COMPUTER AIDED LEARNING OF PROCESS PLANNING USING A 'VIRTUAL MACHINE TOOL'

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Abstract

Process planning is an important stage in the creation of a new product. A design prototype may be seen to function perfectly, but it remains necessary to design the volume manufacturing process itself. Decisions made at the process planning stage may affect the quality, reliability and profitability of a product. Consequently, this was an important subject for Manufacturing Engineering students at the University of Salford.

In conventionally taught process planning it was found that some students did not have sufficient understanding of machine tools, and wrote manufacturing instructions which would have produced misshapen parts, or endangered a machine operator.

The CAL3P ('Computer Aided Learning of Process Planning Principles') software was written using Multimedia ToolBook, allowing students to see a 'virtual machine tool' carrying out their instructions, demonstrating any problems in the students' process plans. This allowed them to learn experimentally without risk. Combining simulation with multimedia, the software was popular with students, and appeared to result in a more effective learning experience.

Introduction

A process plan is a sequence of unambiguous instructions which can be followed to manufacture parts as designed. Effective process planning is vital in industry, and therefore an important skill for a novice engineer to acquire. At the University of Salford the subject was initially taught by a lecture on the theory of process planning followed by a tutorial during which students worked in groups to generate a viable process plan, having been given dimensioned drawings for a part.

Using traditional teaching methods, most of the tutor's contact time was spent correcting gaps in the knowledge of the less experienced students. Their first attempts at process plans revealed misconceptions regarding manufacturing processes and how they should be specified. Having set the exercise, the tutor would examine each group’s process plan and use language and sketch diagrams to indicate any problems that would arise if the process plan were followed. Naturally, the tutor's presence is often required by several groups simultaneously as they wait to have their work checked before progressing. After the three hour tutorial, each group was required to submit their process plan for marking. Errors were still seen in the students’ final submissions despite the efforts of the tutor to give assistance when requested.

The CAL3P Software

As a result of observations made during the teaching of process planning by conventional means, a Computer Aided Learning (CAL) system for Process Planning of turned parts was developed. Turning is a common manufacturing process where a bar of material is gripped tightly in the chuck of a lathe and spun. Tools are brought to bear against the bar, cutting away excess material to leave the finished product (Figure 1).

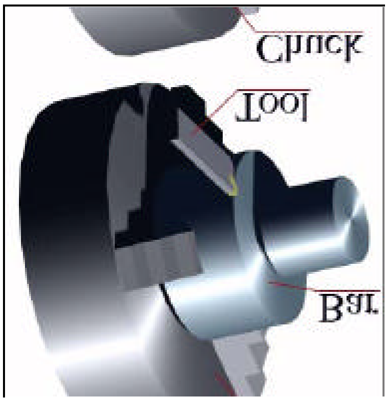

Figure 1: Typical turning process

The CAL3P software presents a number of pages on the general concept of process planning to reinforce the earlier lecture on the subject (Figure 2). After reading these, the students can enter their own set of manufacturing instructions. Their work is later interrogated by the software using a pattern matching technique, looking for key phrases such as 'centre drill' or 'part off'. Because manufacturing instructions are picked from a list offered via a graphical user interface (GUI), typing errors are unlikely to interfere with the pattern matching process. Selecting an operation takes the user to a page describing its purpose (Figure 3) which the student can read to decide if the process is appropriate, and if so enter detailed parameters.

Any turning operation can be described with just a few parameters, such as 'Drill, depth = 45, diameter = 12'.

