Cost-effective computer-based tutorials

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http://www.mech.uwa.edu.au/dynamics/

Abstract

In this paper we examine the cost effectiveness of a particular sort of computer-based engineering tutorial developed at The University of Western Australia. This computer system sets the student a sequence of engineering problems and requires numerical answers as solutions. The software tries to provide diagnostic help in the case of wrong answers, which relieves the teaching staff of a great deal of repetitive teaching. There is also a built-in messaging environment that collates messages about specific problems, and this becomes a cumulative database of comment about specific engineering issues that the students may access - again relieving staff from having to answer the same query many times. This type of tutorial has been used in several engineering subjects at UWA since 1995.

We have found that student learning and student satisfaction while using this computer system are arguably better than in previous years. The issue of cost is not so clear-cut because of the expense of developing the software; however we believe it is possible to demonstrate real savings in the recurring cost of running the course. This conclusion is supported with financial data, examination results and a student survey.

1 Introduction

Computer aided learning (CAL) has become quite a common feature in the teaching of engineering in lectures, tutorials and laboratories. Great interest has been generated regarding the quality and associated costs of the different computer-based tutorials that have been devised by groups all over the world. However comparatively little work has been done which integrates the cost and quality of a program into one evaluation.

The aim of this paper is to measure and compare the efficiency of a traditional tutorial and a computer-based tutorial. The efficiency of the tutorial method is the ratio of ‘input’ to ‘output’. The ‘inputs’ to a tutorial can be seen as the monetary costs of operating, updating and maintaining it; these qualities are relatively simple to measure since there is one common scale of measurement, dollars. This measurement is absolute and objective: once the costs to be considered have been decided upon, estimating their dollar value is a relatively simple exercise.

It is when considering the ‘outputs’ of a tutorial system that problems arise for they are difficult to identify and even harder to measure accurately. Some outputs can be measured with an objective and absolute scale, for example, academic performance reflects the competence of a student and can be measured by the student’s exam marks. However, other outputs need to be measured on a relative and subjective scale. Put simply, the problem of measuring efficiency arises when a concrete measure, such as the inputs, needs to be related to a fuzzy concept of output.

The evaluation model presented in this paper has been developed in the context of a specific unit taught in the Mechanical Engineering Department at the University of Western Australia: Engineering 100 (Dynamics). Up until 1995, traditional tutorials had been used in this unit, however, by 1995 a computer-based tutorial had been developed and put in place. This computer tutorial system is called the UWA Computer Problem-Class System (UWA-CPCS). In this paper the 1996 form of the UWA-CPCS is investigated and compared to traditional tutorials in the same unit. The evaluation model developed does not attempt to combine the cost and quality of a tutorial into one measure but treats them separately. The tutorials can be compared in terms of quality or cost and decisions made based on these comparisons.

1.1 Traditional tutorial method

Traditional tutorials consisted of groups of about 20 students who completed problems with one tutor present. Students were allocated two tutorials each week. Tutorials could last up to one hour. The questions to be answered were selected from a textbook used in the unit. Tutors were expected to be free for consultation with students outside these allotted tutorial times, however, set times were not given and it was up to the students to fit in to the tutor’s often busy schedule. The tutors were typical about 70% postgraduate students and 30% academic staff. It is known that some of the postgraduate students were not among the best teachers.

In each traditional tutorial students were expected to work on two exam-standard problems. Students were asked to submit solutions to these, and tutors were asked to mark and return such solutions. However these marks did not contribute to the final mark for the unit and, after the initial few weeks of the year, few students took advantage of this service.

