

## **Design for Manufacturing Tutorials – A Multimedia Approach**

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### Abstract

This paper describes the content of three multi-media based manufacturing tutorials developed for the purpose of making mechanical and industrial engineering students more manufacturing literate. Also included is a discussion of the preliminary results of current evaluations that indicate the tutors are successful in teaching design for manufacturing concepts.

### I Introduction

Responding to the needs of industry, universities have, over the years, developed undergraduate courses to improve the manufacturing literacy of engineers. Despite the importance of manufacturing courses to both mechanical and industrial engineering students, most programs still require students to take only one manufacturing course. Typically, this course is of a 'show and tell' format where the manufacturing process is described and students are shown drawings and/or photographs of the equipment and sample parts producible by use of that same equipment.

To help increase manufacturing literacy, students are sometimes taken on a field trip where they may see manufacturing processes such as, for example, forging, injection molding, or die casting. In some cases, in place of plant trips they may be shown videotapes of various manufacturing processes. Although much can be learned from field trips and video tapes, it is difficult for one to fully understand the relationship between part geometry and the ease or difficulty of producing a part by simply observing the manufacturing process via a video clip or a relatively short plant visit.

Therefore, students and faculty at the University of Massachusetts Amherst (UMass) have undertaken an alternative approach to making designers more manufacturing literate. These students and faculty have been developing interactive multimedia tutors specifically for teaching design for manufacturing. The purpose of the tutors is to assist the user, a student, or anyone not familiar with various manufacturing processes, in understanding the relationship between part design and the ease or difficulty of producing parts.

To date, three manufacturing tutors have been completed or almost completed, namely, one for injection molding, one for stamping and one for forging. The purpose of this paper is to illustrate the content of these tutors by describing small portions of each. The paper will also include a discussion of the preliminary results of the current tutor evaluations.

## II. Manufacturing Tutors

The manufacturing tutors, developed using Macromedia DIRECTOR, are divided into two distinct modules, an introduction module and an experiential or workshop module. In the first module the user is introduced to a particular manufacturing process via a series of screens that contain text, animations, quick times, and voice-overs. The emphasis in the introduction is to make the user aware of the relationship between part geometry and the ease or difficulty of constructing the dies (tooling) required to produce the part.

The second or workshop module provides the user with the opportunity to determine how well they have mastered the concepts presented in the first module. In this module the user is allowed to design and 'build' a part from a restricted family of part geometries and to obtain a design evaluation of the part. Alternatively, the user may be presented with various alternative designs and engineering specifications and asked to determine which design best satisfies the specifications. If the user has understood the concepts presented in the introduction, they should recognize whether or not the part they've designed or selected is easy to produce and, if not, how to alter the design to reduce costs.

### *Introductory Module*

Each introductory module begins with an overview of the process, and a description of the equipment used. This is then followed by a more detailed discussion of the relationship between part geometry, and the difficulty of producing the required tooling. A combination of text, graphics (still and animated), and voice are used.

For example, in the case of forging, the tutor starts by showing an animation of a mechanical press performing open die forging (Fig. 1). This animation shows an 'open' die attached to the ram of a mechanical press pre-forming a workpiece. For ease of visualization, a sectional view of a simplified mechanical press is shown. Both the text and the optional voice-over explain what forging is and whether billets or bar stock are used to produce the forging. Similarly, in the case of injection molding the equipment shown is an injection molding machine and the text and voice over explain what injection molding is.

Although Fig. 1 depicts the mechanical press as a static piece of equipment, in the multimedia tutor, the ram, which is connected to the flywheel via a connecting rod, moves up and down. While the lower die remains stationary, the animation shows the upper die moving with the ram and striking the workpiece so as to reduce its thickness while increasing its length. As the ram moves up, the animation shows the upper die losing contact with the workpiece and the workpiece removed from the press and placed in the bin shown to the left of the press. Similar types of animation take place in injection molding and stamping. For example, in injection molding the user sees the mold close, followed by the melt being forced into the mold. Upon solidification they see the mold open, and the ejector pins move forward to eject the part from the mold.

In the case of forging, after the opening two frames, the tutor goes on to explain that there are two broad categories of forging, namely, open die forging and closed die forging. Figures 2

shows two snap shots of the animations used to depict open die and closed die forging. The tutor also goes on to clarify when each type of forging is used and to describe the shapes producible by each of them. The introduction further explains that because metal is difficult to form in a single stage, a series of dies is often used in closed die forging. The distinction between blocker-type forgings, conventional forgings, and precision (close-tolerance) forgings is also spelled out.

