Integration of Simulation Tools in Manufacturing Processes Course

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Global competitions and technological advances are forcing manufacturers, designers and engineers to constantly innovate new product manufacturing strategies in reducing product development cost and time. Contemporary manufacturers have the option of selecting optimum technologies or processes to suit their manufacturing environment. Fast paced transformations in Engineering Technology (ET) field require new and enhanced learning and teaching strategies in engineering technology curriculum. More than ever, the educational advance is leaning towards meeting the demands of industrial world. Engineering Technology curricula needs to adapt to novel technologies and modern tools by enabling students to acquire meaningful and relevant practices. Laboratory activities should be incorporated into dry-lectured courses, being vital to ET programs, since they are ultimately enhancing the understanding process, leading towards developing experience-led engineering technology degree.

The desired set of skills required of modern engineers and technologists has been steadily expanding. In addition to familiarity with a number of manufacturing processes and CAD/CAM techniques, various process simulation tools are increasingly becoming an essential tool in the design and manufacturing of complex systems. In this paper, the integration of Moldflow and SolidWorks plastics tools in traditional manufacturing processes course is presented. SolidWorks plastics Standard brings easy-to-use injection molding simulation directly to the designers of plastic parts and injection molds, as well as advanced CAE analysis. It simulates how melted plastic flows during the injection molding process to predict manufacturing-related defects on parts and molds. Students can quickly evaluate manufacturability during design process, to eliminate costly mold rework, improve part quality, and accelerate time to market. A Results Adviser provides troubleshooting steps and practical design advice to help diagnose and avoid potential problems. Similar to SolidWorks plastics, Moldflow software also provides simulation tools for injection mold design, plastic part design, and the injection molding design process. Moldflow simulation software helps reduce the need for costly physical prototypes avoid potential manufacturing defects, and helps bring innovative products to market faster similar to SolidWorks Plastics. In the Manufacturing Processes course, laboratory and term project activities are being developed and used to promote creativity and critical thinking, a place where students develop, practice and improve the required skills using modern tools, and a place where theory meets the real-like scenarios.

The significance of the methodology used in this course redevelopment is to combine theory and practice with modern tools to prepare the students to become better problem solvers and obtain practical solutions to real life/simulated problems using a lab and project-based approach.

Background

At the undergraduate level, many courses related to manufacturing processes, robotics, design, and materials are offered to the students in the Bachelor of Science in Engineering Technology program. Courses such as Robotics and Mechatronics, Quality Control, Manufacturing Materials, Manufacturing Processes, Microcontrollers, and Applied Mechanics can benefit from the laboratory experience in applications of manufacturing processes, fabrication of prototypes and rapid prototyping. As well as helping in the teaching of various courses, such experience benefits students who are pursuing degrees in the engineering field. Students in the Mechanical, Electrical, and Industrial fields along with many others can learn many new skills from multi-disciplinary projects such as material and manufacturing process selection towards design and prototyping of consumer products, or various designs related to capstone senior design projects[1,2]. Such projects show students how to use different types of technology, process selection and demonstrate how advanced technology can be used in an actual design and manufacturing application. Overall, many different fields of engineering can benefit from the application of software simulation tools and CAD designs, enabling the development of skill and knowledge in many different engineering aspects and processes.

In the United States, undergraduate curricula in Engineering Technology (ET), Mechanical Engineering, Industrial, or Manufacturing Engineering generally include a course in Manufacturing Processes. This is also a requirement for ABET accreditation[3]. ABET-ETAC criteria specifically requires that students must attain *Outcome d. an ability to design systems, components, or processes for broadly-defined engineering technology problems appropriate to program educational objectives.* The MET 407-Manufacturing Processes course syllabus comprises topics on variety of manufacturing processes (Table 1). At Drexel University (DU), all the students in the Engineering Technology Program learn the basics of dimensioning and tolerancing as well as surface finish characterization, metal casting, shaping processes for plastics, powder metallurgy, metal forming, machining and welding processes as well as rapid prototyping processes. Students work on several case studies on preparation of optimum process plans on variety of processes while learning the process limits and conditions as well as the cost-tolerance relationship of various processes before engaging in the optimization of tolerance and surface finish allocations.

