Woolf, B., C. Poli, and I. Grosse, Multimedia Systems and Intelligent Tutors for Teaching Design for Manufacturing. *1997 Frontiers in Education Conference,* Pittsburgh, PA, Nov. 1997.

Multimedia Systems and Intelligent Tutors for Teaching Design for Manufacturing

Beverly Park Woolf,* Corrado Poli,† Ian Grosse†,

* Center for Knowledge Communication
Department of Computer Science

† Department of Mechanical and Industrial Engineering
College of Engineering
University of Massachusetts, Amherst, MA 01003
bev@cs.umass.edu, {poli/grosse}@ecs.umass.edu

Abstract – *Our group has built Design for Manufacturing computer modules which instruct students on efficient procedures for designing parts for manufacture across the curriculum. The goal is to assist engineering students to gain a deeper understanding of the interaction between features of a part being designed and the corresponding manufacturing requirements of the part in injection molding, sheet metal stamping, and finite element analysis. Animated sequences of the processes are either generated dynamnically or indexed according to the possible designs. Students create designs, and the tooling complexity is demonstrated through both 2D and 3D animations. An underlying internal representation of the part being designed provides a non-intrusive critique mechanism to provide feedback to the student.*

Problems and Proposed Solution

We have developed computer systems which incorporate manufacturing education across the curriculum, addressing the scarcity of manufacturing-oriented engineering professionals and the increasing specialization of faculty. Intelligent tutors and multimedia systems provide students with an opportunity to work on simulated manufacturing projects. The objective is to improve a student's ability to address design problems and to view different manufacturing practices in the context of specific theme processes which are used recurrently throughout the curriculum.

The primary manufacturing problem lies in the sequential mode of manufacturing operation which begins with the conception of an idea for a new product and the subsequent and often isolated process of the design, engineering, and analysis operations. Manufacturing engineers only see the detailed and production drawings after these early steps are accomplished in isolation. The problems are: nearly 70% of the manufacturing cost of a product is determined at the early conceptual stages of design and yet manufacturing is not involved during these early stages; and no single person or group is in charge.

At present, the educational systems provide several features: teach design for manufacturing (DFM) at the early stage in the design process; provide students and faculty with a realistic understanding of manufacturing processes; identify a set of best practices in design for manufacturing; and state-of-the-art Web-based learning environments.

Funded by NSF Engineering Educational and Centers Division Grant No. EEC-9410393 through the Engineering Academy of Southern New England (the Academy), three tutors have been built in addition to an easy-to-search-and-find Web-based information system to enhance a student's access to professional level design-related information.

Intelligent Tutors

The Intelligent Tutors address topics such as Injection Molding, Stamping, and Finite Element Analysis. They constrain students' design choices, provide straightforward feedback and show a library of visualizations produced by commercial off the shelf systems. The power of the tutors comes from three sources: students interact with content to accomplish a design task; tutors provide immediate feedback (unlike handed-in assignments); and 3-D visualizations supply intuition behind complex geometric problems.

Injection Molding Tutor

The Injection Molding Tutor enables students to construct and examine molded polymer part designs, adding features such as bosses, `thru' holes and tabs. The Tutor provides an animated 3D tooling solution for the student's design, critiques the design, advises about relative cost, and proposes alternative designs to save money. It constrains the students' design choices, provides straightforward feedback and shows a library of visualizations produced by commercial off-the-shelf systems.

The Tutor shows an animation of an injection molding machine along with a simple open/shut mold, see Figure 1. The student then creates new designs, using either an "L-braket" or a box as the base, see Figure 2. The student selects features to add and then defines the mold closure direction. The Tutor then critiques the student's design and a color animation of tooling that would be required to produce the part design is displayed.

