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Creating mathematical learning resources—combining audio and visual components

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Abstract

Students commencing science and engineering degrees at the University of Wollongong are given mathematics skills tests in the first and fourth weeks of session. An evaluation of the results from these tests indicate that the majority of students' basic mathematical skills were insufficient to adequately support the prescribed first year mathematics curriculum. To address this problem a pilot study was set up to develop video solutions. These solutions permit students to see the development of each solution in a step-by-step manner. An audio

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commentary on each worked solution assists learning by providing students with an explanation of the developing solution. Two methods of video capture were investigated. The first used eBeam, a system to capture pen strokes from a whiteboard. The second method used a video camera mounted on a copy stand. We describe the process by which the video solutions were recorded and describe the educational environment in which students accessed them. A preliminary analysis of the impact of this tool on the achievement of students is also presented.

Contents

Table 1: Students' answer to Question 1. Correct answer in bold.

Question	Option	% Answer
Domain of the function	**a)** $\lvert x\rvert < 1$	**25.91%**
$f(x) = 1/\sqrt{1-x^2}$	b) $\lvert x\rvert \leqslant 1$	13.47%
is the set of x such that	c) $\lvert x\rvert \geqslant 1$	13.47%
	d) $\lvert x\rvert \neq 1$	35.75%
	e) x is all real numbers	7.77%
	Missing Value	3.63%

Table 2: Students' answer to Question 5. Correct answer in bold.

Question	Option	% Answer
	a) $a+b$	49.74%
$\sqrt{a^2+b^2}$ is equal to	b) $\sqrt{a+b}$	5.18%
	c) $a-b$	2.07%
	d) a^2+b^2	1.04%
	e) None of the above	**41.45%**
	Missing Value	0.52%

1 Introduction

In recent years' students at the University of Wollongong enrolled in computer science, engineering and science degrees performed poorly in the mathematical subjects that are co- or pre-requisites of their degrees. In order to investigate the reasons, students who undertook an introductory mathematics subject were given a multiple choice quiz in the first week of session. After eight hours of lectures revisiting basic mathematical skills students were quizzed a second time to ascertain if their skills set had been upgraded. Student answers on the quiz provided clear evidence of a need to create learning resources to assist students in gaining and/or refining basic mathematics skills. This need is illustrated by the responses to two questions are shown in Tables 1 and 2.

Analysis of test data revealed that students had very poor skills in basic mathematical manipulations involving algebra, algebraic fractions, indices, logarithms and even plugging numbers into formulae. It is therefore unsurprising that students performed badly on more abstract questions requiring a higher degree of mathematical sophistication.

The distribution of student marks in the first test of 2004 is shown in Figure 1. A mark of 16 out of 20, or higher, is considered to be a pass. Experience shows that students who do not reach this level by the second skills test struggle to pass the course because of their poor ability in performing basic mathematical manipulation and their poor grasp of fundamental concepts. Only 15% of students scored 16+ on the first test in 2004, indicating that 85% of the class did not have the required command of basic skills. This is despite the fact that almost all students in the course have taken a basic calculus course at high school which is designed to equip them for further studies in mathematics as a minor discipline at tertiary level (Mathematics, previously called two unit mathematics, in New South Wales). In fact 24% of the intake had passed a higher level mathematics course in high school which is designed to equip them to take normal first year university mathematics courses (Mathematics Extension 1, previously called three unit mathematics, in New South Wales). Almost half of the class (46%) scored ten or fewer, 24% of the students scored eight or fewer. There is clearly a need to develop new learning resources to help students master basic mathematical skills.

Several recent reports [2, 6] identified a decline in the percentage of Year 12 students taking intermediate level and higher level mathematics in Australia. This decline in numbers will have an adverse effect on "the national capacity for innovation in engineering and technology" (Barrington [2] page iv). Our findings suggest that the situation is worse than envisaged because students who have taken intermediate and higher level mathematics in New South Wales have very poor mathematical skills.