1.2 UWA-CPCS in 1996

Formal computer-based tutorials, i.e. in the presence of a tutor (always an academic staff member or high-quality postgraduate tutor), were held twice a week and again could last for up to one hour each. About 50 students were allotted in each session. The computer terminals could be accessed by students at any time the computer laboratory was open and a terminal was free. Scott (1996) described the essential features of the computer-based tutorials as follows:

a) Students log in using a password.
b) Students attempt problems that are displayed on the computer screen. The current problem must be solved before moving to the next.

c) The words and pictures specifying each problem are the same for all students but each student has unique and stable, numerical parameters for each problem. (Questions which are printed out and made available to students have the same parameter values. This allows students to work through the problem in outline at home, to reduce their work at the computer terminal).

d) Students enter answers that are always a number with units e.g. “3.2 m/s”.

e) There are typically eight ‘lead-up’ problems in each set, followed by two assessed problems. The assessed problems are marked based on the number of attempts required to obtain the correct answer. Although the ‘lead-up’ questions are not marked, they must be completed before the assessed questions can be attempted.

f) The ‘lead-up’ questions form a carefully chosen sequence that explores each of the difficulties arising in the assessed problems.

g) The software surrounding the ‘lead-up’ problems attempts to ‘diagnose’ incorrect answers which contain common student errors. A collection of these errors have been identified and if a student appears to have included any one of these errors in their answer, very specific explanatory material related to the misconception is displayed on the computer screen.

h) Questions can be asked by students who are on-line with the tutors. Tutors give a response as soon as possible. The questions, together with their answers are saved (attached to the problem) and can be viewed by the students at any time. This feature of the computer-based tutorial has been termed the ‘forum’ (Scott, 1996).

i) All students actions are recorded by a central ‘server’ computer.

j) Students are asked to keep a ‘log book’ of working for the problems, which is intended to allow tutors to offer advice about written working style.

k) An open-door policy was followed, allowing students to meet with a tutor at informal times as was the case in traditional tutorials.

2. Measuring quality: Examination marks and the questionnaire

2.1. Measurement of student approval

We decided to use a questionnaire to assess quality. The questionnaire was given to 121 students in the second year of Mechanical Engineering, who had used the computer tutorial system the previous year (i.e. in 1996). 121 responses were received, representing 54% of the target population. A similar questionnaire was given to faculty members, some of whom had used the UWA-CPCS tutorial system.

There were four main aims of the questionnaire:
1. To obtain a comparison of the perceived quality of the two tutorial methods;
2. To obtain an absolute measure of the level of quality perceived in each tutorial method;
3. To investigate whether a student’s perception of a quality tutorial was comparable to a tutor’s perception of a quality tutorial;
4. To determine if the students’ perception of the level of quality of each tutorial method corresponded to the tutors’ perception.

Ten attributes which were thought to indicate the level of quality of a tutorial were identified:
1. Student competence,
2. Quality of teaching,
3. Amount of useful help available,
4. Amount of constructive feedback given,
5. Ease of tutoring,
6. Importance of the human tutor,
7. Ease of completing the tutorials,
8. Students’ interest and enthusiasm,
9. Student and tutor comfort level,
10. Ease of monitoring.

Each attribute would have a question devoted to it and this question would be answered in relation to both a traditional tutorial and a computer-based tutorial separately (see Figure 1). Obtaining absolute measures was desired more than obtaining relative measures. Finding out which tutorial enthused a student more was not considered very useful if, after all, the student was only slightly enthused by either. The questions were short, simple and direct, involving only one directly relevant aspect (i.e. interest level or quality of feedback) to reduce student confusion.

<table>
<thead>
<tr>
<th>13) How fair is the grading of assignments in each tutorial method?</th>
<th>Completely Fair</th>
<th>Quite Fair</th>
<th>Fair</th>
<th>Quite Unfair</th>
<th>Completely Unfair</th>
</tr>
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<tbody>
<tr>
<td>Traditional</td>
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<td>Computer-based</td>
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<tr>
<th>14) Rank the quality of each tutorial method.</th>
<th>Awful Quality</th>
<th>Poor Quality</th>
<th>Average Quality</th>
<th>High Quality</th>
<th>Excellent Quality</th>
</tr>
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Figure 1 Example questions from the questionnaire.
Table 1  Quality attributes probed by the questionnaire

