

Chapter 17

Best Practice in Building Multimedia Tutors: Multimedia Instruction for Engineering Education

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Computer-based tutors, and in particular multimedia tutors, are promising tools for delivery of engineering education. In addition to displaying audio-visual material, graphics, videos and animations, such tutors can interactively engage students in simulated processes and place them in exploratory environments where they create their own designs and receive immediate customized feedback. This paper describes best practices for building interactive multimedia systems and presents basic requirements, obstacles to creating good tutors and examples of tutors built for teaching design for manufacturing. Evaluations of student learning are also discussed.

INTRODUCTION

Engineering topics are often difficult to teach. They may be inherently difficult for students to grasp (for example, Coriolis force and Coriolis acceleration), difficult to teach by a faculty member due to a lack of expertise in the domain (for example, design for assembly), or difficult to address due to the constraints of conventional lecture formats (for example, teaching design for manufacturing). Since engineering is concerned with the design and manufacturing of world class, competitive products, it is ideally suited for multimedia tutors. Large manufacturing processes cannot be transported to the classroom or vice versa. Faculty resort to two-dimensional chalkboard sketches or textbook drawings that often fail to provide students with a sufficient understanding of such systems, how they are designed, how they are analyzed, or how they are manufactured.

Multimedia tutors describe and display audio-visual material for the purpose of instruction. Teachers have used 'multiple media' presentations to enhance learning experience for years, including slide shows, television broadcasts, videos, and animation. Faculty from many universities have developed multimedia tutors [1] that enable students

to solve complex problems [2], understand signals and control systems [3], construct models that would otherwise be too expensive or dangerous to construct at full scale [4] and visualize difficult processes, perhaps through slowed-down animations [5].

Properly designed computer based tutors provide effective learning, similar to that provided by one-on-one tutoring, one of the most effective education delivery methods [6]. Many effective tutors have been built [1] and have facilitated true flexibility for student interactions [6-10]. Clearly engineering departments do not have the resources to support one-on-one tutoring. Multimedia systems that model the student and reason about engineering knowledge and the student's actions are more effective than simple drill and practice computer-aided instruction [11-14]. Students using so-called intelligent tutors can learn in one-third to one-half the time it takes for a control group to learn the same material [8]. In one study, students working with an Air Force electronics troubleshooting tutor for 20 hours gained a proficiency equivalent to that of trainees with 40 months (almost 4 years) of on-the-job experience [12].

This paper describes the best practices for building such multimedia instructional systems for engineering education. We describe 1) the basic requirements of multimedia tutors, 2) obstacles to creating good tutors, 3) examples of tutors built for teaching design for manufacturing and 4) evaluations of student learning using some of these tutors.

BASIC REQUIREMENTS OF A MULTIMEDIA TUTOR

Based on our experience implementing, evaluating and disseminating several multimedia engineering tutors at the University of Massachusetts, including those discussed in [5] and [15-17] and others available on the Web [18], we have identified five essential components in the process of developing multimedia tutors.

Organized Knowledge Domain. To design an effective tutor, one must first obtain and organize the knowledge domain as an 'expert' would organize it. In the case of Manufacturing Tutors, the knowledge must be organized in a form that a vendor would use when asked to provide a quotation for the manufacture of a special-purpose part required for an assembly or sub-assembly. When presented with a piece-part drawing the expert vendor uses 'conditionalized knowledge,' knowledge based on experience, to effortlessly retrieve the relevant knowledge required to provide a cost estimate for producing the part. In the case of injection molded or die cast parts, the expert visualizes both the tooling required and the processing time needed to produce the part. In the case of a stamped sheet metal part, the expert visualizes the tooling required and the potential difficulties presented by the choice of part material and sheet thickness. In other words, the expert does not look for isolated facts that have no

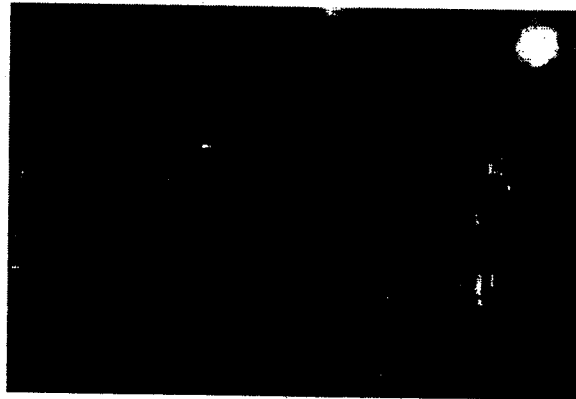


FIGURE 1

ONE FRAME FROM A VIDEO CLIP SHOWING A DIE CASTING MACHINE

bearing on production, but instead looks for features that affect the cost to produce the part.