There is an emergent literature examining different aspects of the transition from the proficiency required in mathematical thinking and skills at

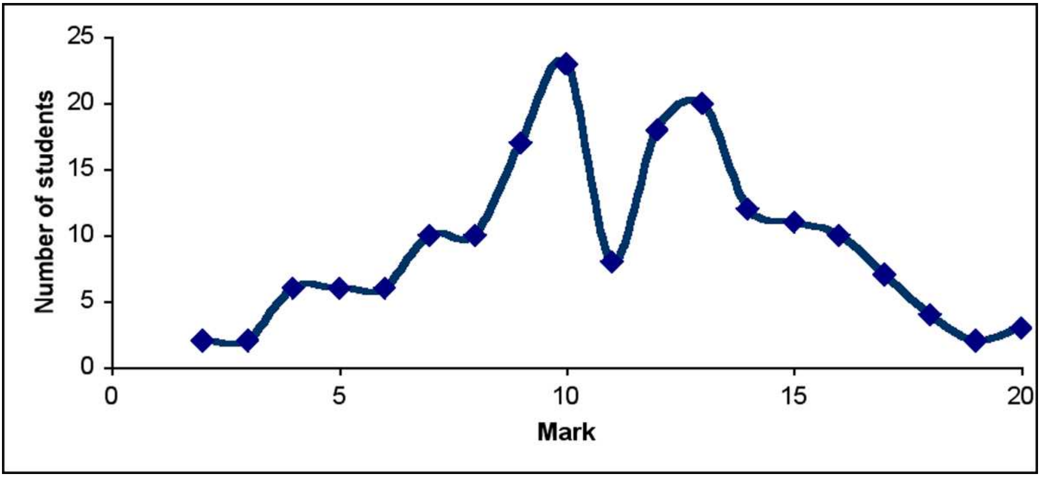

Figure 1: Distribution of student marks. First test, 2004.

the school level to those required at the tertiary level and potential solutions [3, 8, 9, 11, 14, 15]. The poor level of mathematical knowledge and skills of students entering university were identified in earlier studies [1, 9], including those detailing deficiencies in engineering students [5, 14].

Some of the techniques developed to address gaps in the mathematics education of incoming students, or simply to develop mathematical knowledge, fall into an instructivist tradition, whereby the mathematics to be learned is provided to students. Others techniques are based on a constructivist approach [7] where the emphasis is on students constructing mathematical knowledge. Kajander and Lovric [9] implemented a two pronged approach addressing transition issues: they provided students with a Mathematics Review Manual, replete with fully worked mathematics problems, to help them prepare before coming to university and they redesigned the mathematics curriculum. They found those who used the manual prior to coming to university did better than those who did not. Johnson's [8] 2002 approach to correcting deficiencies focussed on the development of an on-line assessment system, with randomized automatically constructed tests and automated scoring systems, providing students with prompt feedback and allowing multiple submissions. Jacobs, using a constructivist approach developed modules based on animation, visualisation and interactive graphs to maximise the comprehension of differential equations and then developed online multiple choice quizzes and worksheets. Engelbrecht et al. [4], in addressing the issue that students entering university in South Africa showed little understanding of basic concepts of pre calculus followed a reform calculus approach with concepts being introduced in four ways: *verbally, numerically, algebraically and visually* (p.710) to investigate the conceptual and procedural skills of students. They found that improved conceptual understanding did not come at a cost of loss of skills proficiency.

Each approach has its own advantages and disadvantages and we recognise that best practice is likely to involve the use of a variety of techniques so as to cater for differing needs of students. The resources discussed in this article were developed to address local problems and contexts. Engineering students at the University of Wollongong take a six credit mathematics course in both sessions of their first year; the subject is oriented toward the development of mathematics skills. The assessment is based on the demonstration of those skills, with multiple choice questions in in-session assessment and problem solving in the final examination. In recent years (2004–6) they have been given a mathematics skills test in the first and fourth weeks of the first session. The results from these tests show that many of our students have an inadequate grasp of high school mathematics. Further, there is a strong association between the performance of students' on the skills test and whether they pass or fail the course.

