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A Collaborative, Cross-Disciplinary Project between Engineering Courses and Programs Centered on Design for Manufacturability

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Abstract

This manuscript describes a collaborative, cross-disciplinary effort between the B.S. in Manufacturing Engineering program and the B.S. in Plastics Engineering program at the University of Wisconsin-Stout. In one course, plastics engineering students are tasked with incorporating design for manufacturability (DFM) in the design of a plastic component and injection mold that will later be machined by a separate course that contains manufacturing engineering and plastics engineering students. After completion of the injection mold, it is utilized by the part designers (plastics engineers) to mold the components they designed. Eight groups in each class work together on separate projects in and out of class. Checklists are utilized to ensure design criteria are met while staying within the scope of the project and the capabilities of the university laboratories. The end result is a real-world experience of the working relationship between a customer and a supplier, complete with design meetings, compromise, and a finished injection mold to mass-produce the designed component.

Introduction

The University of Wisconsin-Stout implemented a manufacturing engineering program in 1994 and a plastics engineering program in 2008. Both programs are housed in the Engineering and Technology Department and emphasize strong, hands-on applied work, focusing on designing solutions for the challenges confronting industry today. As the curriculum for the plastics engineering program was being developed, it was proposed to bring the two programs, in two separate courses, together in a collaborative effort. This effort was discussed and planned amongst faculty from both the manufacturing engineering and plastics engineering programs. In the plastic injection molding industry, custom molders exist as experts to mold plastic components for a variety of companies and industry sectors that do not hold this expertise. A simplified diagram of the companies involved in bringing a product to market is shown in Figure 1. Table 1 lists the individuals working at each company with a short description of their role.

Typically, the original equipment manufacturer (OEM) contacts a custom molder to manufacture a plastic component or assembly. Oftentimes, OEMs may not have the technical expertise to perform the injection molding in-house. The project engineer at the custom molder reviews a part design from an industrial designer at the OEM to ensure the part has been designed for manufacturability (DFM). A strong partnership is extremely important as it is relatively easy to model a part utilizing 3D modeling software and prototype the part using a variety of solid freeform fabrication (SFF) techniques (oftentimes incorrectly lumped as 3D printing techniques), even though it is impossible to actually mass-produce the part due to limitations in injection molding.

