

A Multimedia Application for Teaching Design for Manufacturing

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Abstract

This paper describes the development process and requirements of a multimedia engineering tutor as well as the specific development of a multimedia injection molding tutor at the University of Massachusetts Amherst. The injection molding tutor is beneficial to any user that has little or no previous knowledge of injection molding and design for injection molding.

I. Introduction

There has been a growing drive to incorporate more manufacturing into the engineering curriculums across the United States. With this drive there has been a need for developing better teaching tools to aid in teaching the vast spectrum of manufacturing processes in as efficient a manner as possible. Due to the fact that many engineering concepts are difficult to understand, tools that go beyond simple classroom lecture and textbook work are starting to be developed.

Incorporating design for manufacturing (DFM) methodologies into the undergraduate curriculum at the University of Massachusetts (UMASS) Amherst has been one of the attempts used to introduce students to both product design as well as product manufacturing. At UMASS Amherst an interactive multimedia tutor specifically for teaching design for injection molding has been developed. The purpose of the Injection Molding Tutor (IMT) is to assist the user, a student or anyone not familiar with the manufacturing process of injection molding, in understanding the relationship between part design and the ease or difficulty of producing the part.

The injection molding tutor is divided into two distinct modules, an Introduction Module and an Experiential Module. In the former module the user is introduced to the injection molding process via a series of screens that contain both text and animations. The emphasis in the introductory module 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 module provides the user with the opportunity to determine how well they have learned/absorbed the concepts presented in the first module. In this module the user is allowed to design and 'build' a part from a rather restricted family of part geometries. If the user has understood the concepts presented in the first module, they should be able to design easy to mold parts and/or understand why the parts they have designed are difficult to mold. In the second module the user is able to obtain advice concerning their proposed design and to obtain an animated illustration of the

tooling required to produce the part via injection molding. The purpose of this paper is to describe the requirements of a multimedia design for manufacturing tutor as well as the specific development and valuable experiences encountered during the development of the IMT.

II. EASNE and Related Work

Many academic programs have recently developed new curriculums that attempt to integrate more manufacturing into their engineering classes realizing that manufacturing and design are highly interdependent and that they should be integrated [1,2,3,4,5,6]. Several of these programs have received financial support from the Technology Reinvestment Project (TRP) which was initiated in 1992 to develop education and training programs that enhance U.S. manufacturing skills.

The Engineering Academy of Southern New England (EASNE) is one of the coalitions receiving financial support from the TRP for its “activities that would improve the general state of the U.S. competitiveness and productivity and provide a high-quality work force for the 21st century” [7]. EASNE is a coalition composed of industrial and educational participants. The primary educational participants are the University of Connecticut (UCONN), UMASS Amherst, UMASS Lowell, and the University of Rhode Island. Among several goals laid out by EASNE are [7]:

- To integrate manufacturing concepts in the freshman year and throughout the entire undergraduate program for all engineering disciplines.
- To develop design for manufacturing and open-ended integrated product/process development case studies.
- To develop novel engineering design and manufacturing modules, cooperatively developed and shared across EASNE institutions.
- To emphasize student teamwork and communication skills in engineering projects.

To help accomplish these objectives in part, the Mechanical and Industrial Engineering Department at UMASS Amherst has developed a new freshman engineering course entitled, “Introduction to Engineering Communication Skills and Design for Manufacturing” which is explained in greater detail in [6]. The main objective of the freshman course is to teach students how to effectively communicate in a group/industrial environment. In order to teach freshman engineers communication skills and to provide the semester with some continuity the course is centered around a semester long design for manufacturing and assembly (DFM/A) project. This semester long project is centered around the redesign of a consumer product.

To assist in teaching the students some of the DFM principles required to complete their projects, several design for manufacturing multimedia software tutors have been and are being developed. In addition to aiding freshmen, these modules also help to fulfill EASNE’s third goal of developing novel engineering design and manufacturing modules, cooperatively developed and shared across the EASNE institutions. The first manufacturing multimedia tool to be finished was the Injection Molding Tutor (IMT). The tutor is an interactive multimedia software tutor that provides the user with part design rules and methodologies specifically with the manufacturing process of injection molding in mind. The IMT was tested during the course of its development on freshmen at both UMass Amherst and UConn. Since the completion of the IMT in August of 1996 the tutor is now being distributed and evaluated at other EASNE schools and will be

followed by additional distributions to other educational and industrial contacts who will benefit from its use.

III. Design for Manufacturing and the Engineering Tutor

Many of the specialized parts in consumer products are produced by injection molding, die casting, and stamping. Due to this fact, it is efficient to focus on these three manufacturing processes and to teach students design methodologies that help them reduce part costs. In all three of these manufacturing processes when production volumes are low, less than 100,000, the largest factor that contributes to the total part cost is the tooling cost. Even for high production volumes designers have the ability to quantitatively analyze the die cost at very early stages of design. The DFM methodologies used emphasize the relationship and effect of part geometry on tooling complexity and provide students with a tool for quantitatively evaluating the impact of their proposed design on manufacturing difficulty. Increased tooling complexity drives up tool construction cost which ultimately increases total part cost. It can clearly be seen that DFM is beneficial to designers for reducing product costs at the early stages of design.