<table>
<thead>
<tr>
<th>Competence indicator (C)</th>
<th>Questions measuring how well a tutorial taught a student how to approach solving dynamics problems, how much constructive help was available, and how much constructive feedback was given.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Emotion indicator (E)</td>
<td>Questions measuring the interest levels, the frustration levels and the comfort levels of students in a tutorial.</td>
</tr>
<tr>
<td>Human Interaction indicator (HI)</td>
<td>Questions which measured the value of human interaction in a student’s learning.</td>
</tr>
<tr>
<td>Monitoring indicator (M)</td>
<td>Questions measuring the perceived fairness of assessment in each tutorial and the ease for students to fall behind. A quality tutorial should give all students the same opportunity to learn.</td>
</tr>
<tr>
<td>Teaching indicator (T)</td>
<td>The questions in this category were asked of the tutors exclusively. A quality tutorial is one where teaching students is considered satisfying. Tutors should feel that all students are obtaining the help they require. Demand for a tutorial method was expected to be higher if less time was needed to carry out the administrative tasks of preparing for and marking the tutorials.</td>
</tr>
<tr>
<td>Overall Quality indicator (O)</td>
<td>One question directly asked about the quality of each tutorial - “Rank the quality of each tutorial method”.</td>
</tr>
<tr>
<td>Total Quality (Q), Demand (D) and Uniqueness (U) measures</td>
<td>The measure of total quality was the additive scores of each of the indicators above.</td>
</tr>
</tbody>
</table>

The questions were classified into groups (see Table 1). Each classification was concerned with one attribute of a quality tutorial. A total score for a classification is simply the accumulation of scores given for each question.

2.2 Measurement of engineering competence

In this paper formal, invigilated examination marks are used as the measure of technical competence. An easier exam will result in higher exam marks and it is clear that these marks will not then be a reliable measure of the quality of the tutorials; however the examinations used during the studied period (1993-1996) have been evaluated by an external expert and were deemed to be of essentially uniform difficulty.

In Figure 2 graphs of exam marks and also failure rates are presented.

Figure 2 presents several kinds of student data. Figure 2a are average examination scores given in engineering dynamics. Figure 2b shows the percentage of students who took both exams during each year, but failed the unit (in the sense of getting less than 50% according to the competence measure). Figure 2c shows the average TEE (university entrance) marks given to students. This can be seen as a measure of the ability of students which is independent of the quality of teaching in Dynamics. Note that the TEE score for entrance to Engineering at UWA is typically around 380 and the maximum possible score is 550.

If we apply the Mann-Whitney U Test to the TEE score data at the 5% level we find that the 1995 TEE scores are significantly different from all the other years, and the 1992 TEE scores are significantly different from the 1993 and 1994 TEE scores. Comparing the mean TEE scores across the years, a general trend is seen - that TEE scores become progressively lower with each successive year.

Figure 2d shows a slightly unusual parameter: it is the average dynamics mark divided by the corresponding average TEE score. This is effectively Figure 2a divided by Figure 2c. The ‘confidence region’ shown in Figure 2d was calculated using the 95% confidence limits shown in the other graphs. Figure 2d is intended to be a measure of the improvement in average measured ability of the students during each year – in other words a measure of learning during the year. However it is dependent on so many variables, such as the consistency and comparability of the examinations and marking at TEE and university level, that it is of questionable reliability. The reasoning is simply that, if the ‘intake’ to the teaching process really is of diminishing quality, we need to be able to account for this when assessing the average mark and pass rate data.

Figure 2 Measures of student quality and learning in dynamics 1992-1997.
In the years before 1995 Figure 2d shows what may be a decline in the quality of learning in the course. Then, upon the introduction of UWA-CPCS, the decline is arrested (1995), then a high value is seen (1996), and then a more historically normal value (1997). This variation will be discussed in section 4.1.

2.3 Cost analysis

A detailed cost analysis is presented in another paper in these proceedings (Faye, Scott & Stone, “Computer-based tutorials: cost functions and software durability”). Only one final result of the analysis is presented here (Figure 3).

![Figure 3](image)

**Figure 3** Operating cost functions for 1996.

This graph shows the expected form. The computer-based teaching system was expensive to set up, but then cheaper to run on a daily basis because fewer staff were needed to teach the course.