Unfortunately some of the engineering tutors on the market today simply present the user with a superficial collection of isolated facts and do not provide in depth knowledge of the particular domain. In the field of manufacturing, such systems often fail to present the knowledge in a form that allows the user to visualize the tooling and estimate the processing time. The information is instead presented in much the same way and at much the same level as it is presented in textbooks (often written by faculty who lack practical manufacturing experience). These types of tutors are generally ineffective.

An Interdisciplinary Team. Several experts are needed to produce effective computer based tutors. In addition to the engineering domain expert, who writes the script and directs production of the tutor, animation and software experts are needed. While it may be possible for engineering students and faculty to learn the intricacies needed for the production of high quality animations, it is an ineffective and inefficient use of their time. When the development team does not include software and animation experts it tends to have inferior animations that impinge on the learning process of the user. In manufacturing, high quality animations are needed to illustrate the relationship between part geometry and the required tooling. An instructional expert, i.e., a person who researches instruction and a student's learning processes, should also be part of the team.

A Friendly and Workable User Interface. The overall look and feel of a graphical user interface (GUI) requires good color schemes and an agreeable layout with buttons and drop-down menus properly located to be user friendly. Traditional aesthetic concepts such as rhythm, hierarchy, leading the eye, and negative space, must be maintained across pages. Most tutors produced by science faculty violate all of these rules and as a result do not produce user-friendly software.

Clearly Identifiable Learning Objectives. Learning objectives, such as understanding the advantages of alternative designs or visualizing tooling, need to be clearly identified. An excellent example of software that engages a student in engineering design is the bridge building tutor [4]. Here students design and build bridges and the system evaluates their work. Engagement is a learning objective that textbooks cannot offer. In the case of the UMass Manufacturing Tutors, the learning objectives were to identify the ease or difficulty of creating alternative competing designs, to visualize the tooling needed to produce these geometries *and* to learn with understanding. Traditional multimedia systems often simply duplicate the information found in textbooks and lack any learning objectives that differ from those identified in the preface to a book. Testing, assessment and software refinement is absolutely essential for production of effective multimedia based tutors.

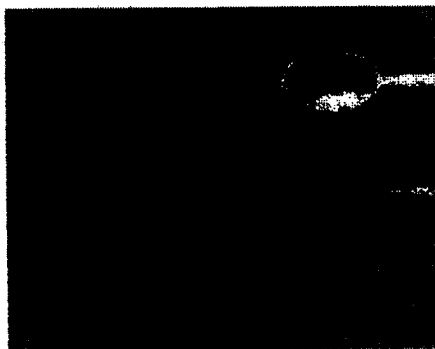


FIGURE 2

A SNAPSHOT OF ONE ANIMATION SHOWING A DIE CASTING MACHINE IN THE CLOSED POSITION WHILE POURING THE MELT INTO THE CHAMBER

Packaging for Learning. Effective tutors contain several modules. There may be components that mimic the traditional classroom, e.g., streaming video of the lecture or PowerPoint slides, provided asynchronously to the student. However, studies indicate that students who actively interact with learning objects have improved attitudes, earlier completion of coursework and better performance on tests [19-22]. To achieve greater interaction with the domain, we recommend at minimum two modules: an *Introduction*, to provide objectives, principles and theories, vital for students who may have no previous knowledge of the domain (Figs. 1-3, 6) and a *Workshop*, to provide experiential and assessment centered activities (Figs. 4, 5, 7, 8). While the UMass tutors have both of these components, many multimedia systems lack the interactive module. The manufacturing tutor produced by Wroblewski and Vanka [23] lacks any assessment. Many multimedia systems, including some cited above (with the exception of the UMass Tutors and the Bridge Design Tutor [4]) do not perform assessment. That is, the above systems enable the student to change parameters in a simulation, but do not record or evaluate the student's action. They provide questions and answers, but there is no critic to respond to the student's mistakes and provide advice.