To assist students master the techniques from high school that are used in their first year at university we have created learning resources, described latter, that combine visual and audio information. The resources are not intended to provide an introduction to the mathematics rather they are aimed at providing a theory refresher and review. We decided against developing a learning resource that involved answering quiz questions online because many of our students have difficulty conceptualizing how to start the solution. In our resources we set out to capture the thought processes that lead the solver to write down the first line of the solution. Other students may need to revisit the definitions or rules before attempting questions. Some students understand how to do a problem once they see a worked solution. For these students, the solution is possibly a reminder of what they learnt in high school and had forgotten.

2 Worked solutions using video

For many years a high proportion of students, have failed the introductory mathematics subject for Engineers. The repertoire of textual materials and resources, lectures, tutorials and assessment system have been insufficient for these students. One solution would be to modify the curriculum or pedagogical approach. At this stage a change in curriculum or approach has not been entertained. Rather the focus has been on the development of additional resources, to complement the existing subject resources. To help students develop their expertise in basic mathematical manipulations it was decided to create a learning resource that provided fully worked solutions to sample questions. Fully worked solution helps students that know how to start a solution but 'lose their way' on the way to their answer. Fully worked solutions can be written in LaTeX, converted to PDF and distributed to students via a WebCT site. However, reading a worked solution does not necessarily help students who do not know how to approach the question. Previous research has indicated that learning resources combining visual and audio components reinforce learning by providing multiple connections that do not occur when the audio is absent [10, 12, 13, 16]. We therefore decided to develop a format combining a video solution with an audio track. The visual component shows the step-by-step development of the solution. In the audio track the solver explains the evolution of their thought processes as they tackle the question. We expected that this would help students understand the thought processes that lead to the first line of a solution and how to think about problem solving. In the following we discuss the two methods that were used to create video solutions.

Prior to creating video solutions some consideration was given to producing the worked solution using Macromedia Flash® (an animation program). This approach was not adopted due to the training that a user must first receive prior to using the program. We thought that this barrier would deter many academics from developing worked solutions. The technology chosen allows resources to be created without significant training.

In this pilot study twenty video solutions were prepared using the two methods described later. The budget required for the production of the video solutions was minimal as the necessary equipment was made available through the Learning, Innovation and Future Technologies Laboratory (LIFT Lab) in the Centre for Educational Development and Interactive Resources (CEDIR) at the University of Wollongong. A student was paid to write the worked solutions and to record the audio for the voice overs. The operation of the equipment was performed by two of the authors: Aminifar, a PhD student, and Caladine. A costing for the production of the learning resources was not determined as this project was a pilot study to determine possible techniques and to develop those determined to be most suitable for the purpose at hand.

2.1 Video production methods

We decided not to base the video around a teacher standing at a whiteboard as it was believed that the image of the teacher would be a distraction. Furthermore, the solution would not be rendered large enough to be legible. To ensure that the recorded solution was legible two approaches were tried. In the first approach a pen stroke capturing whiteboard technology was used. In the second approach a written solution was captured by a video camera mounted on a copy stand.

2.2 First production method: eBeam®

There are now a number of technologies on the market that capture pen strokes from a whiteboard. These included eBeam®,[1] Herma®, Mimio® and SmartBoard®. However at the time that this pilot project started only eBeam® was available at the University of Wollongong, which is why it was chosen the first production method.

To use eBeam® a receiver was placed in the corner of a whiteboard, as shown in Figure 2. The solution was then written on the whiteboard using standard whiteboard pens that were enclosed in sheaths. The sheaths transmitted their position to the receiver using ultrasound. The receiver, using triangulation, detected the position of the pen which was then recorded graphically by software on a computer connected to the receiver. The capturing of a question is illustrated in Figure 2.