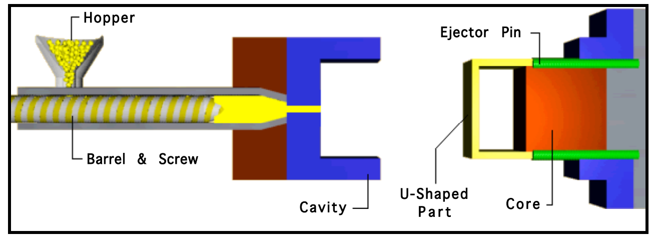
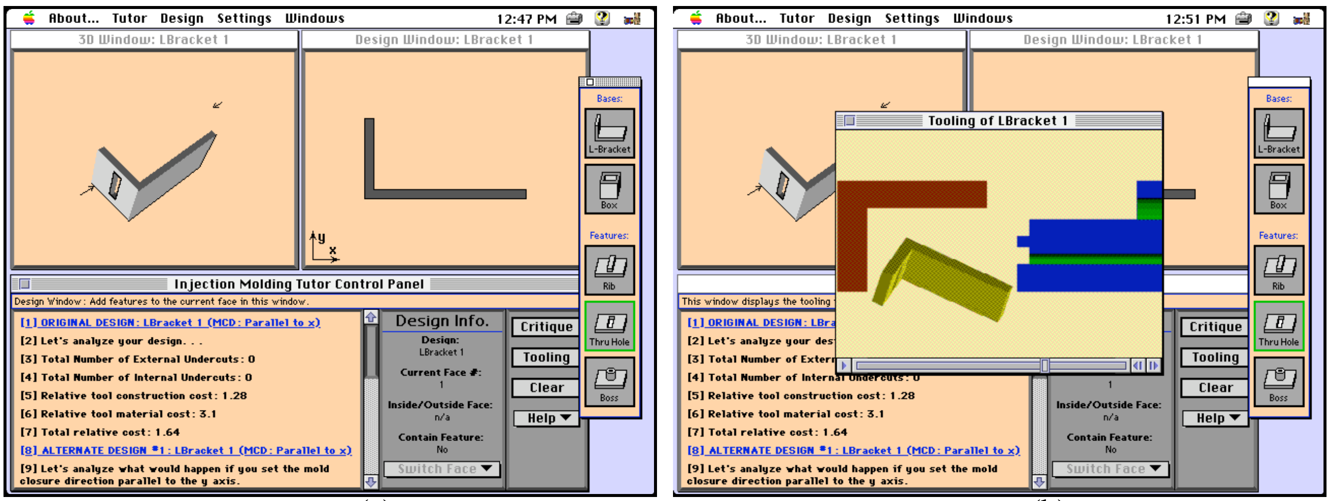


Figure 1. *Injection Molding tooling required to produce a simple U-shaped part.*



(a) (b)

Figure 2. *Critique (a) and tooling animation (b) for an L-bracket.*

Stamping Tutor

The Stamping Tutor helps a student understand the relationship between sheet metal part design and required stamping stations. The Tutor identifies design issues including: dissimilar features, closely spaced features, narrow cutouts and projections and bends. It demonstrates how many stamping stations are needed for each design through both 2D and 3D animations. Then the student designs a part within an interactive environment, see Figure 3. Using an underlying internal representation of rules, the Tutor dynamically generates an animation of the proper number of moving stamping stations required to build the part, see Figure 4. The Tutor also provides a non-intrusive critique explaining why the features chosen may result in an inefficient design. Currently, a cross-platform introduction, an interactive tutor, and 3D animations of stamping processes are available for distribution.

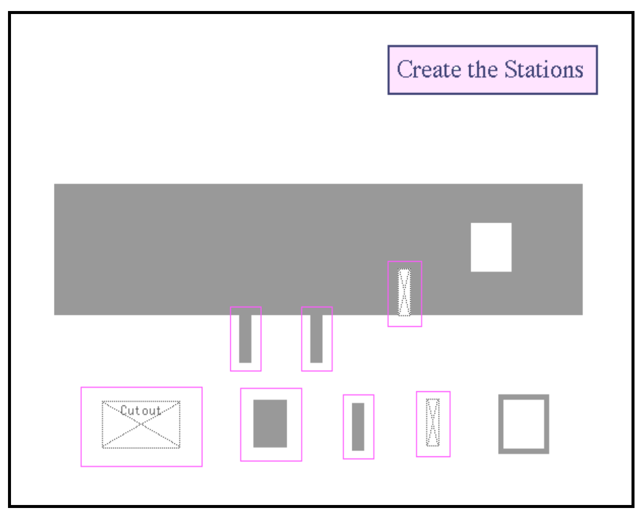


Figure 3. *Students use an interactive environment to design a stamped part, moving cut outs, through holes, and thin or narrow projections onto a blank metal part.*

