*Proceedings of 4th ASME Design for Manufacturing Conference:
1999 Design Engineering Technical Conferences
September 12-15, 1999 Las Vegas

DFM8957

MULTIMEDIA-BASED ACTIVE TUTORS – A NEW APPROACH TO TEACHING DESIGN FOR MANUFACTURING

Corrado Poli/University of Massachusetts Amherst

Ian Grosse/University of Massachusetts Amherst

Beverly Woolf/ University of Massachusetts Amherst

Stamping, Injection Molding, Forging, FEA

ABSTRACT

This paper describes multimedia based manufacturing tutors currently under development at the University of Massachusetts Amherst. The purpose of these tutors to assist the user in better visualizing and understanding the relationship between part design and the ease or difficulty of creating the tooling needed to produce the part. Evaluation of these tutors by both freshman and junior engineering students is discussed as well. A finite element analysis tutor, also under development, is briefly described.

INTRODUCTION

Design for manufacturing (DFM) is a design philosophy that now receives a great deal of attention. It is a philosophy and mind-set in which manufacturing input is used at the earliest stages of design in order to design parts and products which can be produced more easily and more economically. In general, however, design engineers do not have the requisite depth of experience in manufacturing to determine the impact of various design features on the difficulty and hence cost to manufacture. Therefore various DFM tools have been developed [1-3] to help designers assess the impact of their proposed design on manufacturing difficulty.

Experience with various systems indicates that users, both students and practicing engineers, are able to effectively utilize such systems to assist them in identifying various cost drivers and evaluating the impact of these cost drivers on competing designs. However, despite their ability to use the system, experience has also shown that they are not always able to visualize and understand why certain features are in fact cost drivers. Thus, faculty and students at the University of Massachusetts Amherst (UMass) are actively engaged in developing interactive multimedia tutors specifically for teaching design for manufacturing. The purpose of these tutors is to assist the user, a student or anyone not familiar with various manufacturing processes, in better visualizing and understanding the relationship between part design and the ease or difficulty of producing the part. Because the vast majority of components, excluding fasteners, found in commercial batch-manufactured products, such as appliances, computers, office automation equipment, etc. are either injection molded, stamped, die cast, or (occasionally) forged, the first generation of tutors developed at UMass focused on these particular manufacturing processes.

WHY MULTIMEDIA TUTORS?

New tools that go beyond simple classroom lecture are desperately needed in engineering education. Many students have found themselves bored, disinterested and unmotivated, particularly when enrolled in their one required ‘show and tell type’ undergraduate course dealing with manufacturing processes.

Although curricular reform has been taking place, it has met with limited success. One reason is that previous curricular reform was often primarily centered on the freshman year. What reform does exist beyond the freshman year is still essentially centered on traditional lecture-based instruction. Furthermore, over the years, the student body has become more diverse and cannot be reached simultaneously in conventional large lecture settings.

On the other hand multimedia tutoring systems have been shown to respond flexibly and be effective with students [4-7]. Properly designed computer based tutors have achieved the onesigma effect [8], which is the same improvement in learning that results from one-on-one human tutoring over classroom tutoring. Several success stories have described students learning in one-third to one-half the time it takes for a control group to learn the same material [9]. In one example, undergraduate students using a Lisp tutor at Carnegie Mellon University [10] completed programming exercises in 30 percent less time than those receiving traditional classroom instruction did and scored 43 percent higher on the final exam. In another case, students working with an Air Force electronics troubleshooting tutor for only 20 hours gained a proficiency equivalent to that of trainees with 40 months (almost 4 years) of on-the-job training [6]. In a third study, students learned general scientific inquiry skills and principles of basic economics in one-half the time required by students in a classroom setting [9].

THE MANUFACTURING TUTORS

Three manufacturing tutors have been developed to date at UMass Amherst, namely, one for injection molding, one for stamping and one for forging. A die casting tutor is also under development. A salient feature of these tutors is that they are not tied to a particular course and can be easily adapted into existing design and/or manufacturing courses by faculty who may not even be knowledgeable in the tutor subject material. The anticipated education benefit for engineering students is to improve their proficiency in dealing with real-world issues in engineering design and manufacturing.