When the file was played at the speed at which it was recorded the answer appeared at a rate that seemed very slow to a viewer. This slowness was partly due to the solver stopping to think about what to write next and partly because it took more time to write a solution on a whiteboard than it would take to write on paper. To produce a video in which the solution develops at a 'natural' speed the video file was edited using iMovie® to remove pauses. As there is no need for the student to see the question being written this was removed during the editing process. The video therefore starts with the question already written.

[1] http://www.e-beam.com/

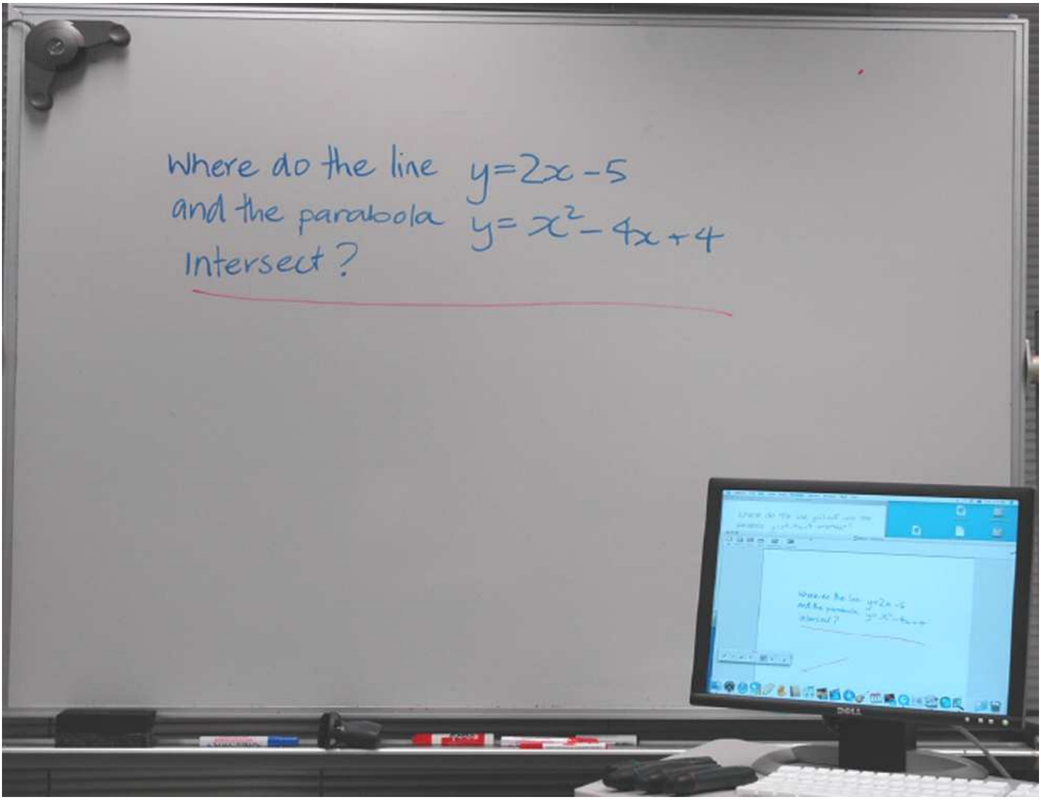

Figure 2: eBeam® apparatus.