In the case of open die forging, the tutor explains that a hot metal workpiece is squeezed or hammered between flat, circular or v-shaped dies. The workpiece is not enclosed so the metal flow is not completely restricted. In closed-die forging the workpiece is squeezed or hammered between one or, more likely, a series of dies enclosing the workpiece on all sides. It explains that closed-die forgings are sub-divided into blocker-type forgings, conventional forgings, and precision (close-tolerance) forgings.

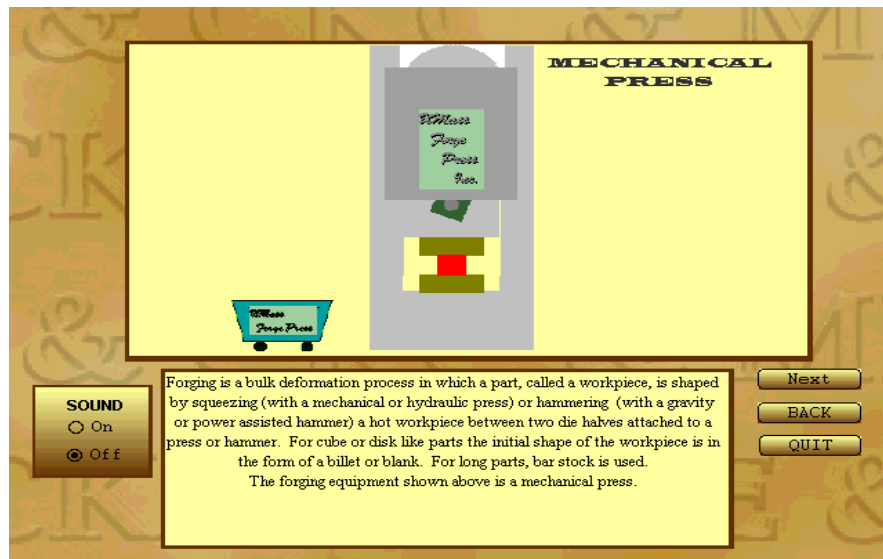


Figure 1. A snap shot of the opening animation from the introduction to the forging tutor. Buttons are present to allow the user to turn the sound on or off, to move to the next frame, to return back to the previous frame or to quit.

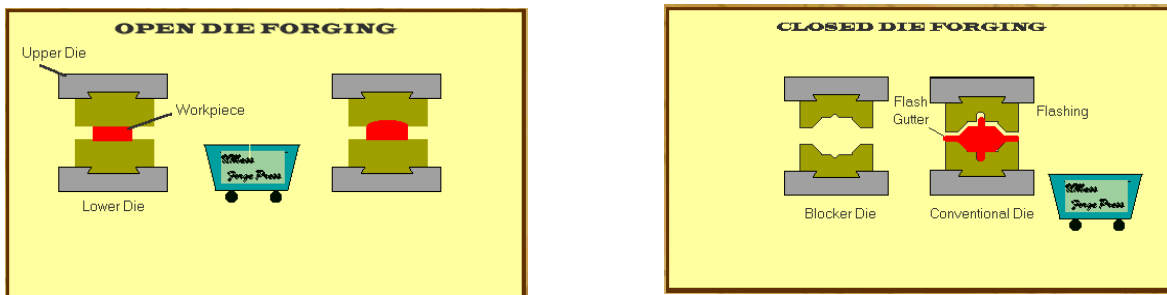


Figure 2. Two snap shots of animations taken from the introductory part of the forging tutor to illustrate both open die forging and closed die forging. In the case of open die forging, shown on the left, the tutor shows the upper dies squeezing the workpiece so as to reduce their thickness while increasing its length. The users see that as the upper dies moves up and loses contact with the workpiece the parts are removed from the die and put into the bin. In the case of closed die forging shown on the right, the workpiece is first preformed between the blocker die shown on the left and then as the upper die moves upward the user sees the workpiece being placed into the conventional die for final forming.

Animations are also used to depict the various types of equipment used in the different manufacturing processes. For example, Fig. 3 shows a still version of the animation used to portray a gravity drop hammer. As seen in Fig. 3, the various components of the equipment are labeled. The text and voice over go on to describe the advantages and disadvantages of the various types of forging equipment, when they are used, and the relative cost benefits of each.