### 3. Results

#### 3.1 Results - questionnaire

The computer-based tutorial was ranked significantly higher than the traditional tutorial in six questions, while the traditional tutorial was ranked significantly higher than the computer-based tutorial in three questions. Both tutorials were given low scores with respect to human tutor enthusiasm, suggesting that this feature is important in the success of both tutorial methods. Both tutorial methods were also given low scores regarding how easy it was to fall behind. Generally, however, the mean responses given to the computer-based tutorial were in the range 3.0 - 3.6, which represents above average scores. The mean responses given to the traditional tutorial tended to be slightly lower and in the range 2.8 - 3.4. A more detailed analysis of the questionnaire follows.

**Competence Indicator (C):** Questions included in this category were given higher scores than in other categories (excluding the question directly measuring quality). All scores given were above 3.1, suggesting that both tutorial methods are expected to produce students who are technically competent. Neither tutorial method was distinguished by the ease of obtaining help, the quality of feedback given and the usefulness in preparing for exams that each offered.

The only question in which a significant difference was seen asked “When students are having trouble understanding something, how useful is each kind of tutorial?”. The students consistently gave the traditional tutorial higher responses. This result implies that traditional tutorials are more useful for students when a conceptual hurdle must be overcome. However, students did not believe that either tutorial methods gave better help with solving unfamiliar problems.

**Human Interaction Indicator (HI):** Generally, lower scores were given to both tutorial methods which means that students do not believe that human tutors are necessarily important and that students do not spend excessive time working together during tutorials (how much time students spend working together outside formal tutorials was not assessed).

Significant differences existed between the response to two questions regarding the importance of human tutors in a tutorial. Students perceived that the success of a computer-based tutorial is less dependent on the amount of human tutor help or on the level of enthusiasm of the tutor. Neither tutorial method was seen as reducing the amount of time students spend working together.

In a separate survey given in 1995 students were asked to rate the value of both human and computer tutorial assistance. See Figure 4.

![Figure 4](image)

**Figure 4** Results from a survey given in 1995

It is clear that students felt that staff assistance was more important – but only slightly so.

**Emotion Indicator (E):** The students believed that the computer-based tutorial method was more interesting but also more frustrating than the traditional tutorial method. While students felt comfortable asking questions in both tutorials, they were more comfortable asking questions in the computer-based tutorials.

**Monitoring Indicator (M):** Students believed that they were less likely to fall behind in a computer-based tutorial system. However the traditional system was perceived as grading assessments more fairly.

**Overall Quality Indicator (O):** The result of the only question asked in this category, indicated that while the traditional tutorial method was of an acceptable quality, the quality of the computer-based tutorial was considered to be significantly higher.

**Average Total Quality Measure (Q):** After all the attributes were incorporated, the scores reflecting each tutorial
method's average total quality were lower than their corresponding scores for 'overall' quality. However, the trend was still the same, with the computer tutorial method receiving a higher measure than the traditional tutorial method.

**Demand (D) and Uniqueness (U) Measures:** On average, students wanted to be taught by the computer-based method in the same proportion as they wanted to be taught by the traditional method. The demand for both methods is equal. It is important to note that second year students were asked what proportion of each tutorial would they like to see next year - i.e. the question was not related to the demand for a first year unit. However, it has not been established if the computer-based method is appropriate in teaching higher-year engineering units. Also, students may have interpreted the question as relating only to the Dynamics 100 unit.

**STUDENT OPINION IN THE WRITTEN COMMENTS SECTION**

The main advantage of the computer-based tutorial in the students’ opinion was that they could work at their own pace and the deadlines and strict monitoring forced students to complete the work and stay up-to-date. Other frequently mentioned benefits of the computer-based tutorials included the decreased dependence on a human tutor - “(the computer-based tutorial) fosters a requirement to work independently and be very exact”, and the ability to obtain help quickly - “you don’t have to waste time to go and (see) tutors because sometimes they are not available”. The major weakness of the computer-based tutorial that was identified by the students was the lack of the help needed to make conceptual jumps and for understanding a concept thoroughly. Students also stated that there had been difficulty in obtaining human help.

**3.2 Results - faculty**

Interpretation of the faculty questionnaire was more straightforward than for the student questionnaire. On average, the computer-based tutorials received higher scores for 16 out of the 19 questions on the questionnaire and were evenly scored for the remaining three questions. In fact, the average scores given to the computer-based tutorial were all above 3 except for two questions. In contrast, the majority of averaged scores given to the traditional tutorial were below 3 and never higher than 3.8.

