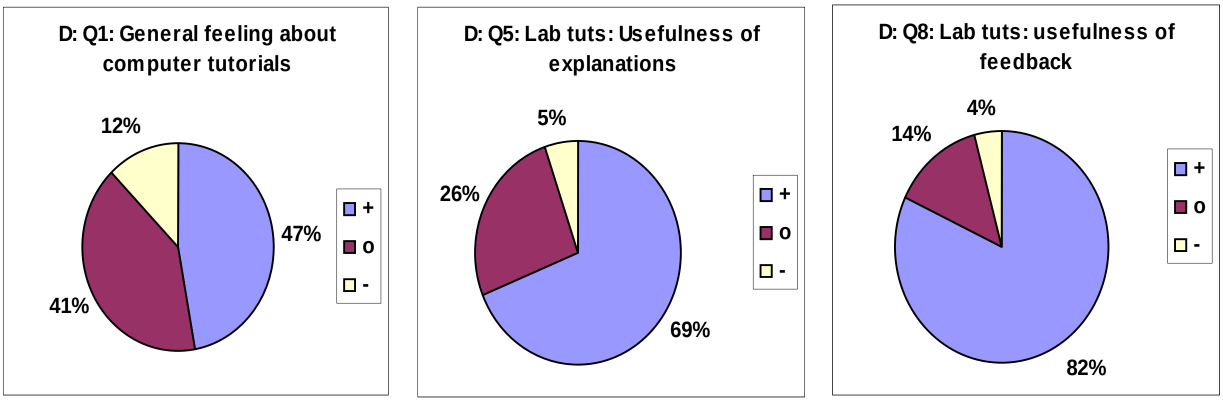

Figure 2: Summary of responses to selected course evaluation questions about usefulness of computer tutorials in the Effective Numeracy course. For every question, students were required to choose either a positive (+), a neutral (0) or a negative response (-).

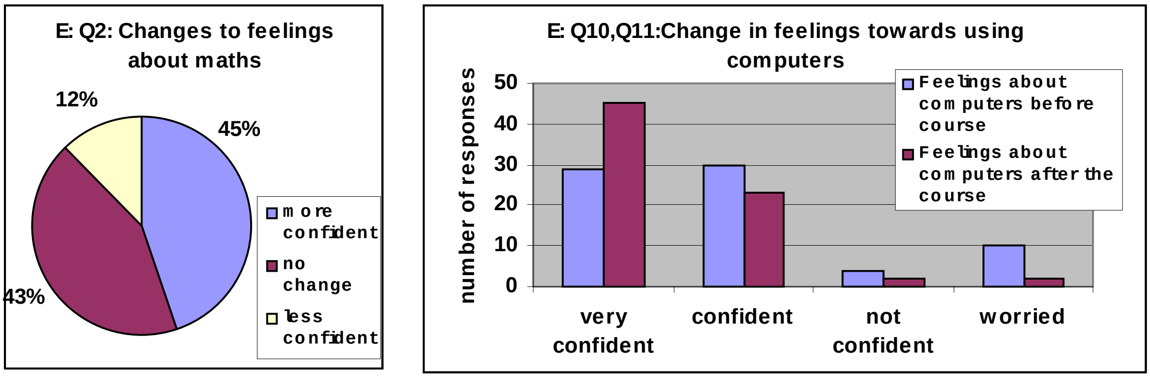

Figure 3: Summary of responses to course evaluation questions about changes to feelings of confidence with mathematics and computers.