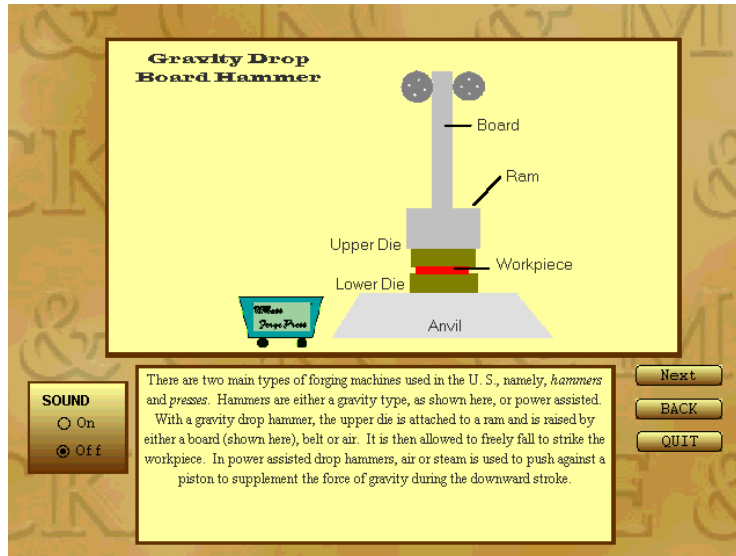


Figure 3. A gravity drop hammer as shown in the introductory portion of the forging tutor. Unlike the situation when a mechanical press is used and the workpiece is struck only once, in this situation the animation shows the upper die striking the workpiece three times before it is removed and placed into the bin.

Upon completion of the general overview, each tutor goes on to explain that the cost of a part is made up of tooling cost, part material cost, and equipment operating cost. AND that a designer's greatest opportunity and flexibility to reduce costs comes in reducing the cost of the tool. For example, in the injection molding tutor the relationship between tooling cost, part geometry and mold closure direction is discussed. The tutor explains that tooling cost is a function of part geometry. It demonstrates, via animations, that when designing a part for injection molding, tooling cost can often be reduced by proper selection of part geometry, mold closure direction, and/or parting surface location, and underscores the fact that understanding these three factors is essential for minimizing tooling cost. Figures 4 show three of the examples used in the introductory portion of the injection molding tutor.

The final portion of each introduction then summarizes the various design for manufacturing (DFM) issues for each process. In the case of injection molding it was the part geometry that could result in the presence of external and/or internal undercuts. In forging it was the choice of material, the presence of tall thin ribs and/or closely spaced ribs that could result in both increased tooling and processing costs. For stamping the issues are summarized as: i) the number of distinct features, ii) whether the features are closely spaced or not, iii) whether narrow cutouts and projections are present, iv) the number of stages required to bend the part.

Figures 5, 6 and 7 show still versions of the animations used to explain, by example, some of these points. In the tutors, the punches are shown moving up and down while the strip is shown moving from right to left through the various stations.