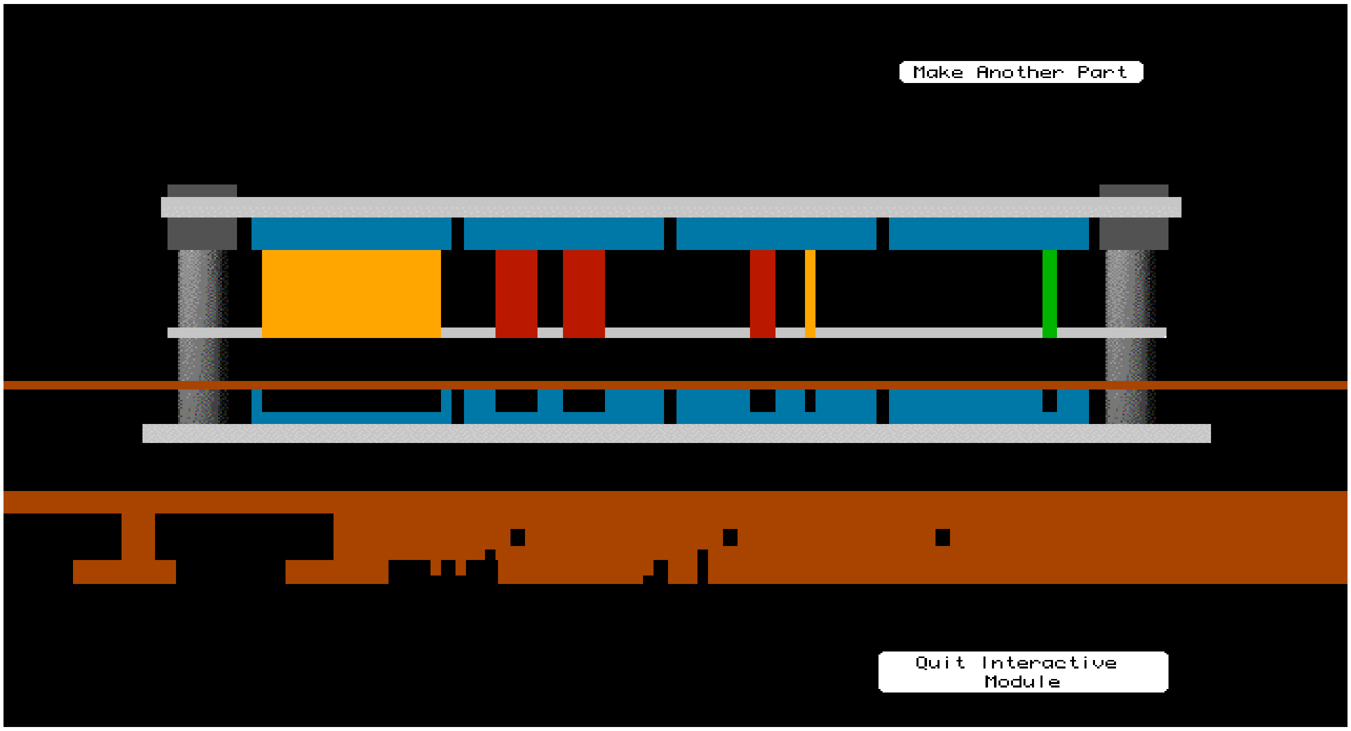


Figure 4. *The tutor reasons about the student's design in Figure 3 and produces an animation of the four stamping stations required to make the student's part.*

Finite Element Analysis Tutor

The FEA Tutor improves the ability of undergraduate mechanical and civil engineering students to address real-world design problems which are typically analyzed using computer-based finite element analysis (FEA) tools. The Tutor illustrates how complex physical systems can be transformed into simple representations and highlights when FEA should and should not be used.

This self-standing, Windows-based intelligent interactive software program teaches the basic principles, concepts and guidelines involved in finite element analysis. The Tutor describes FEA, identifies when it should and should not be used, illustrates the concepts of modeling and analysis and then articulates the process of proceeding from a real-world problem to a solution through modeling, discretization, analysis and results interpretation. Several physical objects are provided and students are asked to identify the symmetry, see Figure 5.