Storybook Introductory Module

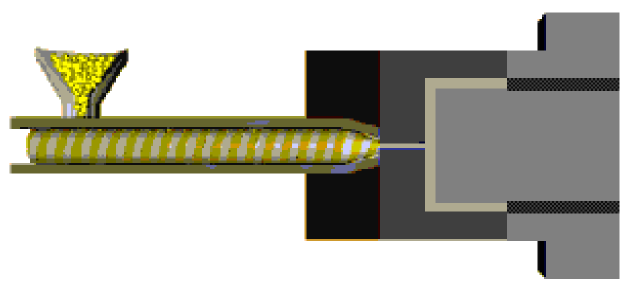
The manufacturing tutors are divided into two distinct modules: a storybook introductory module and an experiential or active learning module. In the first module the user is introduced to a particular manufacturing process via a series of screens that contain text, animations, quick times, and voice-overs. 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. Each introductory module begins with a short video clip of the process, followed by an overview of the process using quick times and animations, 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. The final portion of each introduction then summarizes the various design for manufacturing (DFM) issues for each process. In the case of injection molding the issue was that part geometry could result in the presence of costly to produce external and/or internal undercuts. In forging 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, are the DFM issues addressed by the tutor. 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. The topics covered in the introduction are presented in a sequential order to force the user to learn in an organized manner.

As indicated above, the tutors begin with a video clip of the process in question. For example, Figure 1 shows one of the frames from the injection molding clip. What the user sees is an injection molding machine along with a hopper holding plastic pellets. The video clip shows the mold opening and closing and a part being ejected from the machine. What the user does not see is what is actually occurring internal to the machine and how tooling complexity increases as part geometry becomes more complex.

Following this the user is shown an animation of the same equipment shown in the video. In this case the animation is a sectional view of a simplified version of an injection molding machine (Fig. 2). This simplified version is used so that the user can see and understand what is occurring internally as the injection molding machine creates a part.

Figure 3 shows snap shot versions of some of the animations used to illustrate the effect of mold closure direction and geometry on injection molding.

Figure 1. *One frame from the video clip showing an injection molding machine.*



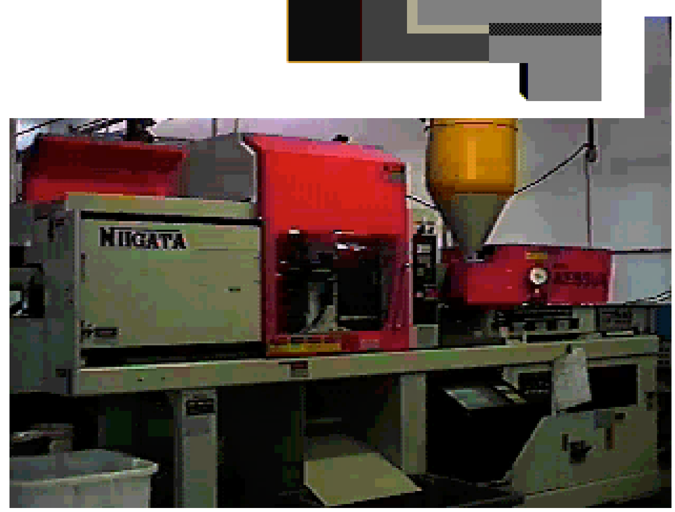


Figure 2. *A snap shot of the animation showing an injection molding machine in its closed position. Text and the optional voice over explain that, "Injection molding is a common polymer process used to form thermoplastics, such as*

polypropylene, ABS, and polycarbonate, into parts that have simple to complex geometries. Pellets are fed from the hopper into the barrel. As the screw forces the pellets down the barrel towards the mold they are melted due to heat applied to different barrel sections. Once a shot of molten plastic is accumulated and the previous part has been ejected, the shot is injected under high pressure into the mold. Once in the mold, the molten plastic takes on the shape of the mold, cools, solidifies, shrinks, and is then ejected."