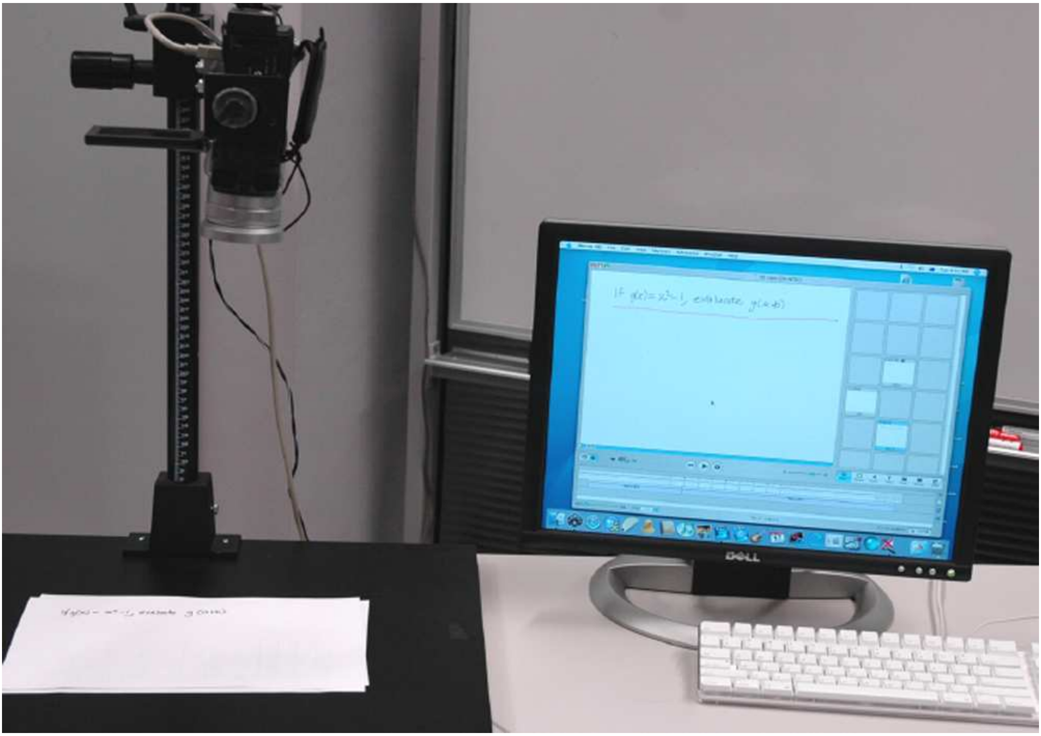

Figure 3: Video camera and copy stand capture apparatus.

2.3 Second production method: video camera

In this method a consumer video camera (that is, designed for home use) was placed on a copy stand, as shown in Figure 3. A piece of paper was placed on the paten of the copy stand underneath the camera. The solution was then written on the paper. The video output from the camera was captured by a computer connected to the camera using DV/firewire. The video file was then edited iMovie®, to remove the writing of the question and speeding up the solution—for the reasons mentioned previously.

2.4 Recording the audio

After editing the eBeam® video to remove pauses an audio commentary was recorded as a 'voice artist' viewed the video. For some solutions a detailed audio commentary was recorded while in others only the key points were recorded. The audio track was captured using a clip-on microphone and fed into iMovie®. The resulting audio track was then combined with the video using iMovie®. The combined file was then edited to ensure that the audio track proceeded at the same pace as the video solution. The voice over was reused to produce the video camera commentary.

2.5 Producing the final video

Prior to the development of solutions it was decided that the primary mechanism of distributing video files would be through the course WebCT site. It was therefore essential that students working at home could download the files over the bandwidth of a dial-up Internet connection. To minimise download time the combined audio-visual file was compressed in iMovie® to reduce its size, although compression also caused a reduction in the quality of the pictures and sound. As most students use either an Apple or a Windows computer the compressed file was provided in two formats, one for each platform. Although this increases the time taken to produce the final product it was thought vital that students could watch the video without having to install software on their computer. Compressed video solutions were therefore produced as 'mp4' files, for Apple computers, and 'avi' files, for windows computers. The software required to play these formats, QuickTime for 'mp4' and Windows Media Player for 'avi', comes as part of the operating system on the computer. Therefore, the need for students to install software to play the video files was eliminated.

To illustrate the compression ratios obtained we present two examples. An iMovie® file for a question on logarithms was 197.1 Mb. After compression the file size was reduced to 948 kb (mp4) and 4.9 Mb (avi). An iMovie® file for a question on matrices was 1.31 Gb. After compression the file size was reduced to 6.7 Mb (mp4) and 41.2 Mb (avi).