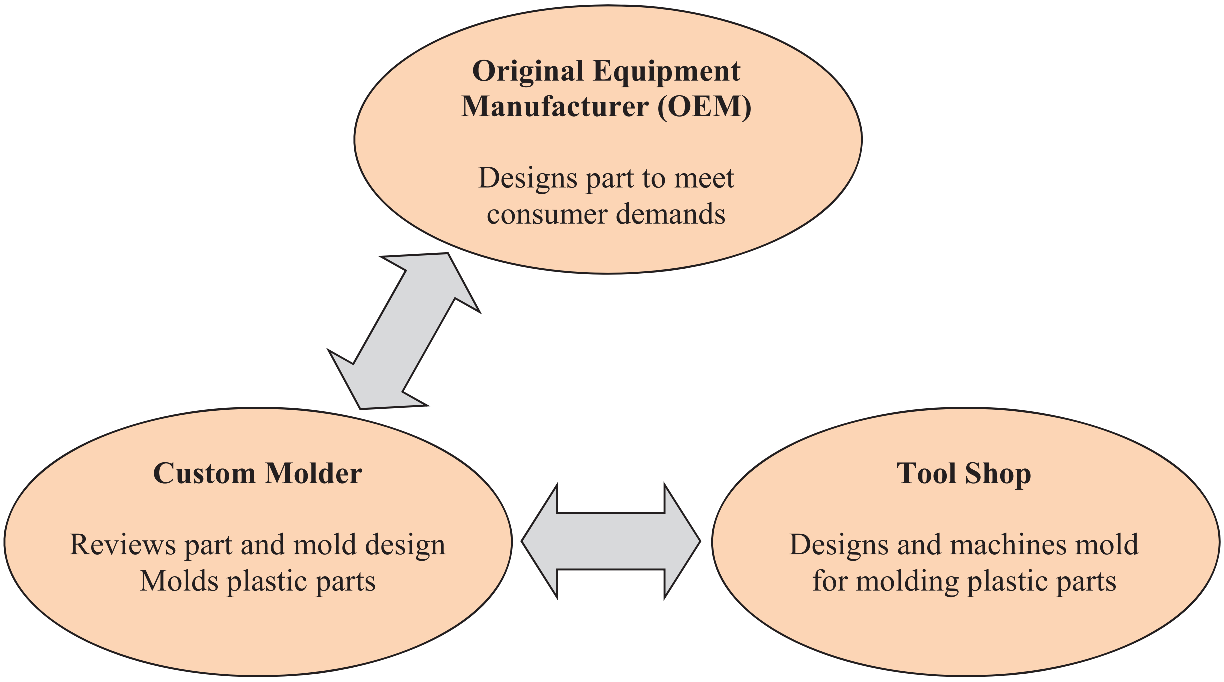

Figure 1: Diagram showing the relationship and roles of the companies involved in manufacturing an injection molded plastic part.

Table 1: List of individuals and their roles in the injection molding process.

Job Title	**Company**	**Responsibilities**
Industrial Designer	OEM	Design part
Project Engineer	Custom Molder	Manage project at custom molder Review part and mold design for feasibility
Tool Designer	Tool Shop	Design mold
Tool Maker	Tool Shop	Machine mold per specifications
Process Engineer	Custom Molder	Mold plastic parts

Once DFM has been implemented to ensure a successful part design for injection molding, the custom molder contacts a tool shop, which has mold design and machining expertise. It is possible the custom molder may have this expertise in-house, but more likely they will subcontract the work. The project engineer reviews the mold design and makes any corrections to ensure the part will be successfully injection molded. Once the mold is machined at the tool shop, it is shipped to the custom molder, where a process engineer will set up a process to produce quality parts that meet OEM specifications. It is noted there are other roles in this process that are left out (e.g., quality, sample technicians, etc…). However, this provides a basic overview of the process involved in bringing a plastic product to market and serves as rationale for the idea behind the class project.

In this class project, it was proposed that eight student groups from both PLE-310: Injection Molding Theory, Design, and Application (plastics engineering students only), and MFGE-325: Computer Aided Manufacturing (both plastics engineering and manufacturing engineering students), would function in the roles described in Table 1 to manufacture a plastic product. The timing of each class in the program sequence, along with prerequisites, is shown in Table 2. Table 3 lists the tasks performed by each class. Individual groups within both classes would consist of 2-3 students, depending on class size. In order for a successful project to be completed, the groups would need to communicate their ideas effectively, and work within student and laboratory capabilities. The part and mold design experience for the plastics engineers in PLE-310 is the first experience the students have had using 3D modeling to design parts and molds, and the computer numerical control (CNC) machining experience for manufacturing and plastics engineering students in MFGE-325 is the first exposure to CNC machining. Therefore, it is critical to design parts and molds that have a high chance for success, while still implementing some degree of complexity. This collaborative project was first implemented during the fall 2010 semester, and has run each fall for three consecutive years (PLE-310 is only offered once per year). To date, 24 sets of mold inserts and plastic parts have been designed and manufactured. Everything from divot tools, money clips, fishing lures, and belt buckles have been manufactured.

Table 2: Placement of the courses in the program sequences along with prerequisites.

Course	Timing	Prerequisites
MFGE-325	5th or 6th semester	• Engineering Graphics Using Solid Modeling (and) • Material Removal and Forming Processes (or) • Injection Molding Technology
PLE-310	5th semester	• Engineering Graphics Using Solid Modeling • Introduction to Plastics • Injection Molding Technology

Table 3: Roles the groups in each class play in the project.