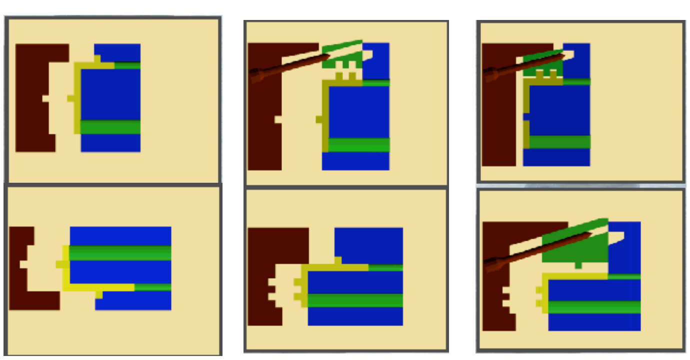
The Active Learning Module

The experiential or active learning module in each tutor provides users with the opportunity to determine how well they have mastered the concepts presented in the storybook module. In this module users are allowed to design and 'build' a part from a restricted family of part geometries and to obtain a design evaluation of the part. Alternatively, users may be presented with various alternative designs and engineering specifications and asked to determine which design best satisfies the specifications. If users have understood the concepts presented in the introduction, they should recognize whether or not the part designed or selected is easy to produce and, if not, how to alter the design to reduce costs. 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. 4, 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, he or she will realize that five stations will be required to produce the part. The user can verify this by clicking on the <show tooling and evaluate> button. 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 5 shows the result of creating a strip, as suggested by the evaluation window in Fig. 4. Although the user should have 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.



(a) (b) (c)

Figure 3. *Three L-shaped parts in which the direction of mold closures is shown in two alternative directions. In the top row the direction of mold closure is perpendicular to the long leg of this L shaped part. In the bottom row the direction of mold closure is perpendicular to the short leg of the part. 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.*

EVALUATION OF THE MANUFACTURING TUTORS

An evaluation of the injection molding tutor was conducted this fall in both a junior engineering course dealing with manufacturing processes and design for manufacturing, as well as in an introductory freshman course which included design for manufacturing as one of its components. The forging tutor was only evaluated in the junior course. Unfortunately, unexpected difficulties with the stamping tutor could not be resolved in time for evaluation.

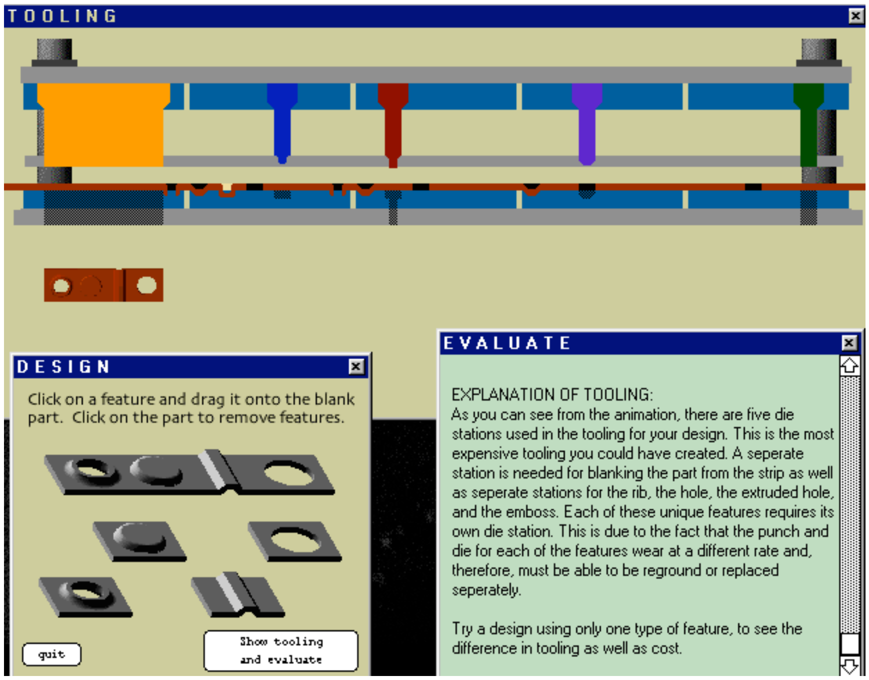


Figure 4. *A snap shot from one of the workshop modules available for the stamping tutor. The tooling window contains an animated version of the five-station tool required to stamp the flat strip shown in the design window. An evaluation window is shown too.*