The computer-based tutorial scored poorly on two measures: Tutors felt that the success of these tutorials depended heavily on the level of enthusiasm the tutor possessed. They also perceived that computer-based tutorials frustrated students ‘often’. Faculty perceived that they had spent significantly less time preparing for tutorials and marking tutorial sets. It should be noted that the faculty demand for the computer-based tutorial was very high compared to the demand for the traditional tutorial.

**FACULTY OPINION IN THE WRITTEN COMMENT SECTION**

There were two commonly identified benefits of the computer-based tutorial. The first was the time that tutors saved on marking and answering routine questions. Another benefit was the monitoring of the system which forced the students to keep up-to-date.

The reduction in personal contact was perceived as a weakness of the computer-based tutorial. One tutor emphatically stressed the following points:

- “(Less) monitoring by (an astute) tutor of the (students’) thought processes (and so) the ability to apply correction where needed.
- (Reduction in the tutor’s) ability to divert to related, interesting areas when appropriate.”

**3.3 Comparison of student and faculty questionnaires**

One major difference was in the perception of how well the tutorial helped a student understand a problem or concept. Surprisingly, students believed that the traditional tutorial was more helpful than the tutors did. Students also placed more value on the tutor’s enthusiasm and the help they gave. Students found the tutorials more frustrating than the faculty thought they did. Finally, student demand for the UWA-CPCS type of tutorial was larger than faculty demand. It has already been mentioned that the students and faculty may have answered this question without specific reference to the Dynamics 100 unit.

**4. Discussion**

**4.1 Student competence 1992-1997**

It is accepted at UWA that the TEE score does not predict success at university provided it is above 360. A student entering University with a score below 360 is statistically much more likely to fail the first year. Several years ago a survey of successful graduates in the final (4th) year showed that none had TEE scores less than 400. In the period 1992-1995 there was a statistically significant and consistent decrease in the average TEE score, and in 1995 it was at an all-time low of about 386. Despite this decline in entrance standards, in the first year that the computer-based tutorial system was introduced, despite many teething problems, the failure rate and learning indicator (Figure 2d) were held at the 1994 levels.

In 1996 entrance standards were still quite low, but the computer tutorial system was well tried and essentially free of software ‘bugs’. Students were able to work with the system from the first day of teaching, without interruption. It should be noted that it was this year of the operation of UWA-CPCS which the surveyed students would have been recalling. It is now the authors’ goal to achieve again the 1996 levels of student satisfaction and competence.

In 1997 the computer system was again somewhat new and unreliable because it had been newly translated to work on the World Wide Web. If we compare the three years of computer-based tutorials (marked 1, 2 and 3 in Figure 2d) we can come to a preliminary conclusion: that the quality of learning in the course is closely connected to the reliability of the computer system.

**4.2 On-line help features and staff workload**

The UWA-CPCS was easy to use when up and running and no training of students was needed. It used clear screens and responded quickly to students’ inputs. This immediate
feedback was repeatedly identified by students as an advantage of the computer-based tutorial in the questionnaires. When a student using the UWA-CPCS made an identified error, assistance was given automatically (see Figure 4). Other assistance available included on-line lecture notes and an integrated messaging system, the forum. The answers to queries raised in the forum were saved and could be viewed by students at any time. This wealth of pertinent information that was immediately available to the students was a great advantage. The following quotes, taken from the student questionnaire, are evidence of this:

- “Lots of computer Help pages ... can use them at any time”
- “The whole Dynamics system was well integrated with the course notes also on the computer”
- An advantage is the “the in-built help and often lecture notes”
- “Can get help when you need it (don’t have to queue for the whole tutorial to ask one question”
- “Often get help more quickly, including human help”
- “the forum is very important though and if answered immediately is satisfactory”

As a student remarked, the amount of on-line help is thought to allow for “more people ... (to) ... be helped at one time”. It is also expected to ‘free-up’ tutorials’ time. This is hoped to increase the amount of useful personal interaction between tutor and student. Much research confirms with this expectation including work done by Brown (1995), DeLoughry (1995), Dobson et al. (1995), Goodwill et al. (1995) and Watkins et al. (1995). Goodwill et al. (1995) also speculated that computer-based tutorials would accommodate the larger intake of engineering students which were a strain on staff when the traditional tutorials were in use.