It is very difficult for students, faculty, or others unfamiliar with these processes to visualize the tooling necessary to produce an injection molded, die cast, or stamped component. Likewise, it is very difficult to convey through pictures in a book, sufficient information about the molds and dies used in injection molding, die casting, and stamping. Mechanical drawing which used to be an integral part of engineering programs has been reduced to a minimum and in some programs even eliminated. For students and faculty this has led to a decreased ability in spatial reasoning and has led to a difficulty in looking at a drawing and visualizing what it represents. Many engineering faculty also lack specialization or expertise in manufacturing processes or DFM so teaching a class in DFM can be very intimidating. One possible solution would be to maintain a large inventory of both parts and the actual dies (tooling) used to produce the parts. These parts could be selected to illustrate all the important concepts that one would like to teach. However, this would be quite inefficient and costly to house and maintain the parts and dies. For the same reason it is also impractical to have students design and fabricate a product over a semester long project. It would be too costly and time consuming to fabricate the dies and to maintain the machines. Field trips to local companies would be beneficial but would be too time consuming and would not allow the student to be exposed to either the tooling's internal parts or for that matter what is happening inside a mold when the machine is actually running.

An alternate, more feasible solution is to develop a multimedia package that allows the limited creation of parts and which would show the user a 3-D color animation of a simplified version of the actual tooling required to produce a part. The multimedia tutor would greatly aid students and others in visualizing the tooling necessary to create a variety of parts. The tutor would also benefit faculty with little DFM knowledge by assisting them in understanding the basics of DFM and by replacing several of the classroom lectures on DFM. This reasoning led to the development of several software tutors, one on stamping, one on die casting, and the one which is the focus of this paper, injection molding.

IV. Requirements for an Engineering Tutor

There are several basic requirements that must be met before and during the creation of an engineering tutor, namely,:

- An organized knowledge domain.
- An interdisciplinary (cross functional) software development team. Expertise in manufacturing engineering, programming, and graphics are required.
- A friendly and useable user interface.

In addition, the final tutor should be self-contained and must be portable to facilitate distribution.

To even begin designing an engineering tutor there must first be an organized and well defined knowledge base for the specific manufacturing topic to be used for the tutor. In the domain of injection molding a typical injection molding handbook like the ones by Rosato [8] and Dym [9] contain an immense amount of information ranging from operating an injection molding machine, to designing an injection molding part, to designing injection molding dies, to selecting the appropriate part material. The problem with these typical handbooks is that they mostly provide qualitative rules and guidelines during early stages of design and any quantitative rules that are provided cannot be used until the parametric design stage. As a designer, it is critical to have tools which allow quantitative analysis of a design at the early stages of product design. It is necessary to have more than qualitative rules like “avoid undercuts if possible.” At the conceptual and configuration stages of design it is beneficial for designers to have the ability to quantitatively compare potential designs by obtaining an objective numerical value indicating which design is better in terms of relative cost. The design for injection molding methodologies found in [10] were selected as the main source for the tutor’s engineering domain because they provide this quantitative tool.

The design knowledge acquisition for the DFM models and methodologies used in [10] is discussed extensively in [11]. “The models used group-technology to develop coding and classification systems that consistently and systematically analyze component part designs by accessing databases of relative costs” [11]. As discussed in [11] the databases of relative costs were developed in conjunction with industry experts and were obtained by statistically analyzing data collected from industry. Experts from industry helped refine the model by pinpointing factors that drive cost. The model building was an iterative process of data collection and model refinement. The results from industry confirmed that all pertinent cost drivers had been identified and included in the final model.

During the planning stage for the injection molding tutor it was envisioned that a balance of engineering knowledge, programming, sound, text, and graphics would be used to produce the final tutor. With so many requirements involved it was necessary to create an interdisciplinary team capable of handling the many tasks required to produce a multimedia engineering tutor. It is critical and essential that a domain expert closely monitor and participate in the development of the tutor. It is necessary for the domain expert to ensure that the engineering knowledge is included and not lost from various programming styles. The experience from developing the injection molding tutor showed that a programmer/computer science student generally has no interest in or desire to learn the engineering knowledge that is contained in an engineering tutor. A computer programmer often has a totally different objective, possibly the efficiency or style of the actual code, and therefore focuses on things that may or may not contribute to achieving the engineering goal. By having an engineering domain expert who understands and is interested in

the engineering knowledge contained in the tutor participate as a programmer, the project can be guided more swiftly towards its engineering education goals. It is normally much more difficult to teach a non-engineer all the manufacturing and design knowledge required in a tutor than it is to teach an engineer, who already has some basic background in programming, a new programming environment. It is still very beneficial, however, to have a programming expert who is aware of the limits of what can and cannot be done within the selected programming environment. Lastly, it is necessary to have the resources for creating high quality graphics and the ability to integrate them seamlessly into the tutor. The work force for the engineering tutor was achieved through a collaborative effort between faculty and students from the Mechanical and Industrial Engineering Department and the Computer Science Department of the University of Massachusetts Amherst.

Much time needs to be spent mapping out and planning the user interface. Attention has to be given to menus, buttons, windows, etc. Buttons and menus should be intuitively labeled and unambiguous. It has to be decided what is the best way to represent and show designs being created by a user. In the case of the tutor discussed here it was decided that for the Experiential Module a three dimensional window showing a simply shaded wire frame part, a two dimensional window showing an orthogonal view of the part, and a window for critiquing designs would sufficiently convey design information to the user. For the Introduction Module a series of animations, text, and voice were sufficient to convey the injection molding background. Hardware constraints also need to be considered during the planning of an multimedia software tutor. The standard computer monitor on most systems is 14 inches. This can be fairly small if a tutor has many windows and objects that need to be displayed at the same time. Consideration must be given to laying out all the windows and pieces of a tutor without the monitor screen becoming too cramped, busy, and confusing. Ideally the user interface should convey information unambiguously and should be intuitive to the user.