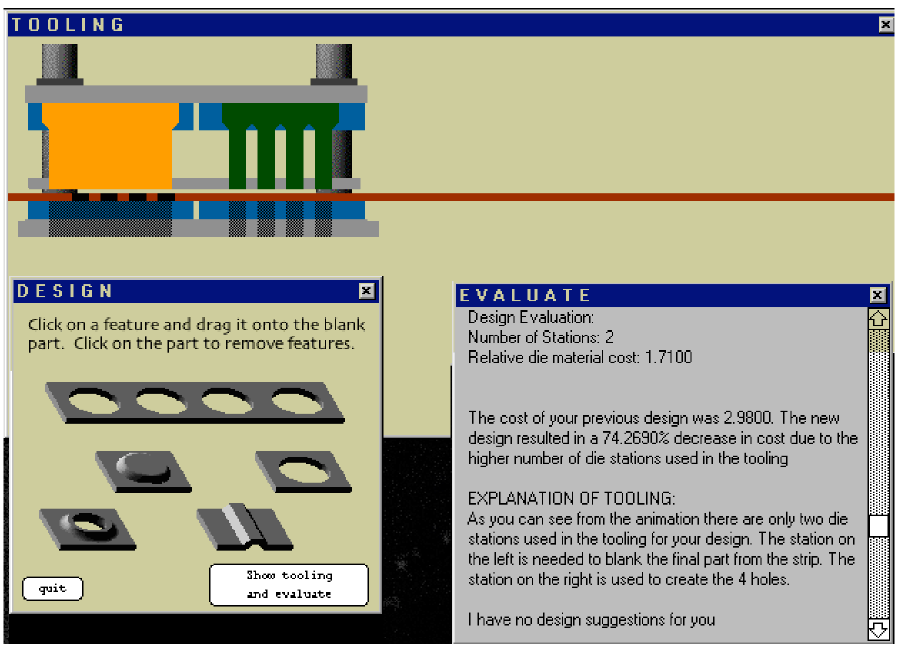


Figure 5. *The strip redesigned as suggested by the evaluation shown in Fig. 4.*

Junior Course Evaluation

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 13 students had never heard of injection molding and had never been exposed to design for injection molding concepts. None of the 42 students had ever been exposed to forging or the concepts of design for forging.

After using the injection molding and forging tutors for about 45 minutes, a quantitative evaluation test was administered. Students were permitted to treat the quantitative test as a homework assignment. Thus, they took the evaluation test with them and returned it the following class period

Quantitative Results

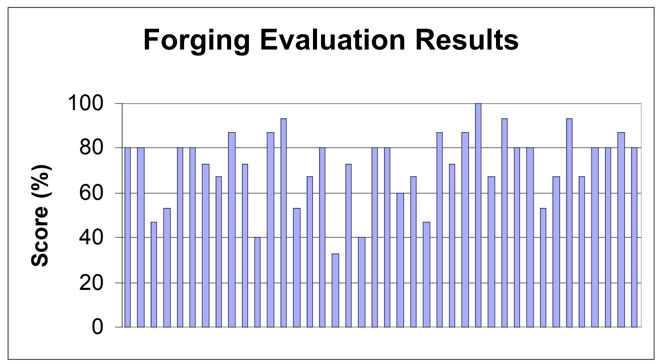
Figure 6 shows the results of the injection molding evaluation. The average score achieved by those students who two years earlier had been exposed to the concepts of design for injection molding was 80%. These students had previously received one or two 50 minute lectures dealing with injection molding and design for injection molding, been assigned several homework problems dealing with design for injection molding and had discussed the solutions of these problems in detail in class. The average score achieved by the remaining students, that is 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 quantitative assignment. 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%.

Figure 7 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 6. *Results of the injection molding evaluation for the junior class. 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 7. *Results of the forging evaluation for the junior class. In this case none of the students had ever been formally exposed to forging or design for forging*

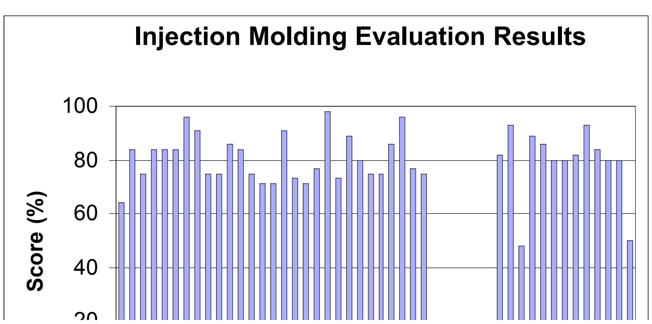


Qualitative Results

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. The results for forging were quite similar. It seems clear from a study of the data and comments presented in these tables that students are overwhelmingly positive about the tutors.