Course Delivery on MET 407-Manufacturing Processes

The course MET 407-Manufacturing Processes has been redeveloped since 2010 and offered in every winter term by the authors at Drexel University. The overview of a course schedule for MET 407 is shown in Table 1. The course provides a requisite understanding of manufacturing processes as it relates to the quality of parts produced for students to progress to the advanced level in the course and the ET curriculum. The course also serves as a means for students to gain exposure to advanced manufacturing concepts before students take senior design project. MET 407-Manufacturing Processes is not only offered for the full time program at Drexel University, but also for the dual enrollment program with Burlington County College (BCC).

Table 1. Overview of MET 407 Manufacturing Processes

Week	**Topics**
1	Introduction and overview of manufacturing; Engineering materials; Properties of Engineering materials;
2	Dimensions, Tolerances and Surfaces;
3	Metal casting fundamentals; Metal casting processes and equipment;
4	Shaping processes for plastics I;
5	Shaping processes for plastics II; Mid-Term Exam
6	Fundamentals of metal forming; Bulk deformation processes in metal working; Sheet metal working;
7	Theory of metal machining; Machining operations and

	machine tools, Cutting tool technology;
8	Fundamentals of welding; Welding processes;
9	Rapid prototyping, Powder metallurgy;
10	Review; Term Project Presentations; Final Exam

Integration of Software Based Simulation Systems into Course Curricula

The key to unlocking the full potential of Mechanical Engineering Technology students lies in ability to train them to use the many productivity tools incorporated into the machine tools (i.e. CNC equipment, controllers of Injection Molding Machines, etc.), providing realistic operation, programming, and maintenance environment. Software and hardware based simulators can simulate processes including machining, casting, plastics processing centers, and compound applications. Engineering technology students can repeatedly practice complex actions and develop process simulations without risks to people or machine tool assets. Simulations also enable development of complex machine troubleshooting scenarios that are not feasible on real equipment. These simulators provide a realistic operation, part programming and maintenance environment at a fraction of the cost of using a real hardware or a production machine tool, therefore lowering training costs. Using actual equipment or machine tools to deliver the hands-on experience that is vital to acquiring and demonstrating competence might be too expensive when multiple locations are used for training purposes. This is the case since the ET program is offered at satellite Burlington County Community College. Multiple display and keyboard configurations can be selected and saved to match each of the machines being used in a school laboratory.