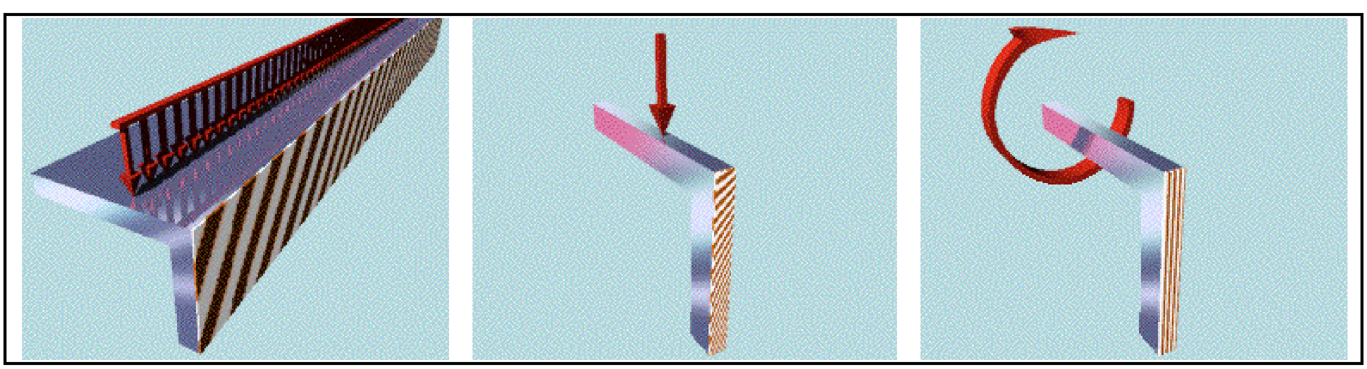
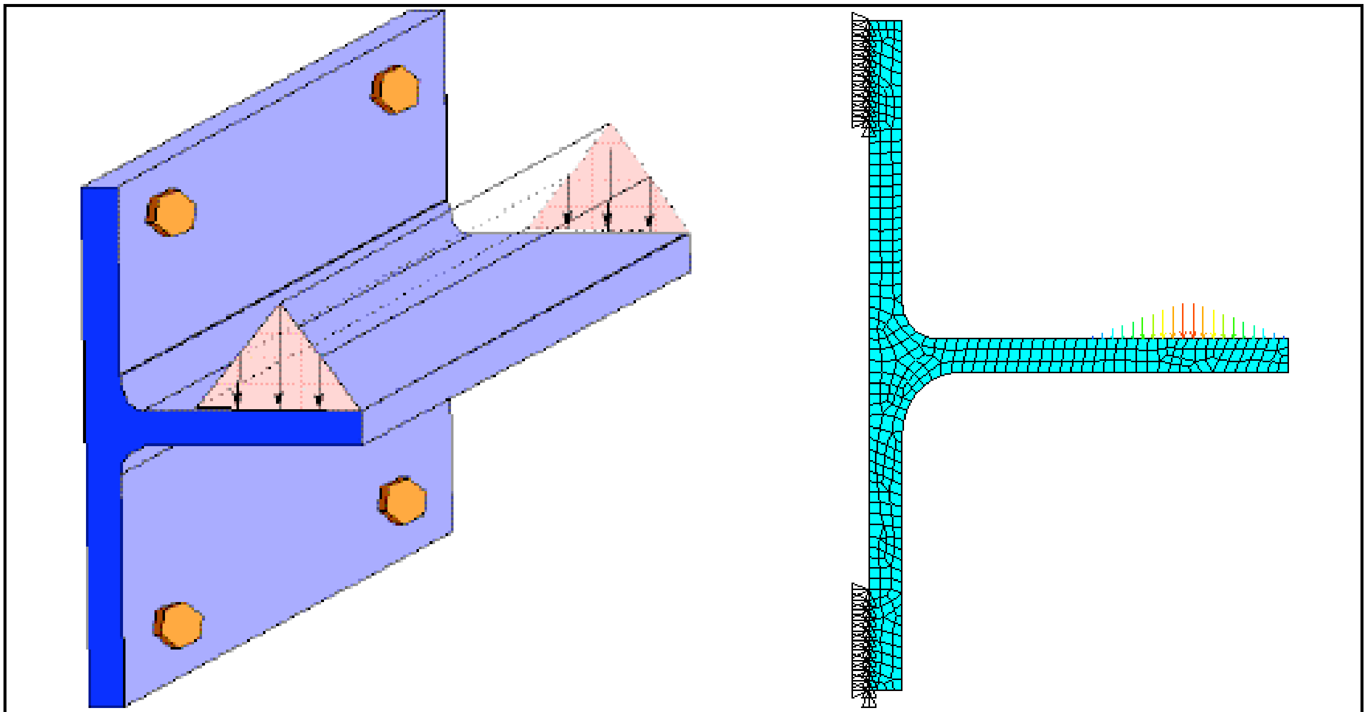


Figure 5. *The FEA Tutor teaches the basic concepts of model symmetry, load and boundary conditions and dimensional symmetry, including axisymmetry, plane stress and plane strain, and feature elimination.*



(a) (b)

***Figure 6.** The Tutor presents a student with predefined model (a), load and boundary conditions and ask for the necessary level of mesh refinement required (b).*

Another part of the tutor teaches that modeling is the cognitive process of transforming a complex physical system to a simplified representation and when to make modeling simplifications. The discretization module teaches basic element and node concepts and discretization. The finite element solution is an approximate one. Since discretization is closely coupled to the concept of convergence, both of these concepts are taught in this module.