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

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

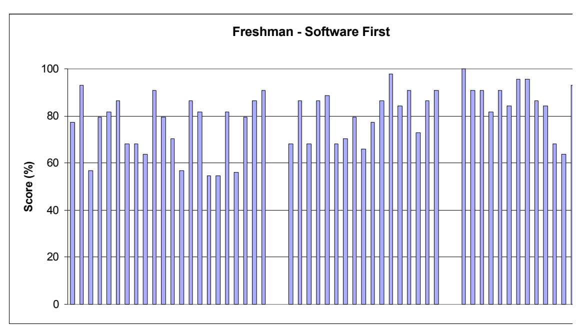
Table 2. *Some comments provided by students concerning the injection molding tutor*.

From Students Who Had Previous Exposure to Injection Molding.
“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.”
From Students Who Had No Previous Experience With Injection Molding
“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.”

Freshman Course Evaluation

As discussed above, an introduction to design for injection molding is a key element of the freshman course at UMass. Thus, the injection molding tutor was tested using approximately 125 freshman who were divided into five different sections.

Three of the sections began their study of injection molding by utilizing the software to learn about the relationship between part geometry and tool complexity. Immediately after using the software they took the quantitative evaluation test. The remaining two sections began their study of injection molding by attending traditional lectures, doing the assigned homework problems, and discussing these homework problems in class. Following this these two sections, referred to as the lecture first sections, took the same quantitative test as the three software first sections. The results of the tests are shown in Figures 8 and 9.



After completing test 1 and reviewing the solutions to test 1 in class, all sections eventually received both the traditional lecture and the opportunity to use the software Following this all sections then took a second test similar in scope to the first. Table 3 summarizes the results.

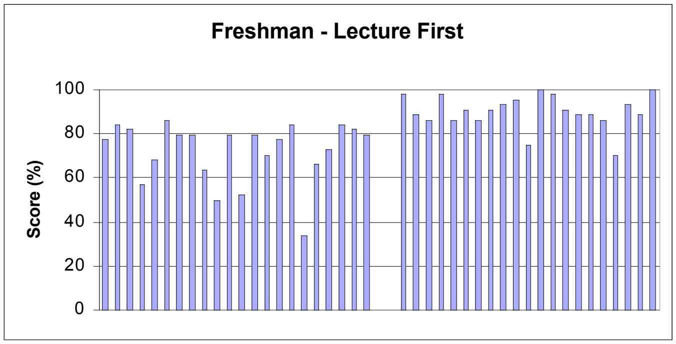


Figure 8. *Test scores achieved by those sections that were introduced to injection molding solely by the use of the multimedia software. The average score was 80 with a standard deviation of 11.8.*

Figure 9. *Test scores achieved by those sections that were introduced to injection molding via the traditional lecture approach. The average score was 81 with a standard deviation of 14. One of the two sections included the freshman honors section. The group of scores shown on the right represents the scores obtained by the honors sections.*

Table 3: Test Score Summary

	Average	Standard Deviation
Juniors		
Forging	72	16.2
Previous exposure to injection molding	80	8.5
No previous exposure to injection molding	79	13.6
Freshman		
Software first	80	11.8
Lecture first	81	14
Both	85	11

OTHER TUTORS UNDER DEVELOPMENT

In addition to the manufacturing tutors described here, a tutor dealing with finite element analysis is under development at UMass [11]. The objective of the FEA tutor is to teach engineering students the key concepts and guidelines involved in finite element modeling within the confines of the existing engineering undergraduate curriculum. In lieu of a mathematical treatment of the subject presently found in textbooks, this FEA tutoring system employs multimedia technology for conveying highly visual concepts and offers the user a set of experiential modules for exploratory learning. The FEA tutor does not seek to replace existing commercial finite element tools. Rather, students who use the FEA tutor are introduced to the basic concepts of finite element modeling and analysis. Students could then practice the concepts presented by the FEA tutor when using any commercial or in-house finite element tool. Thus, the learning goal is for the student to understand basic FEA modeling principles such as feature reduction, the application of symmetry, and component isolation by the proper application of loads and kinematic constraints. With these concepts learned, students will be able to make the proper analysis modeling assumptions that form the foundation upon which optimal finite element models of engineering systems are built.