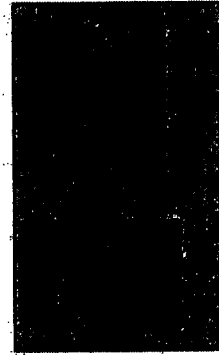


FIGURE 3

THE EFFECT OF MOLD CLOSURE DIRECTION ON ALTERNATIVE TOOLING FOR THE SAME PART. WHEN THE DIRECTION OF MOLD CLOSURE IS PERPENDICULAR TO THE LONG LEG OF THE PART (TOP FIGURE), AN EXTERNAL UNDERCUT (SIDE ACTION CAVITY) RESULTS. CHANGING MOLD CLOSURE DIRECTION TO BE NORMAL TO THE SHORT LEG ELIMINATES THE UNDERCUT (BOTTOM FIGURE)

OBSTACLES TO CREATING GOOD TUTORS

Given our experience building tutors and observing instructional systems built by others, we have also identified various pitfalls and obstacles, including the ones discussed below.

Not Actively Engaging Learners. Many multimedia instructional systems are struck by the 'Tyranny of the Button' [19], in which students press buttons to select materials, e.g., a graphic or video, but are not engaged in active reasoning. Cognitive studies show that learners must remain active and motivated while learning [19-22]. They must want to learn, be involved and challenged to reason. Selecting a new animation, changing parameters or making decisions in a pre-defined simulation is not usually enough to engage a student in authentic work.

Traditional multimedia systems are often frame-oriented, story-board type systems in which every text, graphic or video is preplanned on each page and the student's only activity is to decide which page or animation to view. These systems do not customize teaching for individual students; learners are kept passive, not in charge of their learning. Multimedia tutors can support effective and quality instruction only if the system uses dynamic responses based on a student's design or action. The experience must be relevant to the learner's life [20-22].

Expecting Too Much from Faculty. Some multimedia materials require that faculty increase their workload, develop new lectures, or modify existing lectures. Some materials are tied to a particular course or book. The ideal material should have little or no impact on a professor's workload and in some cases should decrease their workload. Material should be easily be integrated into existing engineering courses by faculty who may not even be knowledgeable in the tutor subject domain.

Difficult and Expensive Development Process. Development of multimedia instructional systems involves extensive costs to employ multiple expertise (e.g. domain expert, programmer, instructional designer, and graphics designer) and extensive resources in terms of planning, programming, testing, observing student reaction, debugging and making the system bullet-proof. Currently, production of this material is more an art than a science. Commercial companies and universities develop instructional systems, yet many are the work of first-time unguided design-and-build teams using few guidelines, tools or basic modules.

Poor Selection of Multimedia Tools. Commercial authoring tools, e.g., Authorware, WebCT, PowerPoint, often constrain the author to present material (text and graphics) and to ask questions. Many commercial tools produce passive systems; learners press buttons for the next page, albeit the next page is a video, sound or image. Effective teaching systems must support the user and preferably customize their response to the widely ranging needs of different students. Currently tools such as Director, Java, .Net and C++ provide the greatest flexibility in developing powerful systems.

Effective instruction and training requires more than simple navigation among media. Conditional branching, employing programming logic, is required to evaluate the student's response, review the current question, keep track of the student's activities and enable an author to identify screens to be repeated or mastery levels to be achieved. We used Director for the tutors described here, enabling authors to:

- Create sophisticated sequences in views and actions, in response to student designs or behavior, e.g., animation of the stamping or injection molding machines;
- Reason about the student's action or design and customize a tutor's response through object-oriented features of the scripting language.

UMASS TUTORS: DESIGN FOR MANUFACTURING

Four design manufacturing (DFM) tutors have been developed at UMass Amherst, namely, one each for injection molding, die casting, stamping and forging. In addition, a strip layout tutor has been developed to supplement the stamping tutor, and a visualization tutor [5, 15-17, 30]. In order to avoid the "Expecting too much from the faculty" pitfall, these tutors were 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 particular tutor subject matter.