An engineering tutor needs to be multi-platform compatible. It is essential that the tutor be developed in a programming environment that is capable of being ported to many platforms so that it can be sufficiently tested, distributed, and used. The main goal of any engineering tutor is to teach students and faculty. In order for an engineering tutor to teach anything it must be used. In the fast paced world of computer technology and the rapid introduction of new computer platforms it is crucial that an engineering tutor be capable of being used on several computer platforms so that it does not become immediately obsolete. The most common platforms at educational institutions are Windows 95, Windows 3.1, Windows NT, Macintosh OS, and Unix. Many of the new World Wide Web and internet applications need to be considered also since many of them are designed to be platform independent and will run on most systems. Major problems can be avoided when trying to distribute a tutor between departments, educational institutions, or companies if the tutor can be run on several computer platforms. Multimedia tutors also become very storage intensive requiring large memory capacities and special consideration when trying to transport the tutor. It may be necessary to create a CD-ROM, use a high capacity removable storage device, or to use a network to transfer large multimedia tutors between systems and/or institutions.

Lastly, the tutor needs 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. Being self-contained also allows faculty to learn the material quickly and efficiently without having to become domain experts in the manufacturing process presented in the tutor. This also allows them to concentrate

more on teaching the engineering communications part of the class rather than spending large amounts of time becoming an expert in many manufacturing processes.

V. Development of the Injection Molding Tutor (IMT)

The IMT is composed of two primary modules. The first module, the Injection Molding Introduction Module (IMIM), provides a short lesson and background on what injection molding is, terminology commonly used in injection molding, and design methodologies. It emphasizes the relationship between part geometry and tooling complexity through the use of a series of screens containing animations, text, and voice. The second module, the Injection Molding Experiential Module (IMEM), provides a highly interactive environment where the concepts learned in the IMIM can be applied and tested. The planning, progress, testing, and learning experiences received from the development of the IMT are covered in the following sections.

One of the first steps in developing the IMT was to decide what platform and programming environment the tutor would be developed in. Through industrial cooperation from Apple Computers, Inc. it was decided to develop the IMT in a programming environment from Apple known as SK8 (pronounced 'skate'). SK8 is an object-oriented, graphical, programming environment for the quick development and rapid prototyping of multimedia software applications. It was agreed that in exchange for the tutor team using, evaluating, and providing feedback on SK8, Apple would provide technical support in terms of hardware, programming classes, and programming support.

With the engineering domain and the programming environment selected, the initial programming started on what is now known as the Injection Molding Experiential Module (IMEM). Initially the programming talent of the tutor team was composed of two students from the Computer Science Department. With their limited knowledge and understanding of design for manufacturing and injection molding their initial goal was to develop a tutor capable of allowing the user to create an open ended number of part designs. In addition, animations of the tooling required to injection mold the user created parts would be generated on the fly. Much time was initially spent on designing the tutor in this fashion. Time was spent and focused on building the ultimate open-ended design environment (more of a computer scientist's goal) rather than on how the manufacturing engineering knowledge was to be incorporated into a tutor that could efficiently teach students and faculty (the manufacturing engineering goal).

To compliment the tutor programming team, a manufacturing engineering student was brought in to provide a better balance between the programming and engineering requirements of the project. A deeper understanding of the injection molding process and DFM methodologies allowed the project to become more focused. It was determined that the amount of programming involved to create a graphics engine capable of generating the endless combinations of tooling animations required for the user part designs would be phenomenal and unachievable in the time period for the project. To limit the total number of design combinations and tooling animations required it was decided to constrain the user in the creation of their design.

Programming on the IMEM progressed until it was felt it had reached a sufficient and stable enough stage that it could be tested on students. The first several test runs helped weed out bugs and provided feedback on the user interface and overall ease-of-use of the tutor. More testing was done on both UMass Amherst and UConn freshman engineering students to test the amount of

knowledge/information a user walked away with after using the tutor. It was found from the testing and evaluation that in order for the IMT to be a self-contained, stand alone application, sufficient injection molding background and information needed to be included. This led to the development and inclusion of the IMIM.

Once all the testing and revisions were completed, a final package was put together for distributing the IMT. To allow the IMT to be as self-sufficient as possible and to require as little set up help as possible, an instruction manual was created for running the IMT. The final IMT package includes a user’s manual and a CD-ROM. The CD-ROM includes a Macintosh OS version of the Injection Molding Experiential Module and Injection Molding Introduction Module as well as a Windows 95 version of the Injection Molding Introduction Module.

VI. Injection Molding Introduction Module

The Injection Molding Introduction Module (IMIM) was developed in Macromedia’s Director and uses a combination of text, graphics (still and animated), and voice to cover the injection molding topics outlined in Figure 1. The topics covered in the IMIM are presented in a sequential order to force the user to learn in a organized manner.

A. Introduction Injection Molding	E. Design Strategies for
B. Description of the Injection Molding Process Direction	1. Effects of Mold Closure
C. Injection Molding Part Cost Surface Location	2. Effects of Parting
1. Material Cost	3. Possible Redesign
Solutions	F. Summary
2. Processing Cost	G. Transition to Injection
3. Tooling Cost	
Molding Experiential Module	
a) Tool Construction Cost	
b) Tool Material Cost	
D. Terminology	
1. Core	
2. Cavity	
3. Ejector Pins	
4. External Undercut	
5. Side Cavity/Core	
6. Internal Undercut	
7. Form Pins	

Figure 1. Outline for the Injection Molding Introduction Module.