2.6 Comparing the two production methods

The video recordings produced by the two methods were quite different in appearance. In the eBeam® method each stroke of the pen appeared on the screen as if by magic—the 'actor's' hand and the pen were invisible. In the second production method the hand of the actor and the pen were both visible. Screen captures from the two methods are shown in Figures 4 and 5.

From a pedagogical point of view the products appeared to be very similar. However, close observation elicited some differences that could impact on the effectiveness and efficiency of student learning. The absence of the 'actor's' hand in the eBeam® solutions may make it easier for students to follow the line-by-line development of the solution as it was not masked by the hand. However, the presence of the 'actor's' hand in the video camera and copy stand productions could add to the learning experience as the 'hand' can be used to point out elements of the solution during its development. For example, it was possible to point back to earlier elements when they were reused later in a solution. As these pedagogical differences are minor and might balance each other out an evaluation of student use, and views, of the resources will be carried out.

3 The environment in which the video resources were viewed

The video solutions were made available on the subject WebCT site where questions were listed according to mathematical concept: algebra, loga-

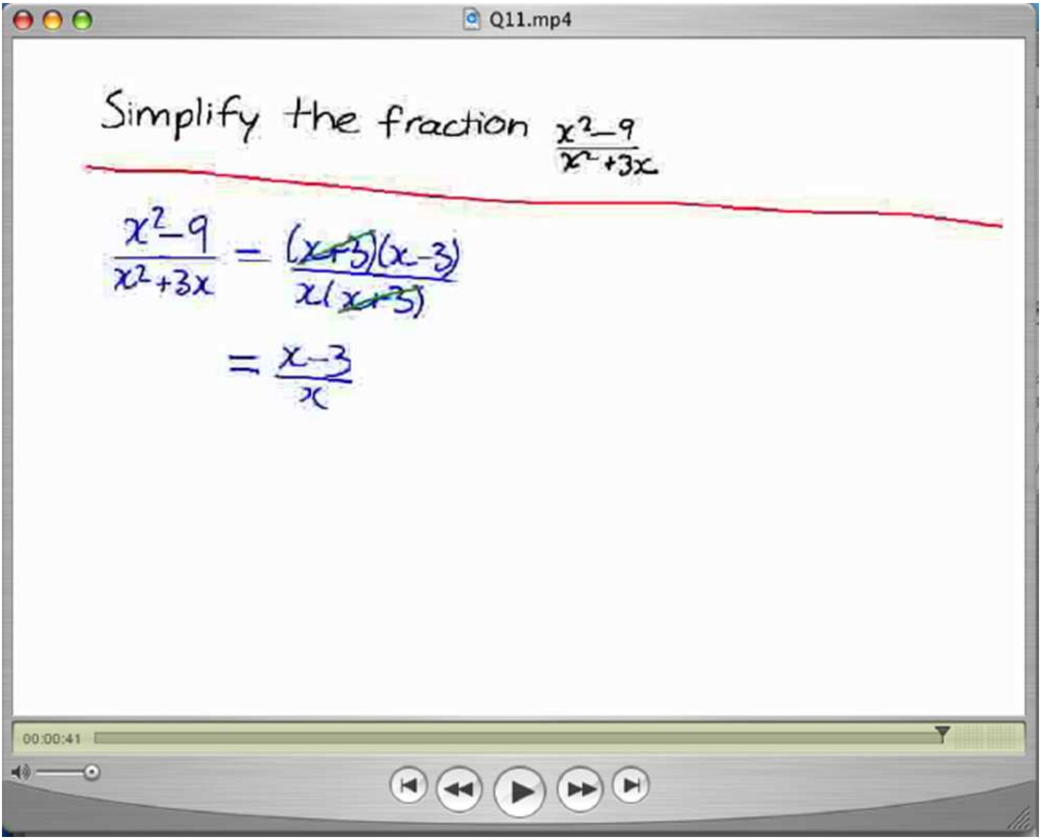

Figure 4: Screen capture of quick time replay of an eBeam® worked solution.