It presents a predefined model, loads, and boundary conditions and asks the student to determine the necessary level of mesh refinement required for the solution of interest (i.e. maximum deflection or stress) to converge to within a specific tolerance of the exact solution (see Figure 6). Results for all possible mesh refinement levels are stored in the Tutor database. The Tutor plots the solution item of interest versus mesh refinement level in a window, as well as the estimated cost of each analysis and the cumulative analysis costs. The student is critiqued based on the total analysis costs and mesh refinement level the student believes is necessary for convergence.

Real-world problems, such as a long pipe under internal pressure and the shrink fitting of a collar onto a shaft, are animated to give the student a very visual representation of the lesson material. At the end of the modeling component, an experiential module challenges the student to construct appropriate simplified models for a number of analysis problems. If the student has failed several times in a row, the system responds with the correct model and the reason why this model is the most appropriate.

The tutors described above have been demonstrated to over a hundred engineering faculty at more than twenty national and international conferences. All tutors, with the exception of the experiential part of the Injection Molding Tutor, run on both Windows-based or Macintosh computers. The first tutor has been pressed to CD-ROM and is available on the Web at http://www.ecs.umass.edu/mie/dfm/imm.html.

The Web-Based Engineering Library (EDLIB)

A prototype Web-based electronic design library, termed EDLIB[1], has been developed to support student design project activities in engineering. The primary objective is to facilitate the ability of undergraduate engineering students to engage in realistic (i.e. real-world) design projects by providing on-line access to a variety of design

1 http://www.ecs.umass.edu/mie/labs/mda/dlib.html

and manufacturing information resources available to practitioners in industry, as well as access to Internet resources that are increasingly becoming available. Thus, a wealth of archival design and manufacturing information is offered by EDLIB, including material property databases, codes and standards, vendor part catalogues, scanned images, etc. A secondary objective of the library is to strengthen the students' knowledge of design procedures, design methodologies and manufacturing processes, particularly large-production-volume processes responsible for most consumer products. Thus, the library includes small example problems, designs for injection molding, casting, and stamping, assembly guidelines, and graphical illustrations of manufacturing processes. A final objective of the library is to improve students' ability to communicate. Examples of good student design projects and project presentations were also put on-line in the library.

The EDLIB provides easy-to-search-and-find Web-based information to enhance a student's accessibility to professional level design-related information. It also provides self-contained multimedia tutorial modules to reinforce design and manufacturing fundamentals. The information relates to the manufacture, general process and laboratory uses of industrial products.

Evaluations

We have demonstrated, based on a formative evaluation of the Injection Molding Tutor at UConn and UMass/Amherst, that these systems can be as effective as several lectures and homework assignments within a traditional classroom setting. For example, three groups of students were tested, those using only the Tutor, only lectures and both. The objective was to determine whether or not the students who used the Tutor had truly understood the relationship between part geometry and tool construction difficulty. The results indicate that the students who made use of only the multimedia Tutor presentation were as knowledgeable about the relationship of part geometry and tool construction difficulty as those who had the advantage of being exposed to a domain expert.

We intend to evaluate the other systems in order to provide guidance to authors for development of new and augmented systems. Evaluation efforts include:

- Formative evaluation of the Stamping and FEA Tutors to eliminate bugs, improve user interfaces and increase teaching effectiveness.
- Evaluation of tutors to measure improvement in students' ability to make better quality designs. The intent is to show higher test scores, retention and progression to graduation, improved teaching efficiency, improved intellectual skills and reduced time to teach a single design topic.
- Summative evaluation to test the hypothesis that students using only the multimedia presentation can be as knowledgeable about the relationship between design features and manufacturing cost station as those who have the advantage of being exposed to a domain expert.
- Formative evaluation of EDLIB to help authors assess and modify each module and determine how students use Wed-based design related information. Evaluation will measure how students retrieve and assimilate design related materials, review course materials and assess informal learning as students acquire knowledge not necessarily included in the web page itself but relevant to design issues.
- Summative evaluation of EDLIB to measure student self-efficacy as well as the design library's ability to empower students and improve their proficiency in solving design problems. Students will be evaluated as they document, display, critique and learn from information.

Future Work

Future multimedia efforts include development, evaluation and dissemination of tutors and multimedia systems. Two remaining tutor components of the FEA tutor are still under development: a singularity tutor module and the analysis tutor module. The singularity module will teach the student the fact that modeling idealizations often result in singularities in the finite element solution. The analysis part of the tutor will teach basic analysis concepts, such as bandedness of the system equations, Gaussian quadrature, and ill-conditioning.

Future work with the EDLIB includes moving it to the next level of intelligence by building interactive and intelligent learning modules and creating an active learning center with a rich design knowledge database and modules covering topics such as product design, design for manufacturing, process design and human factors.