Organized Knowledge Bases

Before designing each tutor, we obtained or created organized and well-defined knowledge bases. Books such as those by Rosato [24] and Dym [25] for injection molding, the American Society of Metals for forging [26] and stamping [27] among others, were considered. These books which contain an immense amount of information ranging from how to operate an injection molding machine, for example, to designing a die cast part, to designing forging dies, to selecting the appropriate part material, were

considered but then rejected. The problem with these books is that they mostly provide qualitative rules and guidelines such as "Avoid undercuts if possible" and any quantitative rules that are provided cannot be used until the parametric design stage when dimensions are being finalized. As a designer, it is desirable to have tools that permit a student to perform a quantitative analysis and comparison of competing designs at the early stages of design. Hence, the design for manufacturing methodologies found in [28] and extensively discussed in [29] were selected as the main source for the tutors' knowledge base. As discussed in [29] the databases of relative costs contained in [28] were developed in conjunction with industry experts and obtained by statistically analyzing data supplied by these experts. As pointed out in [29], the model building was an iterative process of data collection, model refinement and industry confirmation.

The Interdisciplinary Software Development Team

We created a development team for the tutors. At UMass Amherst we brought together faculty and students from the Department of Mechanical and Industrial Engineering (MIE) and the Department of Computer Science (CS). The domain experts, from the MIE department, focused on writing the script and directing the process, while the CS experts contributed multi-media software and hardware expertise. Such interdisciplinary teams require a large investment. In our case, government and industry funding supported these activities (see acknowledgement). It was decided early on that the tutor needed to be self-contained, i.e. no interaction or explanation should be required from an instructor for the student to use the tutor or to learn from it. In addition, it was recognized that attention had to be given to the graphic user interface, menus, and windows to avoid a cramped, busy, and confusing monitor screen. Ideally the user interface should convey information unambiguously and should be intuitive to the user.

Learning Objectives for the Tutors

As stated earlier, each manufacturing tutor had clearly identifiable learning objectives. The objectives for the Manufacturing Tutors were for the student to identify the ease or difficulty of creating alternative competing geometries for injection molded, die cast,

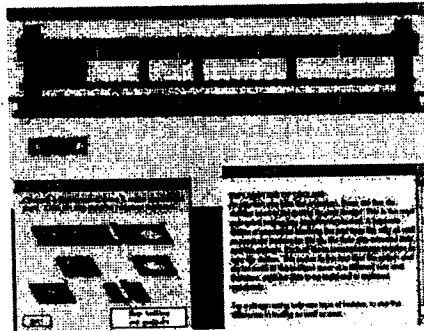


FIGURE 4

A WORKSHOP MODULE FROM THE STAMPING TUTOR. THE STUDENT CREATES A DESIGN (LOWER LEFT). AS A SOLUTION, THE TUTOR PROVIDES A FIVE STATION TOOL TO MANUFACTURE THAT PART ALONG WITH AN EVALUATION OF THE COST OF THE DESIGN (LOWER RIGHT)

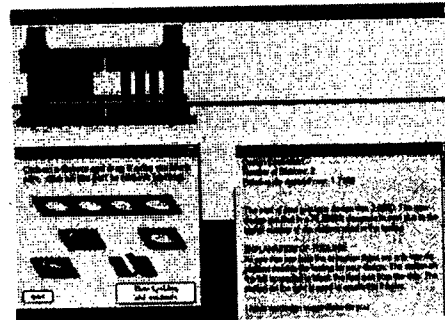


FIGURE 5

THE STUDENT CHANGES THE DESIGN (BOTTOM LEFT) BASED ON SUGGESTIONS SHOWN IN FIG. 4. THE TUTOR PROVIDES A NEW SOLUTION (TOP)

forged and stamped parts. Another objective was to enable the student to visualize the tooling needed to produce these same geometries *and* to learn with understanding. In the case of the Strip Layout Tutor, the objectives were different. Evaluation results of the Stamping Tutor indicated that students had difficulty in visualizing and determining the sequence of operations needed to produce a part. Thus, the Strip Layout Tutor supplemented the Stamping Tutor and provided students with a less visually demanding, more structured approach for determining the relationship between part geometry and the sequence of operations needed to produce the part. The Rotation Tutor also had different learning objectives: to support a student to infer three-dimensional rotation and to apply that rotation to a second object.