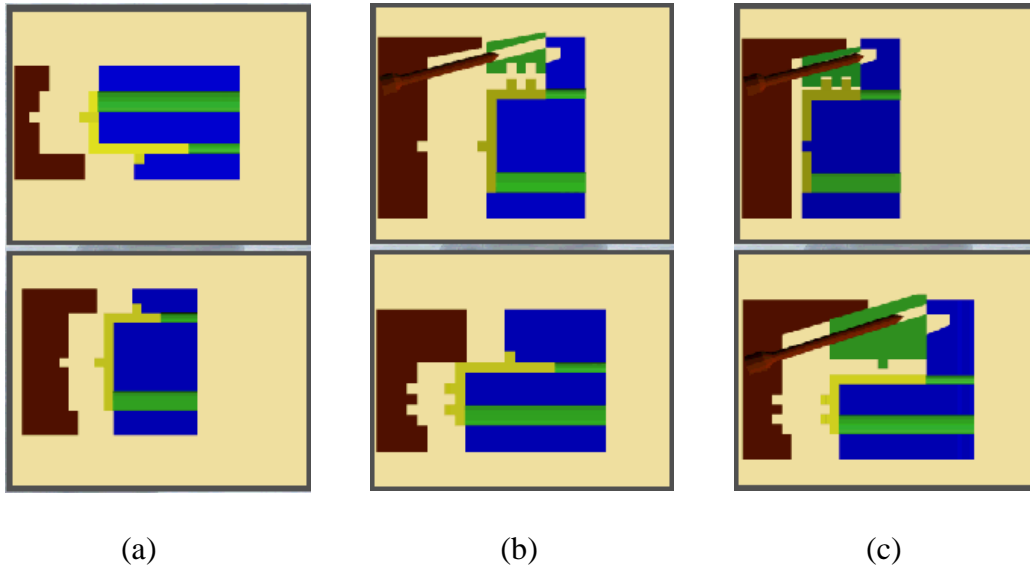


Figure 4. Three L-shaped parts in which the direction of mold closures is shown in two alternative directions. In (a) the direction of mold closure has no effect on tooling complexity. In both situations no external undercuts will result. In (b) when the direction of mold closure is perpendicular to the long leg of the part, an external undercut (side action cavity) results. Changing the direction of mold closure so it is normal to the short leg eliminates the undercut. In (c) an external undercut exists regardless of the direction of mold closure. In one case a side action cavity is needed to create the part, in the other case a side action core is needed.

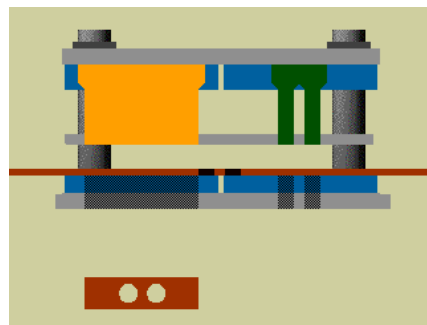


Figure 5. Part with two identical circular holes requires only two stations. One to create the holes and one to separate the part from the strip.

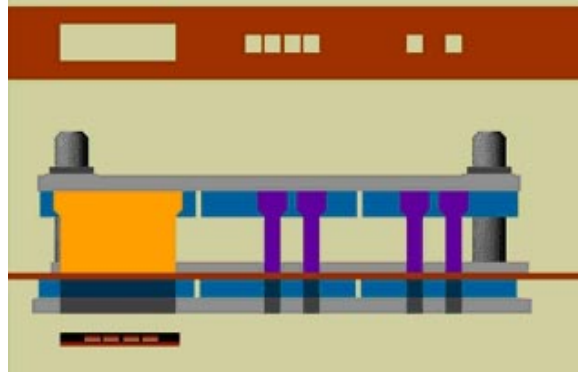


Figure 6. Part with four closely spaced holes. Here three stations are required. Two of the holes are created at the first station and the other two are created at the second station. The part is blanked out at the last station.

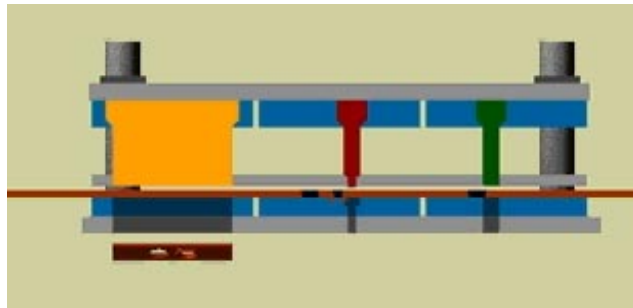


Figure 7. Part with a circular hole and an extruded hole. As shown three stations are needed.

### *Workshop Module*

Once the user completes the introduction module they are then presented with the opportunity to run the workshop module. This module helps reinforce the concepts presented in the introduction, and provides real time feedback. What follows is a description of a small portion of one of the workshop modules found in the stamping tutor. In particular, it deals with the effect of using distinct features on the number of stations required to produce the part.

As seen in Fig. 8, this particular workshop consists of three windows, a design window, a tooling window and an evaluation window. A fourth window, not shown here, is a help window that explains to the user how to design a part and obtain the resulting tooling for that design.

A part is created by clicking on one of the features (hole, rib, emboss, or extruded hole) and dragging it onto the metal strip. In this case four distinct features have been dragged onto the strip. If the user recalls the DFM results summarized in the introduction they will realize that five stations will be required to produce the part. Verification of this can be obtained by clicking on show tooling. Evaluations of the design, the relative tooling cost for this design (not shown here), and a redesign suggestion, are contained in the evaluation window.

Figure 9 shows the result of creating a strip, as suggested by the evaluation window in Fig. 8. Although the user should've recalled that only two stations would be required in this case, the evaluation window also depicts the savings in tooling costs between the two designs.