The IMIM starts by showing an animation of an injection molding machine along with a simple open/shut mold used to form a simple U-shaped (Figure 2). The animation is a sectional view of a simplified version of an injection molding machine. This way the user can see and understand what is happening internally as the injection molding machine creates a part.

The user is first presented with an overview of what injection molding is. For example, both text and 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.”

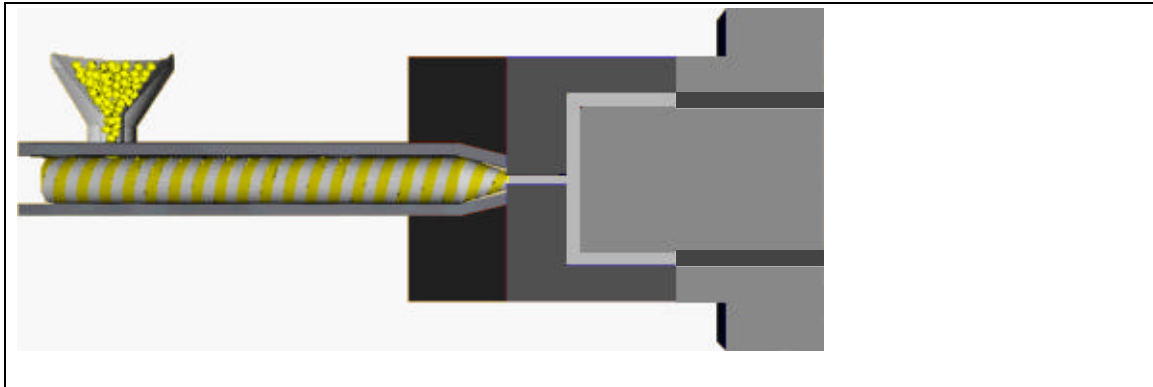


Figure 2. Injection Molding Machine in Closed Position.

The IMIM goes on to explain various terms by using specific examples of parts and tooling. Animated illustrations similar to the one shown in Figure 3 are given to describe terms such as cavities, cores, ejector pins, internal undercuts, external undercuts, etc.

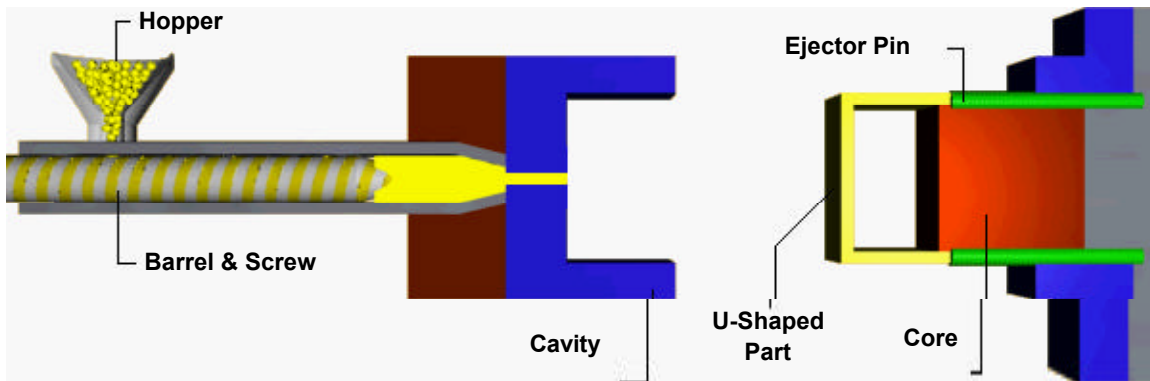


Figure 3. Injection Molding Tooling Required to Produce a Simple U-shaped Part.

As different terminology is being defined, the appropriate part of the animation being viewed is highlighted (flashes) so the user’s attention is focused on the proper area. For example, the tooling in Figure 4 has an additional moving piece known as a side core to produce the hole in the short leg of the L-bracket. As the mold opens, the side core slides along the guide pin and is raised upward which releases the hole in the L-bracket so the L-bracket can be properly ejected out of the mold. The hole in the short leg of the L-bracket is known as an external undercut since it requires a side core to produce. It is a feature that will, without special provisions, prevent the part from being extracted from the cavity half of a mold. External undercuts can be holes or depressions on the external surface of a part which are not parallel to the mold closure direction.

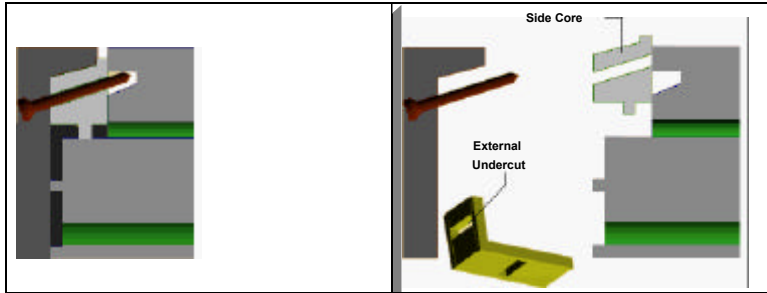


Figure 4. Injection Molding Tooling for an L-Bracket with an External Undercut.

The box (Figure 5) with two ribs on the internal face and a hollow boss on the external face requires an even more complex mold. Not only is a side cavity required to produce the hollow boss on the external surface but a very costly form pin is required to produce the internal undercut caused by the two ribs on the inside face of the box. The tooling in Figure 5 has become more difficult to visualize but the color animations used in the IMIM help the user to visualize and understand the more complex tooling.