Packaging for Learning

The tutors were divided into two distinct modules: an *Introduction* and a *Workshop*. The first module introduced the user to a particular manufacturing process via a series of screens that contain text, animations, quick times, and voice-overs. The emphasis was to present the relationship between part geometry and the ease or difficulty of constructing the dies (tooling) required to produce the part. All *Introductions* began with a short video clip of the process (Figure 1) followed by an animation of the same equipment shown in the video (Figure 2). The animation was typically a sectional view of a simplified version of the tooling demonstrated in the video clip, so students could see and understand what was occurring internally as the machine created a part. Text and optional voice-over explained the activities in detail.

As explained earlier, authors should avoid 'tyranny of the button.' However, there are situations when this rule does not apply. The *Introduction* necessarily resorted to frame-based presentations because the vast majority of students have no prior knowledge of these manufacturing processes. Attempts to make the *Introduction* more flexible led to confusion and misunderstanding. In other words, it seemed to prohibit learning with understanding. Thus, in the case of the *Introduction* we intentionally failed to follow our own advice and forced the user to proceed in a sequential manner. In the *Workshop*, however, students interacted with and reasoned about the design issues.

The *Introduction* continued with an overview of the process using QuickTime movies and animations, and a description of the equipment. A more detailed discussion of the relationship between part geometry and the difficulty of producing the required tooling then followed. Again a combination of text, graphics (still and animated) and voice-over were used. The final portion summarized the various design for manufacturing (DFM) issues for each process. In the case of injection molding and die casting the issues include which part geometry results in the presence of costly-to-produce external and/or internal undercuts. In forging, the issues include choice of material, presence of tall thin ribs and/or closely

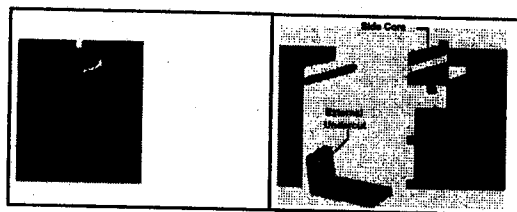


FIGURE 6

INJECTION MOLDING TOOLING FOR AN L-BRACKET WITH AN EXTERNAL UNDERCUT. TEXT AND VOICE EXPLAIN THE RELATIONSHIP BETWEEN PART GEOMETRY, MOLD CLOSURE DIRECTION AND PARTING SURFACE LOCATIONS AS WELL AS THE USE OF SIDE CORES TO CREATE EXTERNAL UNDERCUTS

spaced ribs that could result in both increased tooling and processing costs. For stamping, the issues include the number of distinct features, whether the features are closely spaced or not, whether narrow cutouts and projections are present, the number of stages required to bend the part. The issues covered in the *Introduction* were presented in a sequential order to force the user to learn in an organized manner. Figure 6 shows a snapshot version of one of the animations used to illustrate the effect of mold closure direction and geometry on an injection molding and/or die casting.

The Rotation Tutor is slightly different in that it deals with visualization. The *Introduction* covered the concepts of 3-dimensional rotation of complex shapes. The tutor started with simple shapes (e.g., a few edges and protrusions) and rotations (e.g., a few degrees and axes of rotation) and then added a variety of complexities as it continued.

Workshops enable students to determine how well they have mastered the concepts presented in the *Introduction*. In the case of the Manufacturing Tutors as well as the Strip Layout Tutor, students interacted with the *Workshop* to accomplish a design task and receive immediate feedback. Button tyranny is generally avoided and users must 'build' a part from a restricted family of part geometries and obtain a design evaluation of the part. Alternatively, students may be presented with various designs and engineering specifications and asked to determine which design best satisfies the specifications. If students 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 are descriptions of small portions of three *Workshops*.