The FEA tutor employs an identical learning paradigm as the manufacturing tutors. The student is first introduced to concepts and knowledge on a particular topic via a storybook containing graphics and animations as necessary. The concepts presented in the storybook modules are then reinforced with exploratory or active learning modules. The basic topics covered in the tutor are topics: 1) Overview of FEA, 2) Analysis Modeling and 3) Discretization. Analysis modeling is further divided into three separate storybook submodules: Model Isolation and Constraints, Symmetry, and Feature Reduction. An active learning module supports each of the three Analysis Modeling storybook submodules and the Discretization storybook module. Figs. 10 and 11 show screen captures from two of the tutor's four active learning modules. More details can be found in [11].

An informal evaluation of student responses was performed, considering the application of appropriate forms of symmetry, boundary conditions, loads, and discretization. Preliminary results showed that the students who used the FEA Tutor performed 30 percent better than those who attended the traditional lecture. It should be noted that the tutor was tested on only one class of undergraduate students without a formal evaluation technique. However, one of the benefits of the preliminary testing was to provide feedback on the methods used to convey the subject matter to the students. In particular, it was found that neither the FEA Tutor nor the class lecture adequately conveyed the concept of transforming the constraints of the physical system into an appropriate set of load and boundary conditions. However, the students who used the FEA Tutor performed well in reducing the geometry through symmetry. The preliminary testing, therefore, showed an indication of the strengths and weaknesses of the teaching methods applied to each subject matter. This feedback is being used to direct improvements in a future version of the FEA Tutor.

SUMMARY

Most of the 'multimedia' tutors available today are frame-oriented, storybook type tutors that simply present text, still graphics and on occasion brief video clips. Such tutors tend to permit the student to be passive and to simply press buttons to turn to the next page. No mechanism exists in this frame-based approach to assure comprehension of the material presented. Further, frame-based teaching is usually minimally effective due to its inability to customize teaching for a student. Learners are not typically in charge of their learning and such systems are not supportive of their users. Cognitive studies of instruction have shown that learners ***must*** remain active and motivated while learning from computer-based educational systems [12-15]. Students must want to learn, be involved and be active and challenged to reason about the material presented.

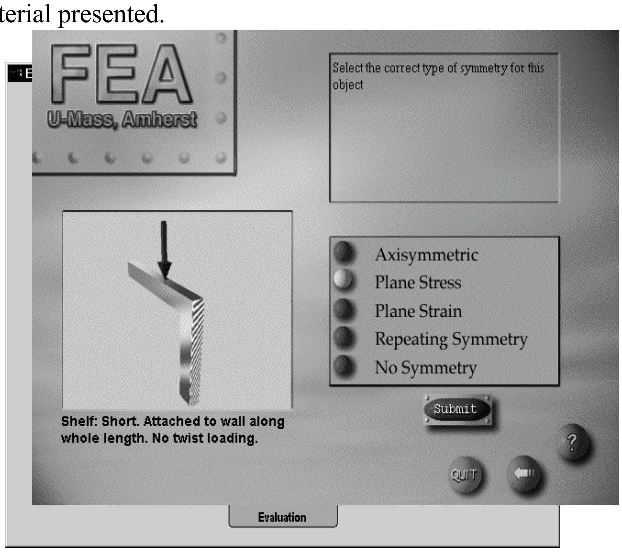


Figure 10: *Part of the Active Learning Modeling Module. After isolating a connecting rod in a can crushing mechanism for structural analysis, the user must now select the appropriate loads and boundary conditions. The tutor provides immediate feedback if the choices are incorrect.*

Figure 11: *The Active Learning Symmetry Module. The user must correctly identify the type of symmetry present in several distinct analysis problems.*