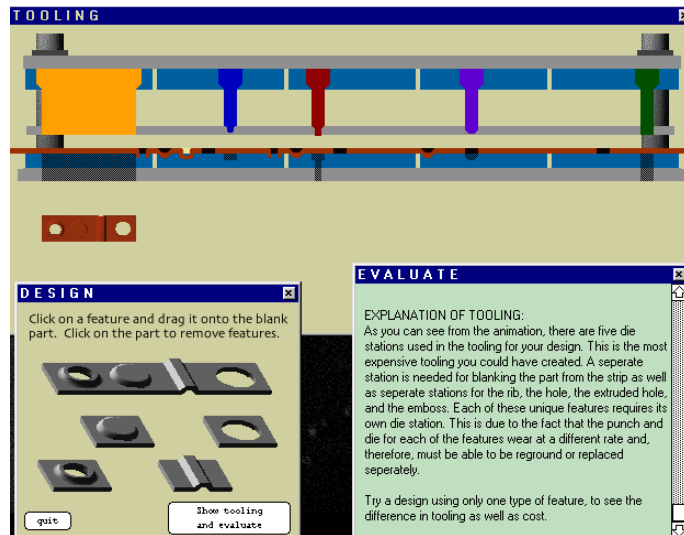


Figure 8. A snap shot from one of the workshop modules available for the stamping tutor. The tooling window contains an animated version of the five station tool required to stamp the flat strip shown in the design window. An evaluation window is shown too.

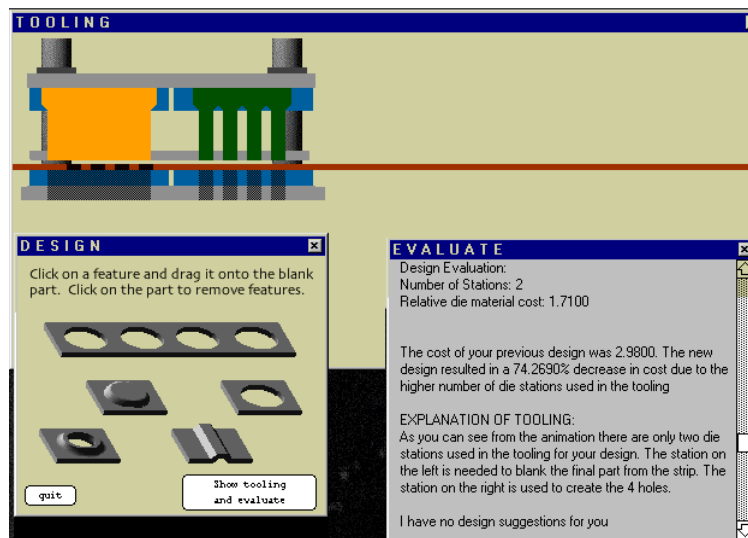


Figure 9. The strip redesigned as suggested by the evaluation shown in Fig. 8.

### III. Preliminary Evaluation Results

A preliminary evaluation of both the injection molding tutor and the forging tutor was conducted this fall in a junior engineering course dealing with manufacturing processes and design for manufacturing. Unfortunately, unexpected difficulties with the stamping tutor could not be resolved in time to have it evaluated.

Of the 42 students in the course, 29 had previously been exposed, via several lectures and homework assignments, to the injection molding process and the concepts of design for injection molding. These were students who, as freshman, had been enrolled in a freshman engineering course which used a semester long, team-oriented, student project centered around design for manufacturing (DFM) as a catalyst to teach engineering communication skills. Most of the DFM portion of that course was centered on the concepts of design for manual assembly and design for injection molding. The other 13 students were either exchange students, transfer students or students who had taken a different version of the freshman course. The important point here is that these twelve had never heard of injection molding and had never been exposed to design for injection molding concepts. None of the students had ever been exposed to forging or the concepts of design for forging.

In both the case of the injection molding tutor as well as the forging tutor, the software was installed on PCs in the College of Engineering PC laboratory. On three separate occasions 75 minutes was reserved in the PC lab for use of the entire class. One week the students used the injection molding tutor, two weeks later they used the stamping tutor, the following week they made use of the forging tutor. As mentioned earlier, problems with the stamping tutor interfered with its use. On all occasions most students finished using the tutors after about 30 to 45 minutes. A handful of students remained for 60 minutes. None took the full 75 minutes allocated for use of the tutors.