Stamping Tutor Workshop. The design complexity of a part affects the cost of the tooling required to manufacture it. The student designs a part and the tutor, using an expert system, generates a solution tooling to manufacture the student's part. As seen in Figures 4-5, the *Workshop* includes design, tooling and evaluation windows. The student creates a part by clicking in the bottom left window on one of the features (hole, rib, emboss, or extruded hole) and drags it onto the metal strip. In Figure 4, she has designed a part with four distinct features. If she recalls the DFM results summarized in the introduction, she will realize that five stations will be required to produce the part. She can verify this by clicking on the "show tooling and evaluate" button and the required tooling is automatically generated and animated (top window, Figures 4-5). Evaluations of the design, the relative tooling cost for this design, and a redesign suggestion are contained in the evaluation window, bottom right. Figure 5 shows the result of creating a strip with four

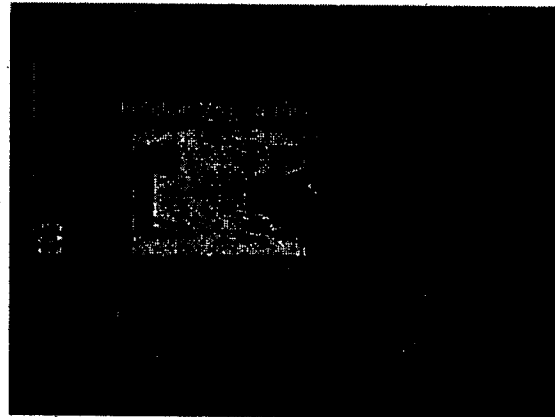


FIGURE 7

INJECTION MOLDING TUTOR: THE STUDENT CREATES A BOX (RIGHT WINDOW) AND ADDS SEVERAL FEATURES USING THE PALLET (LEFT). THE TUTOR SHOWS AN ANIMATION OF THE TOOLING REQUIRED TO MANUFACTURE THE PART (CENTER WINDOW)

identical features, as suggested by the evaluation window in Figure 4. Although the student 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.

Injection Molding Workshop. The Injection Molding Workshop enables a student to design a part (Figure 7) and to observe how easy or difficult it will be to manufacture that part, based on a discussion of issues in the *Introduction*, Figure 6. The student constructs and examines various L-bracket and box designs, by adding features such as bosses, holes and ribs to a basic L-bracket and box (parts menu, left side Figure 7). After completing the introductory module the student should understand whether or not each of the proposed part designs are difficult to mold and why. Clicking on the critic button (bottom, Figure 7) provides advice concerning the students' proposed design, critiques of the design, advice about relative costs and alternative design choices to save money. It also provides an animated illustration of the tooling required to produce the part via injection molding.

Rotation Tutor Workshop. The Rotation Tutor dynamically adapts 3-dimensional rotation problems to a user's skill level [30]. We first measured the complexity of rotation tasks, developed an organized knowledge base and associated 3-D rotations with user skills. The rotation characteristics differentiated objects that were easy to rotate from those that were hard to rotate and various subskills were identified that govern student performance. The Tutor uses a complexity metric to assess a student's ability in real time and generates appropriate new problems. It tracks the student while she infers the rotation of an object, Figure 8, and clicks on features of the required rotation (e.g., orthogonal axes, direction clockwise (C) or counter-clockwise (CW), and number of degrees (90, 180, or 270)). The Tutor contained significant intelligence in the form of an expert system designed to generate problems dynamically. Based on the student's current skill values, e.g., complexity of the object and rotation, the tutor isolated the "weakest-link" and targeted new problems for that area. The expert system queued multiple related problems and kept track of recent problems to avoid redundancy and boredom. Graduation or remediation levels were adjusted dynamically based on the student's performance. Students who struggled were allowed to "graduate" at a lower value or were offered remediation sooner, while stronger students were pushed to graduate at a higher score and remediation was delayed.

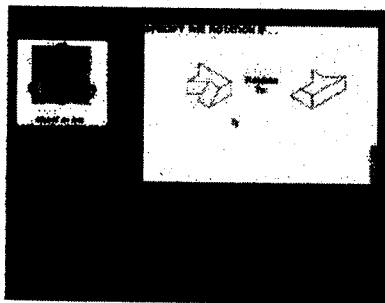


FIGURE 8A
THE TUTOR PROVIDES TWO VIEWS OF AN OBJECT (RIGHT) AND THE STUDENT IDENTIFIES FEATURES OF THE ROTATION BY CLICKING (LEFT), FIGURE 8B