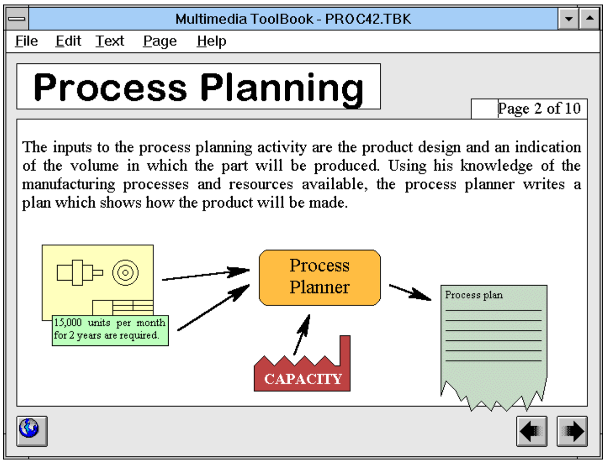

Figure 2: Sample page from CAL3P's conventional section

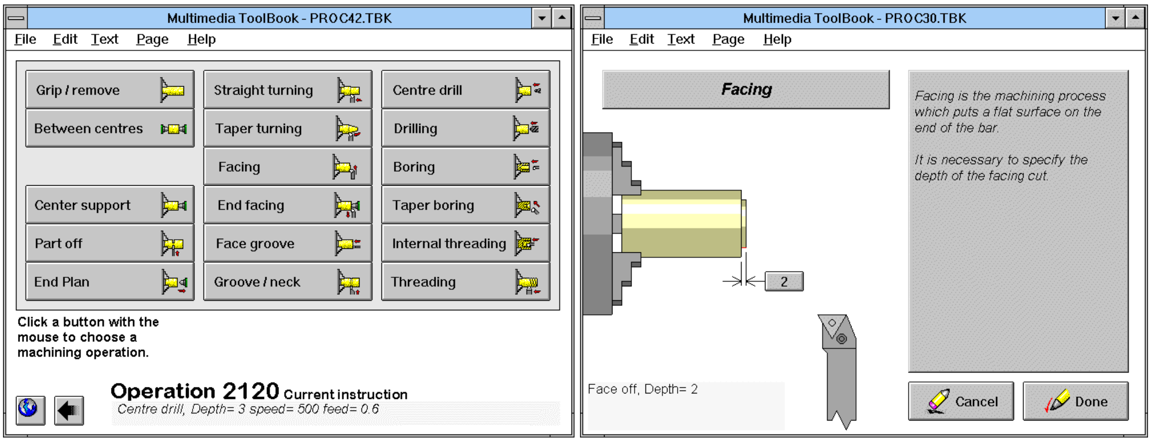

Figure 3: Manufacturing processes available to the student process planner - each button links to a page like the one shown

Animation is employed to show how a lathe would be used to carry out the student's specified operations. The instructions are followed literally, demonstrating any flaws in the process plan. A typical hazard can be seen when the student specifies a long cut which would cause the tool to collide with the jaws of the chuck. This would snap an expensive tool, and possibly put a machine operator in danger – students' opportunities to use real machine tools are necessarily limited, requiring close supervision. With CAL3P, it is possible to allow a whole class to have hands-on experience at once, sharing as many (virtual) machine tools as there are PCs. Any fundamental errors in their process plans are brought to the student's attention as they arise (Figure 4). The students also perform their own evaluation in that an operation may be safe, but not an efficient way to remove the material desired. Lines in the process plan can be altered until satisfactory. After a few iterations, most students learn to pick the right instruction first time. Meanwhile, the tutor is released from a repetitive task, leaving them free to address more detailed issues when they arise.

Figure 4: The student is alerted when an error is found in the process plan

Inside CAL3P

The authoring package used to develop CAL3P was Asymetrix Multimedia ToolBook. While the initial, purely informative sections of the CAL package were fairly simple and could have been achieved with a variety of multimedia authoring packages, producing animations dynamically demanded a powerful scripting language.

CAL3P demonstrates the turning process through a number of scripted commands relating to the generation, display and manipulation of coloured polygons. By creating these 'on the fly' rather than displaying prerecorded media such as photographs, the system is flexible enough to accommodate virtually any student instruction.

A representation of the bar of material is drawn, based on the student's specifications for length and diameter. A chuck is added, such that it grips the bar. Then, areas of the bar which are machined away in accordance with the student's instructions are indicated by blanking them out with polygons, the vertices of which are set appropriately. It soon becomes clear whether an instruction has removed the desired area of material or not.

Animations are typically achieved using while ... end while loops which incrementally change the position of a graphical entity (or some of its vertices). CAL3P has a single, large script on the simulation page which refers to a field elsewhere in the book where manufacturing instructions are stored, one per line. Each supported manufacturing instruction has a section in the script. For example, drilling involves adjusting the size and position of the group of polygons which make up the drill tool, showing the drill tool, animating it as it moves into contact with the bar, blanking out the area behind the drill, retracting the drill (Figure 5), and then hiding it again.