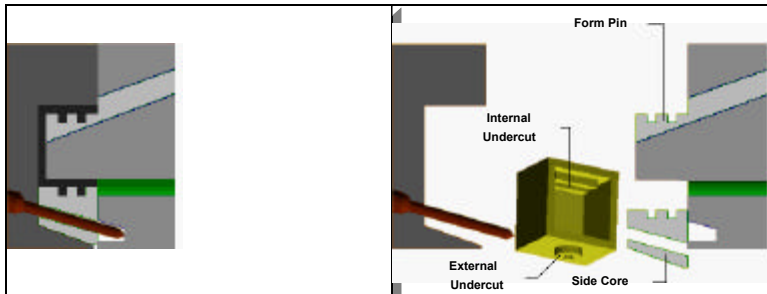


Figure 5. Injection Molding Tooling for a Box with One External Undercut and One Internal Undercut.

Once the necessary terminology has been defined and hopefully understood by the user, the IMIM goes on to present different design strategies for reducing injection molding part cost. The IMIM teaches the user that tooling cost is a function of part geometry, mold closure direction (MCD), and parting surface location (PSL). The user is taught that understanding these three factors is essential for minimizing tooling cost. Once again a series of animations is used to illustrate these facts. Figures 6, 7, and 8 are just three of the examples used in the tutor.

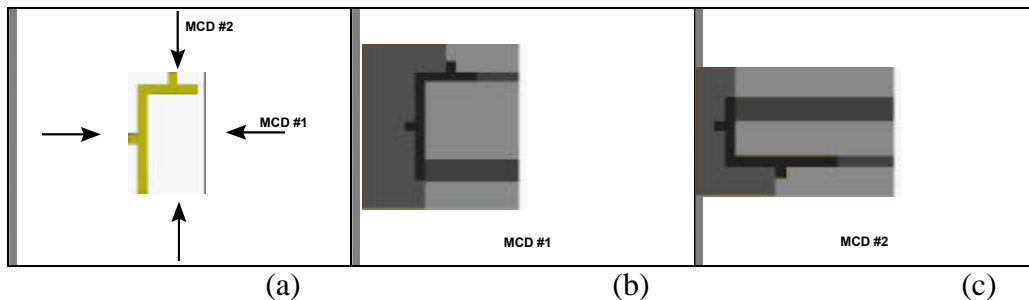


Figure 6. MCD and Tooling for an L-bracket. Changing the MCD from MCD #1 to MCD #2 does not affect cost.

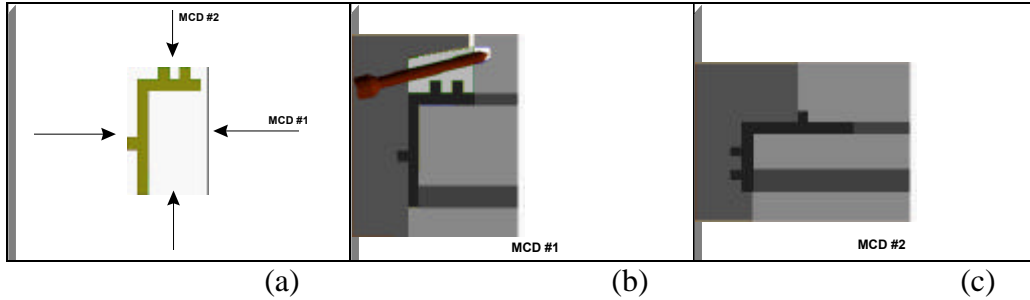


Figure 7. MCD and tooling for an L-bracket. MCD #1 requires a side cavity to create the external undercut caused by the two ribs. In MCD #2 the external undercut is eliminated and therefore the tooling costs less for the exact same part.

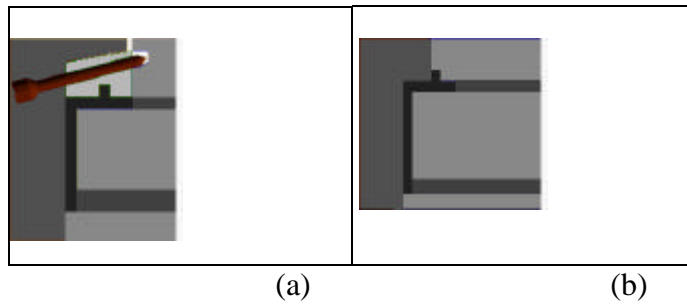


Figure 8. Effects of Parting Surface Location (PSL). The PSL chosen in (a) requires a costly side cavity. The PSL location in (b) for the exact same part eliminates the need for a side cavity and therefore costs less.

The IMIM then discusses the possibility of redesigning a proposed part design. The original part in Figure 9a would require a side core to produce the external undercut caused by the hole. A side-shutoff is used in the redesign in Figure 9b which eliminates the need for the external undercut thus reducing tooling cost.

Lastly, the IMIM gives a brief summary of what was taught throughout the introduction and then prompts the user to proceed to use the Injection Molding Experiential Module to apply what he/she has just learned in the IMIM.