### *Quantitative Results*

After using the injection molding and forging tutors a quantitative evaluation test was administered. Students were permitted to treat it as a homework assignment. That is they took the evaluation test with them and returned it the following class period. A few students completed the test while waiting for the 75 minute period to end.

Figure 10 shows the results of the injection molding evaluation. The average score achieved by those students who two years earlier had been exposed to the concepts of design for injection molding was 81%. These students had previously received one or two 50 minute lectures dealing with injection molding and design for injection molding, been assigned several homework problems dealing with design for injection molding and had discussed these solutions of these problems in detail in class. The average score achieved by the remaining students, those with no previous exposure to injection molding, was 79%.

Among the group that had never studied injection molding were two students who received exceptionally low scores on the post test. These two students had obviously not clearly read the problem statements and as a results achieved low test scores. If these two scores are dropped, the average score by this latter group becomes 85%.

Based on this preliminary result it would appear the injection molding tutor was meeting its objective.

Figure 11 shows the results of the forging evaluation. These students received no class room lectures on forging and had not been given a reading or homework problem assignment dealing



with forging. The overall average for all students was on the quantitative assignment was 72%. Due to the interaction of material and geometry on forging, the design for forging concepts are somewhat more involved than those for injection molding. Hence, lower evaluation scores were expected. However, the results indicate that the concepts of design for forging, that is to a knowledge of those combinations of geometry and material selection that lead to costly to produce forgings, can be achieved without the need for standard classroom lectures and assignments.

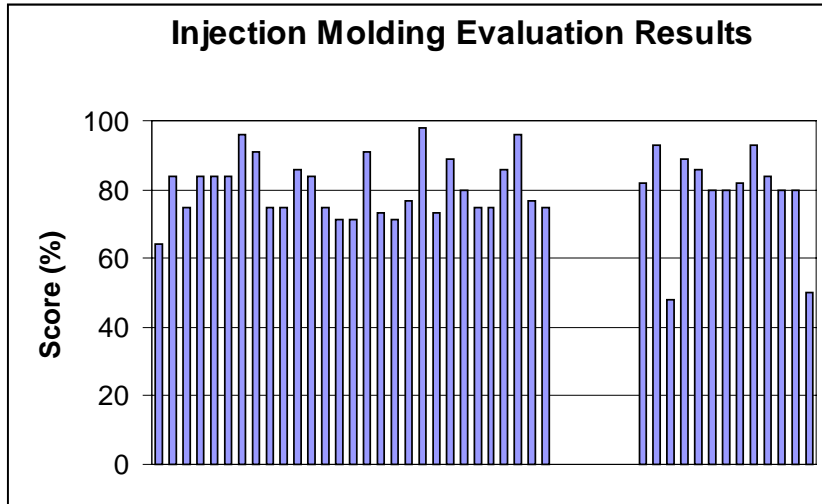


Figure 10. Results of the injection molding evaluation. The group of scores on the left represents those students who had previous exposure to injection molding and the concepts of design for injection molding. The group of scores on the right represents those students who had no previous exposure to injection molding.

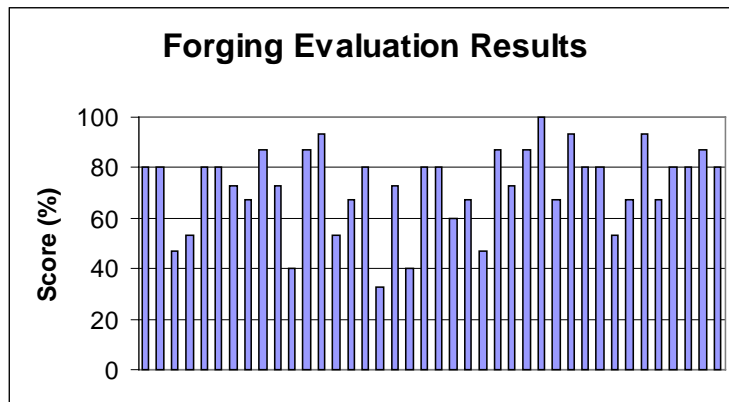


Figure 11. Results of the forging evaluation. In this case none of the students had ever been formally exposed to forging or design for forging.

*Qualitative Evaluation – Injection Molding*

After each homework assignment was turned in, students were asked to complete a qualitative questionnaire dealing with the two tutors. Some of the results for injection molding are shown in Tables 1 and 2. It seems clear from a study of the data and comments presented in these tables that students are overwhelmingly positive about the injection molding tutor.