The UMass tutors use a combination of still graphics, animations, quick-times, and video clips and require students to be active learners. To prevent information overload, the subject material for each manufacturing tutor is restricted to a handful of specific design-for-manufacturing issues. A two step teaching paradigm is employed: presentation of the material in multimedia storybook modules, followed immediately by active engagement of the student in active learning multimedia modules to ensure comprehension of the material just presented. In the active learning modules of the manufacturing tutors the user actively creates parts, animated solutions are created on the fly, and feedback concerning the designs are rapidly obtained. The FEA tutor also employed the same two-step-teaching paradigm of short storybook modules supported by active learning modules. The subject material of the FEA tutor is focused on modeling guidelines, as opposed to formal mathematical treatment. In the active learning modules of the FEA tutor, the user is presented with analysis problems and is required to make appropriate analysis model idealizations, such as the identification of symmetry, elimination of unnecessary geometric features, and proper isolation and modeling of a component within an assembly. Feedback on the validity of the user's modeling idealizations is provided immediately.

Formal and preliminary evaluative testing of the tutors revealed that the tutors were as effective as traditional lecture instruction.

ACKNOWLEDGMENTS

The work described here was supported in part by the National Science Foundation, Grant number NSF DUE-9813654.

REFERENCES

1. Corbett, J., Dooner, M., Meleka, J., and Pym, C., "Design for Manufacture – Strategies, Principles and Techniques," Addison Wesley Publishing Co., Reading, MA 1991

2. Dixon, J. R. and Poli, C., “Engineering Design and Design for Manufacturing,” Field Stone Publishing, Conway, MA 1995

3. Boothroyd, G., Dewhurst, P. and Knight, W. “Product Design for Manufacture and Assembly,” Marcel Dekker, New York, 1994

4. Anderson, J.R., Boyle, C.F., and Yost, G., “The Geometry Tutor,” Proceedings of the Ninth IJCAI, Los Angeles, Morgan Kaufmann: San Mateo, CA, 1985.

5. Katz, S., Lesgold, A., Eggan, G. and Gordin, M., “Modeling the Student in Sherlock II,” *Journal of AI and Education*, Vol. 3, No. 4, 1992.

6. Lajoie, S. and Lesgold, A., “Apprenticeship Training in the Workplace: Computer-coached Practice Environment as a New Form of Apprenticeship,” *Machine-Mediated Learning*, Vol. 3, 1989, pp. 7-28.

7. Woolf, B., “AI in Education,” *Encyclopedia of Artificial Intelligence*, Second Edition, John Wiley &Sons: New York, NY, 1992, pp.434-444.

8. Bloom, B.S., “The 2-Sigma Problem: The Search for Methods of Group Instruction as Effective as One-to-One Tutoring,” *Educational Researcher*, Vol. 13, 1984, pp. 4-16.

9. Shute, V.J. and Glaser, R., “A Large-scale Evaluation of an Intelligent Discovery World: Smithtown,” *Interactive Learning Environments*, Vol.1, 1990, pp. 51-77.

10. Anderson, J.R., "Analysis of student performance with the Lisp tutor," *Diagnostic Monitoring of Skill and Knowledge Acquisition,* Lawrence Erlbaum, Hillsdale, NY, 1990.

11. Milton-Benoit, J., Grosse, I.R., Poli, C., and Woolf, B., "The Multimedia Finite Element Modeling and Analysis Tutor," *ASEE Journal of Engineering Education*, Vol. 87, No. 5, 1998.

12. Fletcher, J.D., "What Have We Learned about Computer Based Instruction in Military Training?," NATO Research Study Group, RSG 16: Workshop on Lessons Learned, 1995.

13. Regian, J. W. & Shute, V. J., "Evaluating intelligent tutoring systems," *Technology assessment in education and training*, edited by E.L. Baker and H.F. O'Neil, Lawrence Erlbaum, Hillsdale, NJ, 1994, pp. 79-96.

14. Seidel, R.J., and Perez, R.S., "An Evaluation Model for Investigating the Impact of Innovative Educational Technology," edited by E.L. Baker and H.F. O'Neil, Lawrence Erlbaum, Hillsdale, NJ, 1994, pp. 177-208.

15. Shute, V. J. & Regian, J. W., "Principles for evaluating intelligent tutoring systems," *Journal of Artificial Intelligence in Education,* vol. 4, no. 2/3, 1993, pp. 245-272.