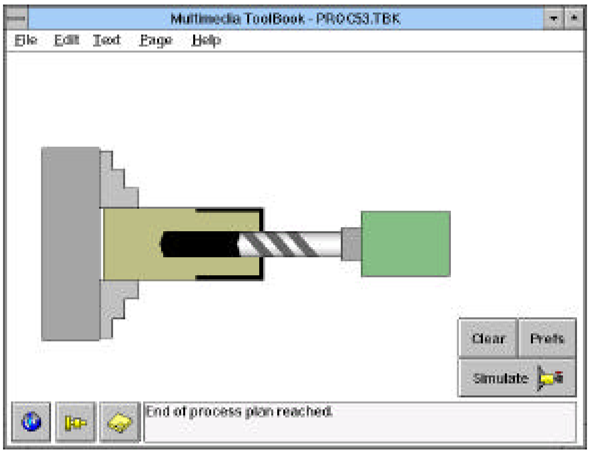

Figure 5: Screen shot from a CAL3P machining simulation

Since all the scripts which refer to graphic objects are parametric, a single script can be employed several times, such as when drilling holes of different sizes. CAL3P is thus a simulator, able to represent a large variety of different situations. Although some use is made of prerecorded media such as digital video elsewhere within the software, it would not have been possible to use movies to show the student's plan being carried out because there are an almost limitless combination of possible manufacturing instructions.

Discussion

Students are given CAL3P exercises in the form of a paper-based part drawing. While it would have been simple to construct CAL3P with a built-in exercise, this might have reduced its appeal. Using animations means that the software need not be 'hardwired' to perform only one exercise. The software can be used repeatedly, on different exercises suitable for users at a variety of levels, the difficulty of the exercise simply being controlled by the complexity of the part for which a process plan is required.

CAL3P can be used in a variety of different ways, at the preference of the tutor. The purpose of the basic exercise is to generate a viable process plan for an existing part drawing, but the software could also form part of a design exercise, or redesign with the aim of making manufacturing easier. One tutor also required students to give a short, informal presentation to their classmates, justifying the approach taken.

By allowing a near infinite variety of exercises to be attempted, the development effort invested in CAL3P should be better justified, because the software is likely to be useful to a wider audience than a conventional CAL program, and the software can be usefully revisited several times [Farr and Lawlor-Wright, 1997]. The development effort required to complete a comprehensive piece of CAL software is often a critical factor, being expressed as a ratio against anticipated playback time, as by Marshall, Samson and Dugard [1994]. For CAL3P, initial development effort was high, with individual elements such as showing a drilling operation taking longer to code with animated polygons than when simply capturing digital video, but the parametric version can be useful repeatedly, illustrating a variety of situations. When considering development effort this, and the larger number of potential users must be taken into account.

Findings

It is difficult to measure learning directly, but some quantifiable results have been obtained:

For two years, student engineers have been introduced to CAL3P and asked to complete an evaluation form after using the software. These have indicated that a clear majority find CAL3P an enjoyable learning activity.

Using CAL3P instead of conventional instruction, a process planning exercise can be completed with student work of a higher standard (less fundamental errors), in under two hours rather than the three required previously. CAL3P provides rapid feedback, compared to the previous approach which required the intervention of the tutor to mark written assignments. Pressey [1960] and Wheldall [1983] both commented that delay between performance and reward in a learning situation significantly reduce the effectiveness of the reward; in CAL3P, seeing the part take shape correctly is the ‘reward’, and the delay between proposing a set of manufacturing instructions and seeing the results has been reduced as far as possible. Where a typical multimedia CAL package might test the student at the end of an informative section, and require that the section is repeated if unsatisfactory performance is demonstrated, CAL3P offers a much tighter loop in that the student enters manufacturing instructions, sees the result, applies his/her own evaluation and makes changes as necessary. This is closer to the cyclic models of learning proposed by Kolb [1974] and Crampes [1991].

Experiments were also conducted using a built-in quiz, to be undertaken just before leaving CAL3P. This provided the student with a further form of rapid feedback, and also allowed the amount of learning which had taken place to be inferred. Results showed that performance was best on questions relating to manufacturing techniques which had been employed in the simulation, with poorer performance on pages which facilitated only passive learning.

Conclusions

It appears that closer student involvement, or 'ownership' of the data being used, in the learning exercise maintained student interest. High interactivity was seen to produce the most effective learning despite the fact that animations generated in runtime could not be as attractive as video clips, which are a much more demanding medium to present within CAL software. Without video clips, CAL3P will install from 4 floppy disks and will run adequately (just) on a 25MHz PC. This is a valuable bonus to the approach of using dynamically generated animations, important to institutions which cannot always afford to update whole computer suites as technology moves on. This further increases the size of the potential audience for software like CAL3P.

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