Task	Role	Course Responsible
Design part	Industrial Designer	PLE-310
Review part design for DFM	Project Engineer	PLE-310 and MFGE-325
Design mold	Tool Designer	PLE-310
Review mold design for DFM	Project Engineer	PLE-310 and MFGE-325
Machine mold per specifications	Tool Maker	MFGE-325
Mold plastic parts	Process Engineer	PLE-310

Part Design

During the first week of PLE-310, each group (eight total), are tasked with developing two different part concepts using 3D modeling software and presenting them on the third day of class. No engineering design should be performed at this time, though the x and y dimensions of the part must be smaller than 4.5” x 2.75”, and the height of the part should be no more than 1.5”. All features must be able to be formed using end mills no smaller than 1/8” in diameter. This creates some limitations but also makes the projects more likely to be successful for the first-time CNC machinists in MFGE-325. Basic guidelines given to the students include 1) up to four parts can be machined in each mold, 2) try to create some complexity, whether it be a contoured parting line (see Figure 2) or some unique geometry on the part, 3) no undercuts, meaning the use of retractable slides in the mold is prohibited due to complexity, and 4) the part must have some useful function.

(a) (b)

Figure 2: Examples of a part concept with a a) contoured parting line and b) a flat parting line.

The 16 different part concepts are reviewed by the instructors for PLE-310 and MFGE-325. From these 16 concepts, four concepts are chosen that, while still complex, have a high probability of success. Functional use of the part design is also considered. Each concept will be taken into production by two groups. This not only increases the likelihood of success, it emphasizes how one concept can lead to two completely different part and mold designs.

The engineering design, or DFM, is implemented using plastic injection molded part design guidelines to ensure successful molding of the final part design[1]. Material selection is also performed utilizing the students' knowledge of plastic materials and their corresponding properties from previous courses and other resources[2]. During the part design phase, the students are required to produce prototypes of their designs using fused deposition modeling (FDM). Once the final part design is completed, a part design review checklist must be initialized by each group member from each course prior to the mold design process. The part design checklist includes items to ensure the part can be machined and molded. This simulates the relationship between the industrial designer at the OEM and the project engineer at the custom molder.

Mold Design

Upon completion of the final part design, students in PLE-310 utilize software to select the appropriate parting line and create the mold inserts to be machined. The sprue, runners, and gates (melt delivery system) are added to the mold inserts to allow for molten plastic to fill the part cavity or cavities effectively. Calculations[3], prior experience, and Autodesk® Simulation Moldflow® are used to adequately size and place the melt delivery system. Cooling lines are also added to the mold inserts to allow for proper cooling of the part, and ejector pin holes are cut to allow for part ejection. An example of a completed mold insert design can be seen in Figure 3, and the Modular Unit Die (MUD) base they are inserted into can be seen in Figure 4. All inserts, as well as the MUD base, were machined by UW-Stout students in the material removal laboratory.