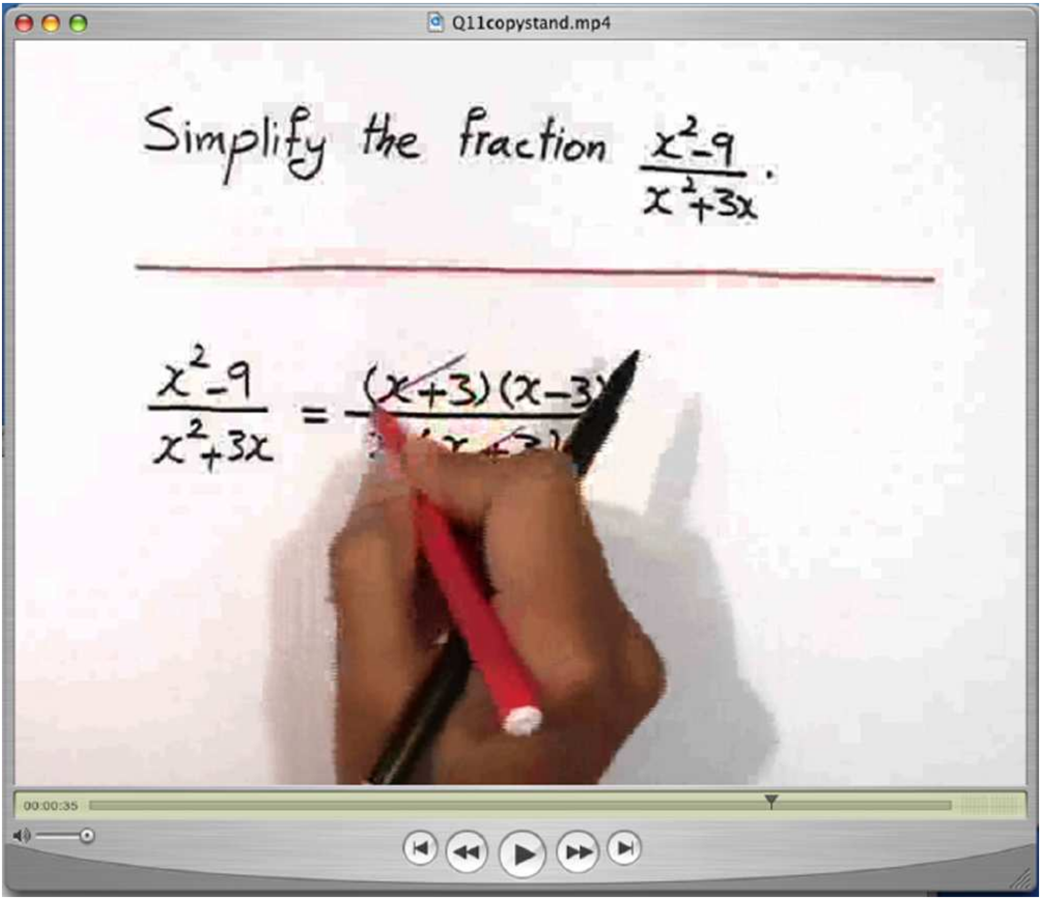

FIGURE 5: Screen capture of quick time replay of a video camera worked solution.

rithms, surds, etc. The site was structured so that having looked at a question a student could choose one of the following options: 'Answer', 'Worked Solution' and 'Video Solution'. Clicking on the 'Answer' gives the answer to the problem. If a student answered the question correctly they could move on to another question. If they answered incorrectly they could

- click on 'Video Solution' to run the video (choosing between a Windows video solution and an Apple video solution),
- click on 'Worked Solution' to see a fully worked solution to the problem, obtained as a still image from the last video frame,
- click on 'Definition' to access a text based summary of the mathematical concept,
- try another question.

By making these resources available in this way an environment was created in which students decided upon their own navigational directions and which encouraged them to make connections between:

- correctly/incorrectly answered questions,
- their prior knowledge,
- the provided materials.