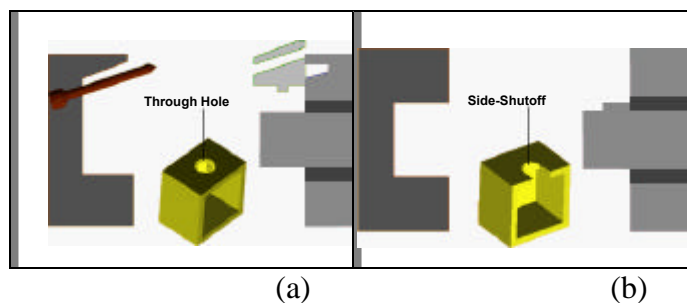


Figure 9. The through hole (a) requires a costly side core. A side-shutoff (b) is used which reduces tooling cost by eliminating the need for a side core.

VII. Injection Molding Experiential Module

Once the user completes the Introduction Module they then run the Experiential Module which helps reinforce the concepts learned in the introduction and provides real time feedback. The general organization and structure of the highly interactive Injection Molding Experiential Module (IMEM) is shown in Figure 10.

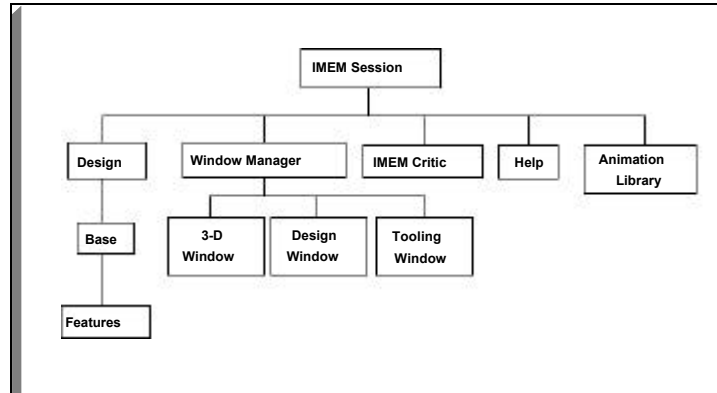


Figure 10. Essential Objects of the Injection Molding Experiential Module.

Every time a user starts the IMEM it can be thought of as a brand new sheet of paper being placed on a drafting board. A session is a programming object that is completely invisible to the user. The session object is in charge of running all the major objects in the IMEM such as the 3-D Window, Design Window, and the Injection Molding Tutor Control Panel. Since a user can have several designs open at one time the session object keeps track of all the user's designs and all their relevant design information. A single design contains information on its base, features, faces, vertices, etc.

Extensive programming efforts were put into developing the graphics engine which runs the 3-D Window. The 3-D Window displays a simply shaded 3-D part that the user has created. The Design Window was created to show the user an orthogonal view of the part being created and to allow the user to add features to the part. The Tooling Window shows the appropriate tooling animation for the current part being created.

The “brains” of the IMEM is the critic object which is visually displayed as part of the Injection Molding Tutor Control Panel. This is where all of the DFM methodologies and rules have been encoded into the software. The critic object is capable of retrieving the necessary part design information to produce and output a critique for the user. An example of a part design and its critique are shown in the next section.

If the user forgets terminology from the IMEM then they can refresh their memory with a definition and example provided by the built in help in the IMEM.

The last major part of the IMEM is the library of tooling animations. This library contains animations for the 164 L-bracket designs and the 48 box designs capable of being produced in the IMEM. In order to prevent the IMEM from becoming too large and cumbersome the following part design variables had to be constrained: base type, base size, feature type, feature size, feature location, mold closure direction, and parting surface location. Even with these

constraints the IMEM is still flexible enough to incorporate all the major design for injection molding issues and design scenarios necessary for teaching all of the topics in the IMIM.

Part design is first constrained by allowing the user to choose among two bases, either a box or an L-bracket. Next the box and L-bracket size are set to a standard size which the user has no control over. Once the user choose a base, the user is constrained to selecting among three features: a rib, a through hole, or a hollow boss. Feature location is constrained to four faces for an L-bracket (Figure 11a) and three faces for a box (Figure 11b). Features may be placed on a maximum of two faces out of the four L-bracket or three box faces. For the maximum of two faces that may contain features, each one of these faces can contain one rib, two ribs, one through hole, or one boss. Feature size and feature location within a face are standardized. It does not benefit the user to have control over these variables.

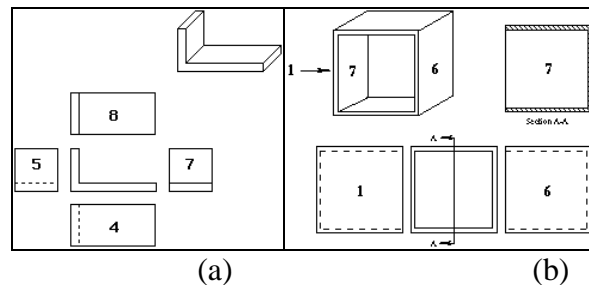


Figure 11. (a) L-Bracket Feature Locations: Only faces 4, 5, 7, and 8 may contain features. (b) Box Feature Locations: Only faces 1, 6, and 7 may contain features.

It was decided that by allowing the user to select the placement of the parting surface location (PSL) it would be infeasible to develop the tooling animations which would result from the endless number of part designs. Because of this, the user is constrained from specifying where the PSL is and it is placed in the most cost effective location. The user does have full control over setting the mold closure direction (MCD) for the part design. The MCD can be set parallel to the three major axes for the box and L-bracket as shown in Figure 12.