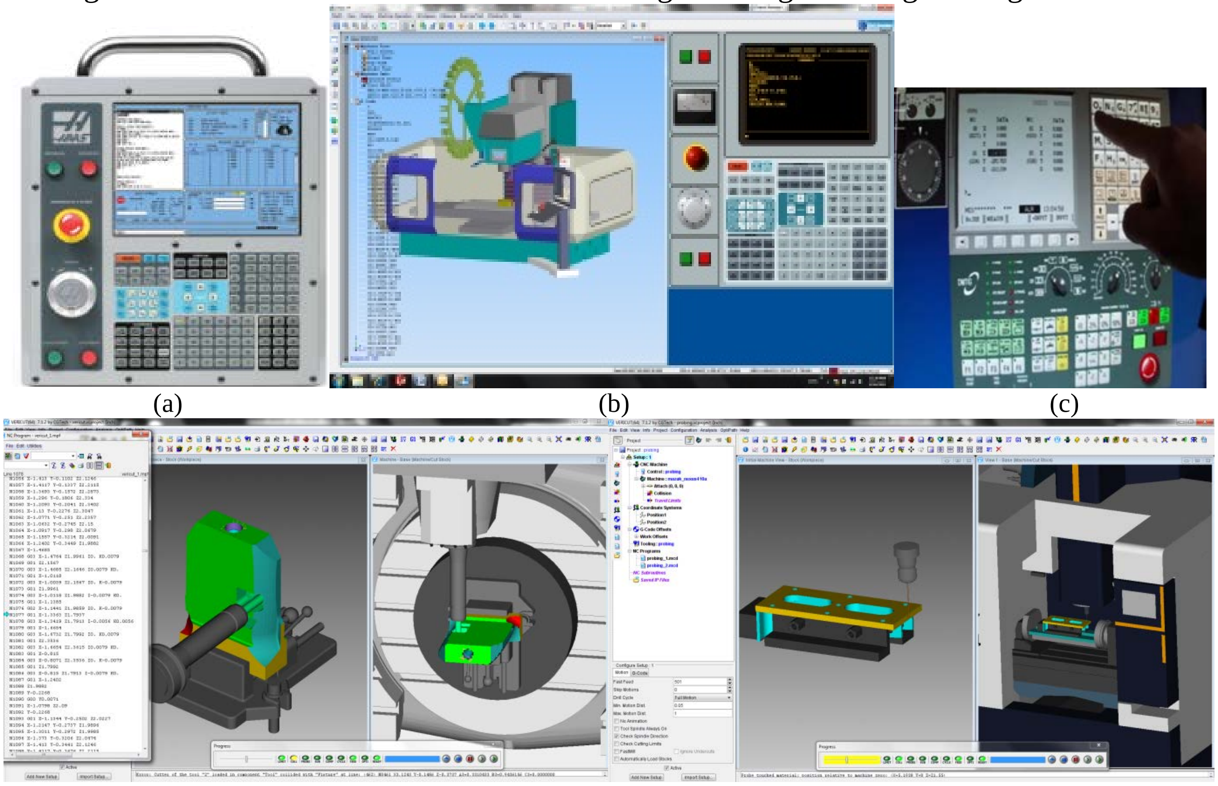
Software and hardware based Simulators can provide:

- Enhanced comprehension and increased speed of development by performing hands-on exercises in an ergonomically-friendly class room environment;
- Increased safety and productivity by allowing students to repeatedly practice complex actions and develop custom process parameters without risks to people or machine tool assets;
- Reduced training equipment cost by emulating multiple machine combinations using the machine setting tool, the option setting tool, keyboard and screen size selections, and actual parameter settings, and by integrating custom screens developed and provided by the machine tool builder;
- Expanded training opportunities for more students and reduced testing bottlenecks by allowing online access to the simulator software or hardware.
- Increased productivity by allowing users to attain "expert" level through repeated practice on the simulator before running the actual equipment;
- Complete processing environment can be simulated in a single, user friendly interface that will be an excellent teaching tool and instructor aid[4].

As an example for CNC machining applications, with NSF funding, authors acquired HAAS dual system control simulators housed in a class room environment and is used in tandem with software based tutor/simulator based systems[5](Figure 1a).

Benefits of Using CAE Tools for Plastics Processing

The injection-molding industry has recognized that computer-aided engineering (CAE) enhances an engineer's ability to handle all aspects of the polymer injection-molding process, benefiting productivity, product quality, timeliness, and cost. This is illustrated by a wealth of literature and the ever-growing number of CAE software users in the injection-molding industry. Therefore these high end skills are desired in students who are graduating from engineering schools[6].



(a) (b) (c)

(d) (e)

Figure 1. (a) HAAS dual system control simulator hardware. (b) Swansoft CNC simulation software showing machine control panel simulation for HAAS control. (c) Swansoft CNC simulation software showing machine control panel simulation on a tablet pc for Fanuc control. (d) VERICUT CNC machining and program verification software (e) VERICUT CNC on machine probing simulation.

Ideally, CAE analysis provides insight that is useful in designing parts, molds, and molding processes. Without it, process engineers rely on previous experience, intuition, prototyping, or molding trials to obtain information such as polymer melt filling patterns, weld-line and air-trap locations, required injection pressure and clamp tonnage, fiber orientation, cycle time, final part shape and deformation, and mechanical properties of molded parts, just to name a few. Without CAE analysis, other equally important design data, such as spatial distributions of pressure, temperature, shear rate, shear stress, and velocity, are more difficult to obtain, even with a well-instrumented mold. The process behavior predicted by CAE can help novice engineering technology students overcome the lack of previous experience and assist in pinpointing factors that may otherwise be overlooked. By using CAE analysis with iterations and what if scenarios students are able to evaluate alternative designs and competing materials. Engineering know-how in the form of design guidelines can be established relatively faster and more cost-effectively.