Students interacted in different ways with these resources depending upon their current understanding and level of expertise. Additionally, by distributing these resources through the WebCT site students were able to access them at the time of their choosing. We hoped that this structure increased the richness, efficiency and effectiveness of the learning experience.

4 Discussion

These resources were developed in 2005 and used for the first time in Autumn 2006. At the end of session students were surveyed regarding their use of the resources. Students were asked a variety of questions that included: whether the picture and audio quality of the video solutions was adequate, if the video/eBeam® solutions had improved their understanding of mathematics and how the resources had been used. Students were also asked how the resources could be improved. Ninety-two students, from a class size of 216, took part in the survey. Of the 61 students who had used the video resources, 93% (57 students) felt that the resources had helped them to understand and learn mathematics. Student comments included:

- "Often a problem involves a long procedure $\cdots$ the video solutions allowed me to discover what step I am having difficulty with or if it was simply a silly/careless mistake I had made."
- "It provokes your thought processes to understand the method to solve the problem."
- "the addition of audio helps to understand the reason behind each step."
- "It allows me to understand the thinking processes needed to solve a given problem."

The resources developed on this pilot study and made available in the Autumn 2006 session covered approximately 15% of the course material. In particularly, it only covered the material taught in the 'revision' component of the course. This may explain why a significant number of students who took part in the survey (34%) had not used the videos.

Analysis showed that students who were to use the resources averaged 9.7/20 on the first basic skills test whereas students who would not latter use the resources averaged 12.6/20.0. This difference was statistically different ($t_{74} = 2.175$, $p = 0.033$). In the second basic skills test in week four there was no significant difference in mean marks with the first group of students averaging 11.95 and the second group averaging 12.4. A paired t-test analysing the change in marks between the two tests found a significant difference between those who used (mean of differences $= 2.25$, sd $= 2.97$) compared to the non-users whose marks declined on average (mean of differences $= -0.2$, sd $= 2.97$). This equates to about a 12% change in approximate grade. More significantly, this is a change from a fail grade to a pass grade. Thus by the end of the fourth week use of the resources allowed the weaker students to catch the stronger students. This is an encouraging finding as many teaching innovations are used by the better students; it is difficult to provide resources for weaker students. Whether or not these results were sustained for the entire subject is now under investigation. Also under investigation is whether it is sufficient to provide the resources for the earlier topics to facilitate catch up or whether they also be provided for the latter topics.

We are currently analysing the responses we received to this survey and hope that it will lead to insights into the effectiveness and efficiency of these resources, in addition to indicating how they can be improved. Although our initial concept was to distribute these resources through a WebCT site we have realised that other mechanisms for their distribution exist such as CD-ROM, DVD and iPod. In particular it is now common for students to download files onto a USB drive. In fact we received a number of requests in our student survey to make it easier to save the videos.

One of our referees has suggested that another option to describe the developing solution is the use of a 'talking head' insert in the corner of the video. This was considered at the time, but not used because the pedagogical value of a talking head was considered not equal to the bandwidth cost. Furthermore, such images could date the resources, increase the file size and raise issues about the representation of different student groups. With voice over it is straightforward to provide male and female voices, with other background remaining anonymous.

Since this pilot started, an Access Grid Room has been installed at the University of Wollongong which means that we now have a second mechanism to create 'digital ink' through the use of the Mimio® whiteboard. At the time of writing this functionality is not operational. We hope to investigate its advantages and disadvantages for producing video solutions in the future.

5 Conclusion

We have described the development of learning resources that combine audio and visual components, and show solutions being developed in 'real time'. We also indicated how these resources have been made available to students. These resources were trialled for the first time in Autumn 2006. Almost all students who used the resources commented that their use had helped improve their understanding of mathematical concepts. This anecdotal evidence is supported by provisional analysis which showed that the performance of weaker students who used these resources matched that of better students who did not to use them. We hope to describe the insights gained from this survey, in addition to our own insights gained through further developments of the methods described in this paper at a latter date.

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