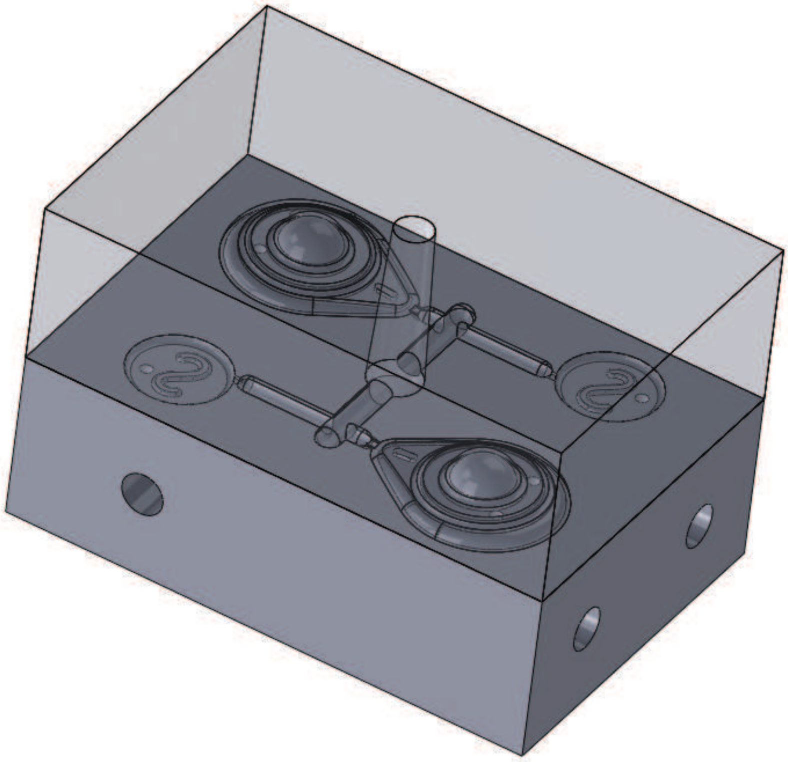

Figure 3: A completed mold insert design for a two-cavity family mold of a fishing lure, minus the cooling lines in one side to more clearly show the design.

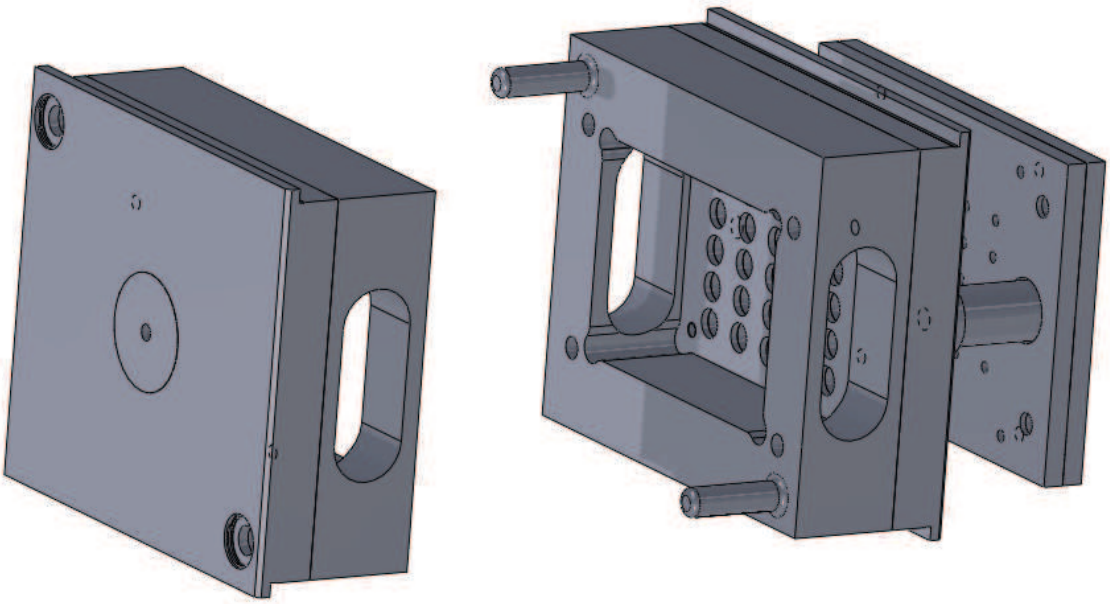

Figure 4: The MUD base used to house the completed mold inserts for molding in the injection molding machine.

Items to be taken into consideration during the mold design phase include 1) the volume of the melt delivery system and part cavity or cavities must not exceed 80% of the available plastic shot size of the injection molding machine, 2) the surface area of the part in the plane parallel to the parting line is small enough to allow for the clamp tonnage of the injection molding machine to keep the mold closed, and 3) no undercuts are present in the mold. A mold design checklist is then reviewed and initialed by a representative from each group in each course prior to machining the mold. This simulates the relationship between the tool maker at the tool shop and the project engineer at the custom molder.

Mold Machining

As stated previously, the instructor for MFGE-325, Computer Aided Manufacturing (CAM) establishes eight groups of three students each. Intentionally, each group has students representing plastics engineering and manufacturing engineering. Proper group sizing has been crucial in order to effectively maximize CNC machine tool usage, in addition to facilitating inner-group collaboration.