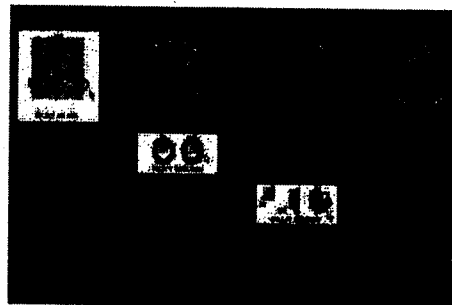


FIGURE 8B
THE STUDENT CLICKS FEATURES OF THE INFERRED ROTATIONS, INCLUDING ORTHOGONAL AXES, DIRECTION CLOCKWISE (C) OR COUNTERCLOCKWISE (CW) AND NUMBER OF DEGREES (90, 180, OR 270)

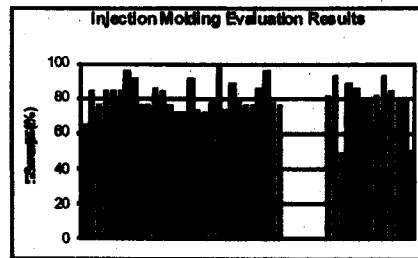


FIGURE 9
INJECTION MOLDING EVALUATION FOR THE JUNIOR CLASS. THE SCORES ON THE LEFT (RIGHT) REPRESENT STUDENTS WITH (NO) PREVIOUS EXPOSURE TO INJECTION MOLDING

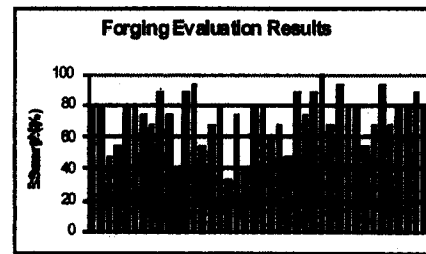


FIGURE 10
RESULTS OF THE FORGING EVALUATION FOR THE JUNIOR CLASS

Selection of Multimedia Tools

We used interactive multimedia authoring tools (Director), 3-D modeling software (Infini-D and Animation Master), and Web animation software (Flash) to build the Manufacturing Tutors. The "brains" behind the workshops were the critic objects that encoded the DFM methodologies and rules. The critic object retrieved the necessary part design information to produce and output a critique for each student. Definitions and examples were obtained via the built-in help in the workshop. A session object was in charge of running all the major objects in the workshop such as the 3-D window, design window, and the control panel.

Several methods were used to customize the response to the student's actions. The tutor might *calculate* the response, based on the student's design or *store* all possible responses. The Stamping Tutor *calculated* the stations needed for each student design and constructed the animations shown in Figures 4 and 5 dynamically. The Injection Molding Tutor *stored* a library of 164 L-bracket designs and 48 box designs in response to the student design. In order to prevent the workshop from becoming too large and cumbersome the following part design variables were constrained: base type, base size, feature type, feature size, feature location, mold closure direction, and parting surface location. Even with these constraints the workshop was flexible enough to incorporate all the major design for injection molding issues and design scenarios necessary for teaching all of the topics in the tutor.

EVALUATION OF THE TUTORS

Testing, assessment and software refinement are absolutely essential for producing effective and active learning tutors. All the UMass tutors have been evaluated and described elsewhere [5, 15-17]. We summarize these results below.

Design for Manufacturing Evaluation

An evaluation of the injection molding tutor was conducted in fall 1998 in both a junior engineering course dealing with manufacturing processes and design for manufacturing, as well as in an introductory freshman course. The junior course evaluation tested 42 students, of whom 29 had previously been exposed, via several lectures and homework assignments, to the injection molding process and the concepts of design for injection

molding. After using the injection molding and forging tutors for about 45 minutes, a quantitative evaluation test was administered. Figure 9 shows the results of the injection molding evaluation. The average score achieved by students who had prior experience with the concepts of design for injection molding was 80% and the average score achieved by students 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 result achieved low test scores. If these two scores are dropped, the average score by this latter group becomes 85%.

Figure 10 shows the results of the forging evaluation. These students received no classroom lectures on forging and had not been given a reading or homework problem assignment dealing with forging. The average for all students 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 can be achieved without the need for standard classroom lectures and assignments. Students completed a qualitative questionnaire dealing with each tutor. Some of the results for injection molding are shown in Tables 1 and 2. The qualitative results for forging were quite similar. It seems clear that students are overwhelmingly positive about the tutors.