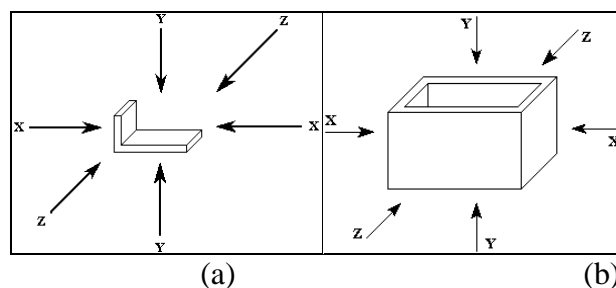


Figure 12. Allowable mold closure directions can be set parallel to the X, Y, or Z axis. (a) L-bracket MCD's. (b) Box MCD's.

The major parts of the IMEM already described combine to form an interactive design environment which provides real-time feedback (critique) to a user along with highly illustrative tooling animations to form a highly effective educational multimedia tool for teaching design for injection molding.

VIII. IMEM Part Design Example

The following example illustrates a typical scenario a user might follow when using the Experiential Module. Once the user has printed out and read the IMT Instruction Manual or has read the instructions that show up at the start of the IMEM the user will be ready to create a part design. After starting up the IMEM the first thing a user will do is to create a new design. This will bring up a new 3-D Window and Design Window as seen in Figure 13. Next, the user selects either a box or an L-bracket to use as the base for his/her part design. Figure 13a shows the user has selected an L-bracket.

Next, the user can add several features to the L-bracket. In Figure 13b the user has added a rectangular through hole to the short leg of the L-bracket by clicking on the “Thru-Hole” button.

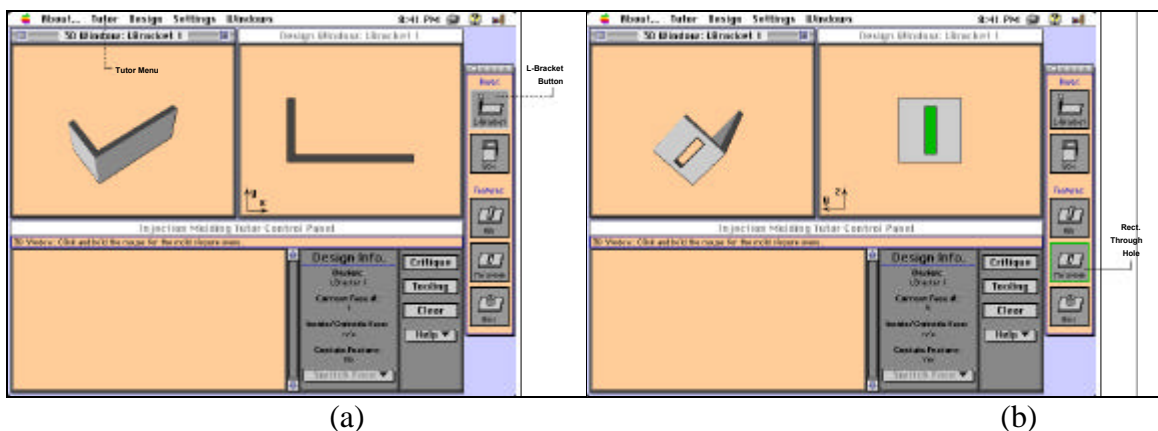


Figure 13. User creates a new design and then selects an L-bracket for the part design's base (a). The user has added a rectangular through hole to the L-bracket (b).

Once the user is satisfied with their part design they must define the mold closure direction (MCD). This is done by first clicking on the “Settings” menu and then selecting a MCD that is parallel to the X, Y, or Z axis. It can be seen by the arrows indicated in the 3-D window in Figure 14a that the user has set the MCD parallel to the Y axis.

Now that the user has sufficiently defined the part geometry and has set the MCD, the user may now have the IMEM critique their design. Hopefully, since the user will have completed the Introductory Module this critique will simply confirm what the user already knows concerning the ease or difficulty of molding the part.

The user can also view a color animation of the injection molding tooling that would be required to produce the part design created by pressing the “Tooling” button shown in Figure 14b.

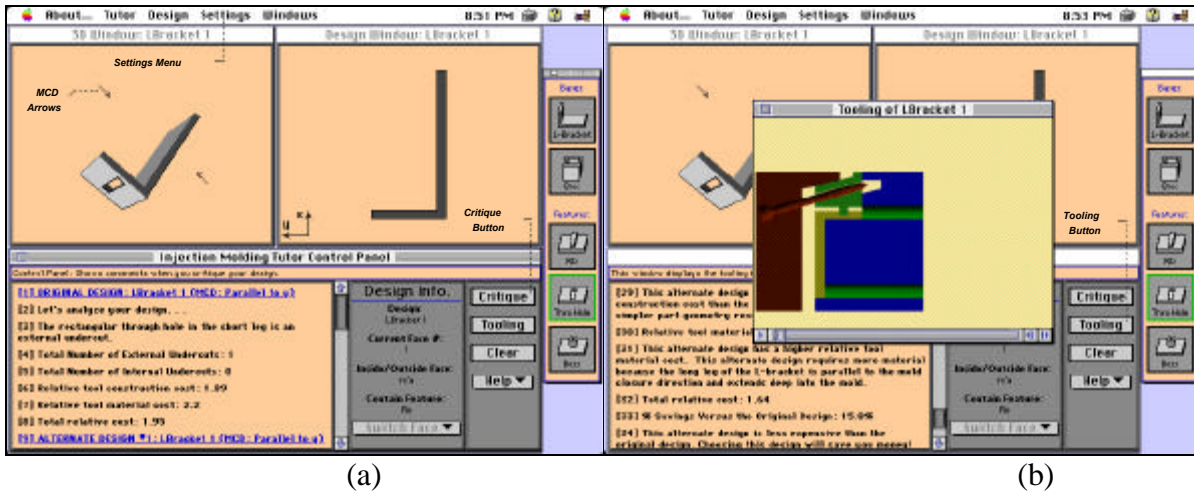


Figure 14. The user has set the mold closure direction parallel to the y-axis and critiqued the part design (a). The tooling animation for the L-bracket in (a) is shown in (b). The user should recognize that the hole is an external undercut and requires an expensive side core to produce.