*Qualitative Evaluation – Forging*

Table 3 summarizes the results of the questionnaire completed by the students following use of the forging tutor. Table 4 lists some of the comments made by the students. Once again the students appear to be overwhelmingly positive about the forging tutor.

The class was also allowed to make us of a still to be completed stamping tutor. Despite the fact that the tutor was only about 50 percent complete, the qualitative responses were once again positive. Since the stamping tutor was not complete no quantitative assignment was given.

Statement	Agree/Strongly Agree (%)
After using the tutor I have a clear understanding of the injection molding process.	82
After using the tutor I understand why undercuts increase part costs and how side cores and side cavities are used to create undercuts.	95
I feel confident that I can explain the relationship between geometric complexity and tool cost to another student.	62
Being able to visualize the tooling required for side cores and side cavities help me understand the material in a way that the textbook or lecture never could.	79
I found the injection molding tutor easy to use.	90
The interactive workshop part of the tutor was difficult to use.	16
The tutor was user friendly	87

Table 1. A summary of some of the student experiences with the injection molding tutor.

<b>From Students Who Had Previous Exposure to Injection Molding.</b>
“The tutor gave me a more visual application of injection molding and gave me an interaction between the lecture and the book ...the most helpful for completing the assignment was the multimedia tutor and friends in the class.”
“The tutor was great to refresh my memory with the terminology, and was helpful with the homework. If there was some question in my head I wasn’t sure about, I could look in the book and knew when I found the answer thanks to the tutor.”
“In doing the homework, the 190 (freshman) class helped more, but it (the tutor) did refresh a lot of material for me that I didn’t remember.”
“The lectures, reading and the tutor helped give me an understanding of the workings of the injection molding process. The tutor provided excellent visual effects.”
“I already had a general understanding of injection molding and the costs related to complexity from 190 (freshman course), but the tutor helped me to understand how some of the complex undercuts were made.”
<b>From Students Who Had No Previous Experience With Injection Molding</b>
“It was helpful to see the process of injection molding on multimedia. The book was also helpful, however, it doesn’t offer step by step visual representation.”
“The tutor helped me to understand what makes an injection molded part expensive. This is very important for design.”
“Multimedia is a good direction in teaching. I wish we had something like that in thermo and strength of materials. The tutor needs a little work on the interactive part.”

Table 2. Some comments provided by students concerning the injection molding tutor.

Statement	Agree/Strongly Agree (%)
After using the tutor I have a clear understanding of the forging process.	71
After using the tutor I understand why some materials are more costly to forge than others..	88
After using the tutor I understand why some geometries are more costly to forge than others..	92
I found the forging tutor easy to use.	85
The interactive workshop part of the tutor was difficult to use.	21
The tutor was user friendly	75

Table 3. A summary of some of the student experiences with the forging tutor.

The tutors are very important in visualizing what is happening.
The interactive part was somewhat confusing.
This tutor was more informative than the other two.
There were only a few examples. I think more than that are needed to fully understand manufacturing processes.
The tutors did not necessarily increase my interest, but the animations did make concepts much easier to understand.
They (the tutors) have given me a much better understanding of manufacturing processes.

Table 4. Some comments provided by students following use of the forging tutor. Since the forging tutor was the last of the tutors to be used, some of the responses appear to refer to the tutors in general.

#### IV. Summary

This paper has described three multi-media based manufacturing tutors developed for the purpose of improving the manufacturing literacy of engineering students. Student evaluations of the tutors shows that they are successful at providing highly illustrative, visually stimulating animations, something a text book cannot provide. Evaluation results also indicate that the tutors are successful in educating students about design for manufacturing concepts and making them aware of those features of a part which are costly to produce.

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Corrado Poli is currently Head of the Mechanical and Industrial Engineering Department at UMass Amherst. Over the years he has been involved in several NSF-funded research projects dealing with design for manufacturing. His publications include over 80 papers and three textbooks and during the last couple of years has been almost exclusively in the area of multimedia based tutorials.

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Beverly Woolf is Director of the Center for Knowledge Communication at UMass Amherst.. She has a Ph.D. in Computer Science and an Ed.D. in Education, both from UMass and has more than 15 years experience in educational computer science research, production of intelligent tutoring systems and development of multimedia systems. She has published over 50 articles and is A Fellow of the American Association of Artificial Intelligence