Prior student knowledge and skill of operational sequencing, proper machine tool setup, tooling selection, and CAM programming are reflected in the choices each group makes as they proceed to manufacture the injection mold inserts in MFGE-325. Groups are also faced with making decisions on how to collectively utilize their own talents to assure timely completion for the PLE-310 class (to allow for molding of the samples prior to the end of the semester). While some groups choose to work on all aspects of the project equally (i.e.: machine tool setup/operation, programming, documentation, etc.), other groups choose to define their roles more deliberately. Due to student knowledge, skill and experience levels, and the complexity of the machining operations, most groups come to realize the importance of cross-checking each other's work.

Part Production

Upon receiving the machined mold inserts from their respective group in MFGE-325, students in PLE-310 inspect the mold insert to ensure it has been machined per the model developed in the mold design step. Group times are scheduled for use of the injection molding machine and a process is setup using previously developed skills, which are well documented[4] and widely used in the injection molding industry. This simulates the role a process engineer would take once the mold is received at the custom molder. After successfully molding samples, each group presents to the class to showcase the engineering design (material selection, part design, and mold design) implemented along with final results and lessons learned.

ABET Assessment

To facilitate a degree of group accountability, MFGE-325 students evaluate each other upon completion of the injection molding project, a point all students are informed of at the beginning of the semester. Peer evaluations assess attendance, cooperation, contribution, knowledge of job operations, and additional areas (laboratory safety, work attitude, machine maintenance) on a 4-point Likert scale. Students can provide additional comments on the team member at the bottom of the form. For each group member, two scores are averaged and recorded as a portion of their final MFGE-325 project grade. Two items from the peer evaluations (engages others with a cooperative attitude, and contributes to the mission, goals, and outcomes of the team) were written to be consistent with the Accreditation Board for Engineering and Technology (ABET) Outcome D: "An ability to function on multidisciplinary teams" for both the Bachelor of Science Plastics Engineering Program and Bachelor of Science Manufacturing Engineering Program at UW-Stout. Because peer evaluations are conducted each semester for MFGE-325, data is readily available to assess this ABET outcome. Results from Student Outcome D for fall 2012 can be found in Table 4.

Table 4: Results from ABET Student Outcome D in fall 2012.

Performance Indicator	**Score**
Engages others with a cooperative attitude	3.81/4
Contributes to the mission, goals, and outcomes of the team	3.73/4

In addition to peer evaluations, MFGE-325 student groups are tasked with writing a reflection paper upon completion of the project. The learning objective of the reflection paper is for students to re-examine their project experience, describe any change(s) in knowledge, skill, or attitude as a result, and to discuss how this might impact future decisions. More specifically, students are asked to describe the injection mold itself (dimensions, material and other attributes), the molded parts (intended purpose/function, relative size, material, number of parts per shot, etc.), and in more detail, describe how they contributed to the group, how the experience changed their knowledge and skills related to CAM and precision tool making, and how they might use their experience as they move toward their career aspirations. Assessment criteria for meeting this objective cover the aforementioned points, a minimum paper length, and proper technical writing procedure. Groups are given the freedom to write their reflection papers individually or collaboratively. One of the most frequently cited overarching themes from semester to semester is the appreciation students develop for the time, skill, and knowledge necessary to produce production grade tooling (which all students are exposed to in introductory plastics classes).

Conclusion

This project is very unique to UW-Stout and its manufacturing engineering and plastics engineering programs. Specialized skill sets are required from each set of students (including plastics material selection, part and mold design, injection molding machine setup/processing, CNC machine tool setup/operation, and CAM software programming). In addition, faculty, equipment, support staff, and a cohesive curriculum are contributing factors to the success of this collaborative project. The project continues to be refined, and more complex and challenging parts are attempted, due to the systems developed (checklists and strict deadlines) as well as the instructors' abilities to manage the projects to ensure success. Potential future endeavors include enhancing the collaborative experience to reflect industry practice and procedure even closer by incorporating another course of industrial design students at UW-Stout to develop the initial design concepts.

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