Student 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

The injection molding tutor was also tested using approximately 125 freshmen 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 these two sections, referred to as the lecture-first sections, the students took the same quantitative test as the three software-first sections. The results of the tests are shown in Figures 11 and 12.

From Students with 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 with 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."

TABLE 2

SOME COMMENTS PROVIDED BY STUDENTS CONCERNING THE INJECTION MOLDING TUTOR

	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

TABLE 3

TEST SCORE SUMMARY

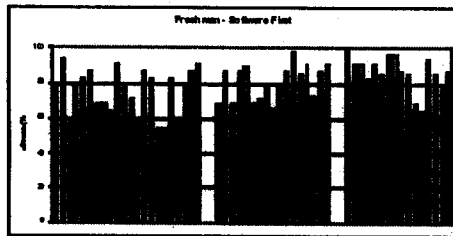


FIGURE 11

STUDENTS WHO USED ONLY THE MULTIMEDIA SOFTWARE EARNED AN AVERAGE SCORE OF 80%.

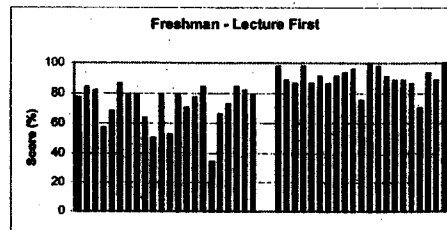


FIGURE 12

STUDENTS WHO HAD THE TRADITIONAL LECTURE APPROACH EARNED AN AVERAGE SCORE OF 81%.

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.

Rotation Tutor Evaluation

Twenty-eight participants who tested the Rotation Tutor were given several pretests to identify their visualization skill; the ten highest scoring participants were classified as "high spatial" and the ten lowest classified as "low spatial." After interacting with the tutor the participants retook a spatial skills post-test. The most interesting results were realized when comparing the ten high spatial to the ten low spatial participants. High spatial students had an average increase in score from pre to posttest of 1.10 points with the mean increasing from 35.0 to 36.1. The low spatial students had an average increase of 8.4 points with the mean increasing from 13.0 to 21.4. Using a one-way ANOVA, this result was statistically significant, $F_{(1,18)}=10.763, p < .01$.

The expert system was designed such that students with advanced spatial abilities would graduate from the tutor faster than students with lower spatial abilities. This allowed students with lower spatial skills to receive more practice and feedback during their session while, at the same time, preventing students with high spatial skills – who already have an intuitive grasp on the subject matter – from becoming bored or frustrated. The students with high spatial skills required an average of 9.7 problems to reach mastery criterion while the students with low spatial skills required an average of 17.9 problems to reach mastery criterion. This result was statistically significant, $F_{(1,18)}=6.717, p < .01$.

While the students with high spatial skills had higher overall scores (41.5 pretest; 51.5 posttest; 10.0 point change) than low spatial (37.8 pretest; 37.8 posttest; 7.2 point change), there was no significant difference between high and low spatial participants on post-test visualization score increase. This demonstrates that the additional practice the students with low spatial skills received with the tutor helped their overall scores the same amount as practice helped the students with high spatial skills.

CONCLUSION/SUMMARY

Computer-based tutors, and in particular multimedia tutoring systems, are promising tools for delivery of engineering education in a cost-effective manner. We have shown that such multimedia systems are effective when certain best practices are followed and obstacles avoided. We described the Design for Manufacturing Tutors at the University of Massachusetts, Amherst and indicated how their development followed these basic requirements and resulted in equal or better learning results than classroom learning. We demonstrated that these tutors increased teaching efficiency, meaning that they require less time to teach a single topic and achieve the same or better learning results than do several lectures, e.g., students achieve higher or equal test scores. These tutors were also effective in delivering engineering education: Students who made use of only the multimedia tutor were as knowledgeable as those who had the advantage of being exposed to a domain expert. Students were overwhelmingly positive about these tutors; they liked the software, believed that it helped them better understand the complex tooling and tested at a level equivalent to that of students who had several lectures and several homework assignments.

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