On-line help, together with the free access to the computers had a number of advantages. Students are thought to appreciate the increased access (Goodwill et al. 1995) and the ability to work at their own pace (Watkins et al. 1995), and also prefer to work without the embarrassment of appearing ignorant (Goodwill et al. 1995). Students expressed some of these sentiments in the questionnaire:

- “(I) feel more comfortable getting help from a computer by looking at example problems”
- “You don’t have to feel embarrassed if you ask a stupid question”.

It appears that the students perceived that the role of the tutor had been diminished by the computer package or, more likely, they believed that the computer-based tutorial was the computer-package. In the written comments section of the questionnaire, under the heading “What do you miss out by using a computer package rather than being taught in the traditional way?”, students wrote:

- “Human contact and additional information provided by the tutor”
- “Explanations and being told how to conceptualise problems”
- “Human explanation, i.e. the ability to ask questions that are not premeditated by the programmer”
- “Specific explanations on minor points of confusion”
- “Understanding difficult problems is usually harder”
- “Basically I found that the traditional style tute is more effective for learning and enhancing one’s understanding of the subject. Computers provide more of a practise base for already understood concepts”

Students did not seem to realise that human help was part of the overall tutorial system: that the diagnostic help given by the computer was designed only to answer common mistakes, leaving more time for human tutors to answer more specific and detailed queries.

The monitored nature of UWA-CPCS motivated students to keep-up with the tutorials. As was explained by a student on the questionnaire – the tutorials “are due in and are therefore done”. While faculty were delighted that routine marking was completed by the computer, some students were slightly disgruntled by the fact that the system did not reward working, only the final solutions. It was noted by one student that this “fosters a requirement to ... be very exact”.

5. Conclusions

5.1 Quality

Analysis of exam results do not indicate any drop in student competence due to computer-based tutorials. In fact, with TEE marks used as a measure of the students’ initial ability in dynamics, there is evidence to suggest that computer-based tutorials have the ability to increase student competence.

Results indicate that quality control is possibly more important in computer-based tutorials. There was evidence that suggested faults in the system, i.e. frequent crashes, can drastically reduce student competence (and most probably student satisfaction). Traditional tutorials did not experience drastic differences in exam results across the years and furthermore, the results were very satisfactory. Traditional tutorials did not experience drastic differences in exam results across the years and furthermore, the results were very satisfactory. However, let us remember that traditional tutorials have the advantage of being established while the UWA-CPCS is still in its initial stages. With time, it is expected that flaws will be ironed out and changes in quality of the system will be minimal.

The students perceived the computer-based tutorial to be of slightly higher quality overall while faculty were more convinced of the fact. One of the reasons for higher faculty satisfaction is the automatic marking of the tutorial questions by the computer.

A high quality diagnostic computer-based tutorial is likely to lead to higher student and faculty satisfaction. Also, students will be of equal or perhaps even higher competence than if tutored in the traditional way. Therefore, the real determinant in choosing between the tutorial methods comes down to costs.
5.2 Costs

Leaving aside the issue of development costs, for low student enrolments, traditional tutorials are more cost-effective. It is only when we have a durable course with enrolments over about 250 students that operating costs for a computer-based tutorial system can be lower. The number of students enrolled in Engineering 100 (dynamics) at UWA is high enough for computer-based tutorials to be cost efficient. UWA is a medium-sized university which implies that computer-based tutorials would be cost efficient in similar sized and larger universities (depending on the size of their Engineering faculty).

The large development costs of computer-based tutorials are a consideration. With student enrolment of 250 students every year, the development costs will be recovered provided the system is in place for at least 15 years with no major overhauls required. Since this is an unreasonably long life-expectancy for a computer program, development costs can only be recovered if income can be generated through software sales.

6. Bibliography


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