The user can now analyze the effects of changing the MCD on the exact same part by setting it parallel to the X axis. Once again, the user should be able to anticipate the results of the critique and hopefully start to visualize the required tooling (Figure 15) if he/she absorbed the material presented in the introductory module.

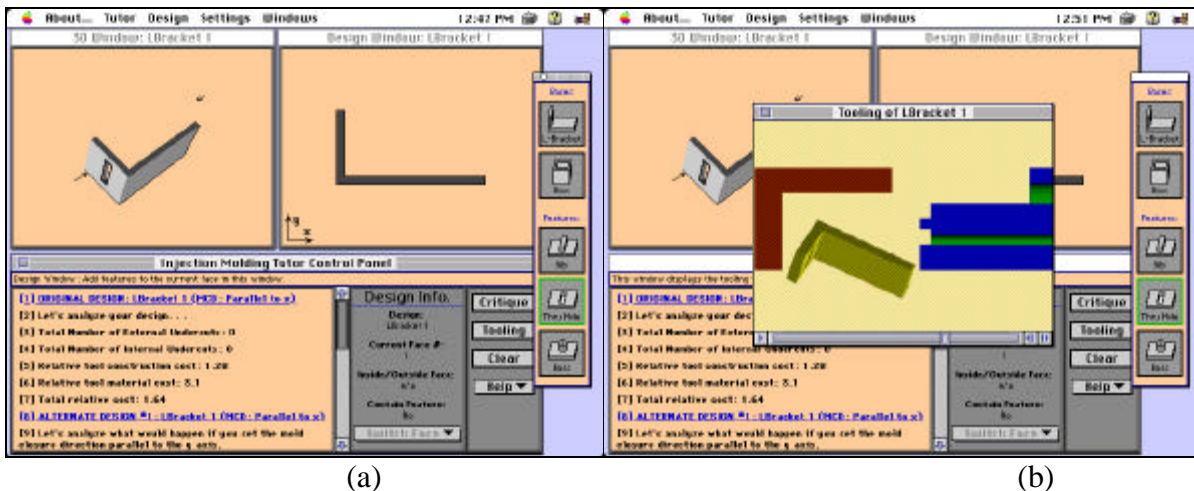


Figure 15. Critique (a) and tooling animation (b) for an L-bracket with the MCD set parallel to the X axis. The user should recognize that this MCD produces simpler tooling than the tooling shown in Figure 16 for the same part.

IX. IMT Testing

Preliminary testing was done on the IMT during the course of its development. These tests helped eliminate programming bugs, improve user interface, and increase the teaching effectiveness of the IMT. The results of the preliminary testing of the IMT are shown in Figure 16.

Many findings were generated from group A through E. First, all the students liked the software and believed that it helped them understand the tooling involved in injection molding. Second, the software as it existed during the preliminary testing (IMEM only, no IMIM) did not help students with the exam given (M1 and M2). It was concluded from this that the students were focusing on the wrong material in the tutor and that the addition of the IMIM should solve this problem.

Group	Sequence	Lecturer	Test #1 (M1)	Test #2 (M2)
A	Software First Lecture Second	UMASS - A	16.7/33	25.6/32
B	Software First Lecture Second	UMASS - B	13/33	14/32
C	Lecture First Software First	UMASS - B	12/33	9.6/32
D	Lecture First Software Second	UMASS - A	23/33	23/32
E	Lecture Only	UMASS - C	N/A	16.4/32
F	Software (With IMIM) Only	UCONN	N/A	17.9/32

Figure 16. Preliminary IMT evaluation and results. Note: “Software” means the Injection Molding Experiential Module only, unless otherwise specified.

A qualitative survey produced many responses from students and helped improve the content and user interface of the IMT. Several of the student responses follow:

Positive Responses

- “It was easy to use the software effectively.”
- “The 3-D effects are the most interesting.”
- “The mold movement was the most helpful.”
- “The most helpful aspect was the critique of your part and the ability to rotate objects.”
- “Learning through experimentation was helpful.”
- “The visuals are the best asset.”

Negative Responses

- “The program could go into more detail about other elements of injection molding.”
- “The program is a little slow.”
- “I found it somewhat difficult to rotate the parts.”

After the addition of the IMIM, the whole IMT was tested on group F at UConn. With the inclusion of the IMIM into the IMT, it determined that the IMT is an effective instructional replacement for the classroom lecture and problem sets on injection molding.

X. IMT Results

In summary, the UMass Amherst tutor team succeeded in developing a tutor that is capable of teaching a user how to produce cost efficient injection molded part designs. The multimedia injection molding tutor is successful at providing highly illustrative, visually stimulating animations, something a text book cannot provide. The IMT is beneficial for any one with little

previous knowledge of injection molding and who wants to learn more about reducing injection molding part cost at very early design stages.

Acknowledgments

The authors would like to express their appreciation to the Technology Reinvestment Project, the National Science Foundation, and the Engineering Academy of Southern New England for the financial support provided in support of this project.

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