Tutorial Development for MET407 Students using Moldflow CAE Tool

One of the simulation tools authors adopted during plastic shaping processes discussions is Autodesk's Moldflow adviser CAE tool[8]. Moldflow adviser comes as free software for higher education community including a free download of the software for students and educators. Autodesk provides three year license for this software. The software is also accessible via virtual desktop computer using windows remote access tool for ET students. ET students are already familiar with AutoCAD interface in the earlier MET 100 computer graphics course. Using Moldflow adviser, students have become capable of conducting modeling of a single and multi-cavity mold and run several types of analyses including Fill, Pack, Cool and Warp analysis (Figure 3).

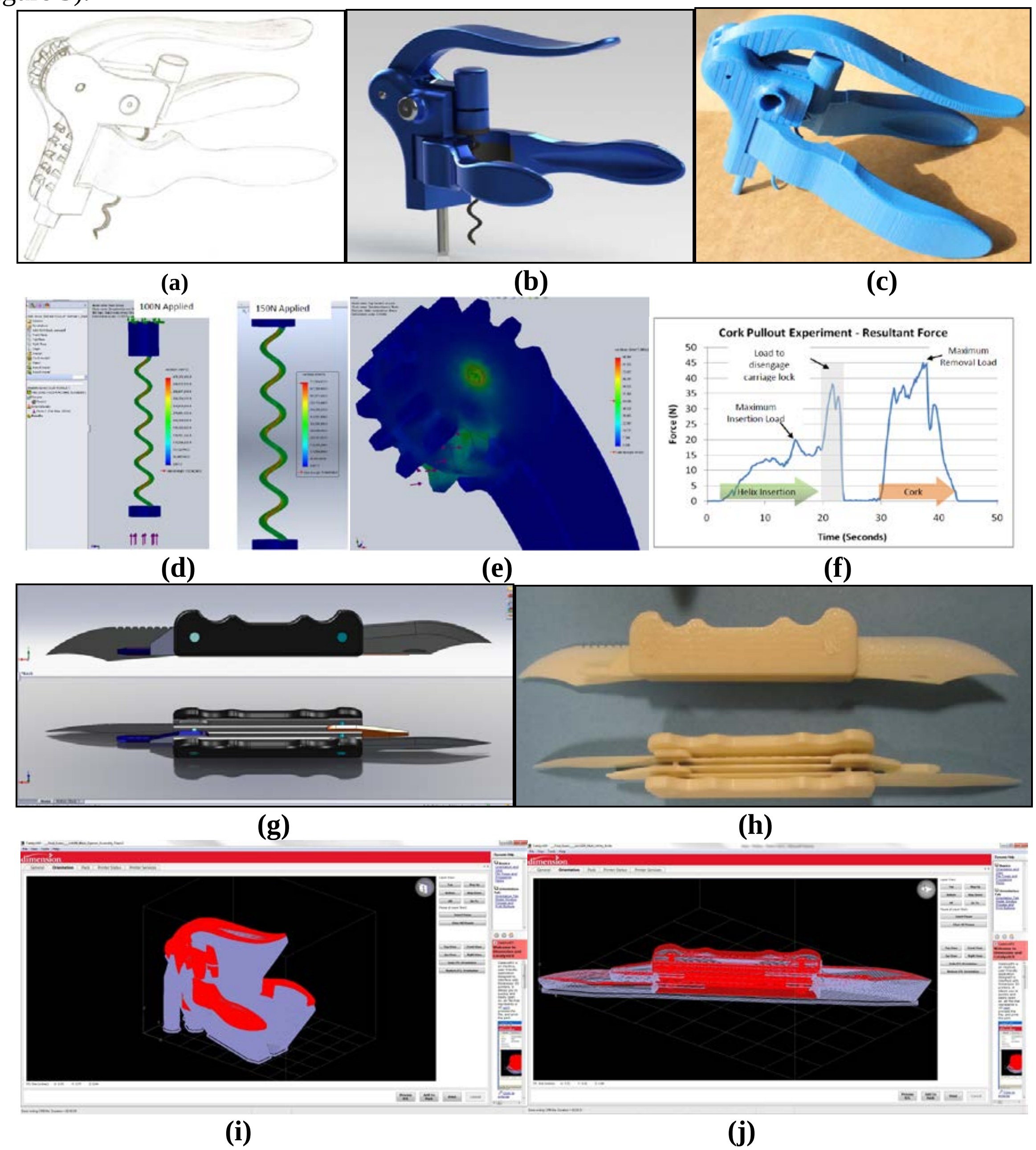
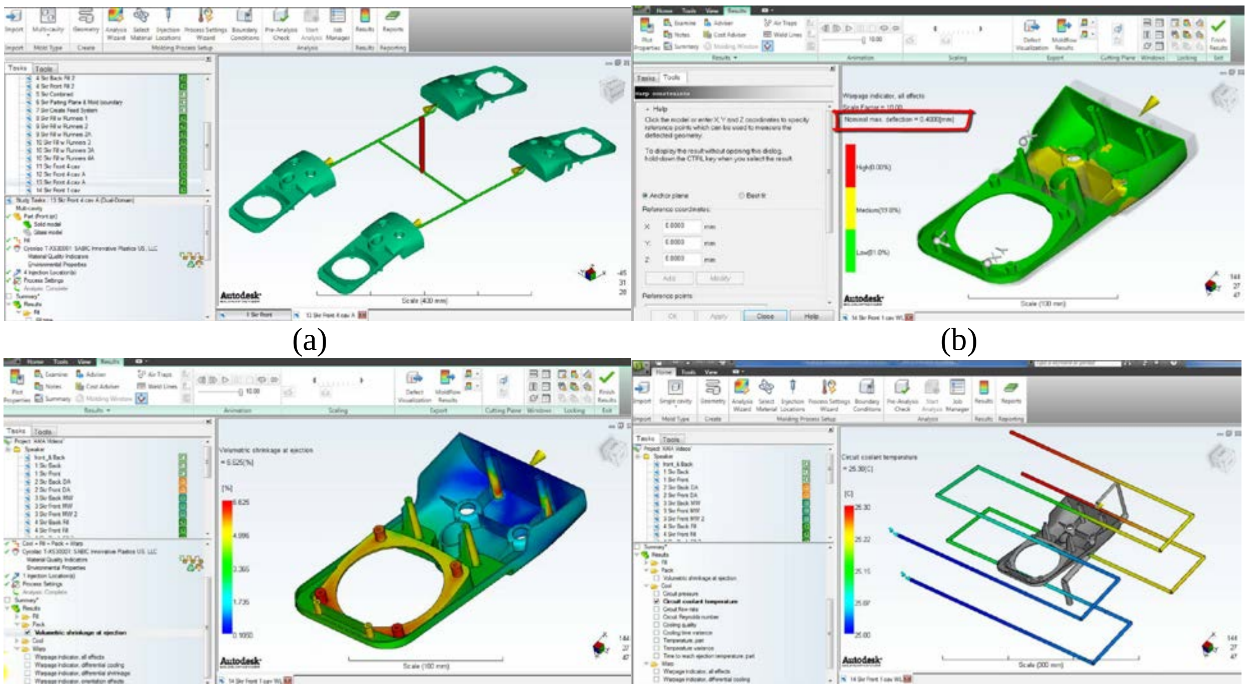


Figure 2. Samples of student term project of a consumer product development in MET 407. (a) Concept sketch (b & g) SolidWorks® CAD modeling (d & e) SolidWorks® Finite Element Analysis (c, b, i & j) Rapid prototyped models using FDM method[7].

Insight the Moldflow software provides to solve molding problems would be better applied ahead of actual molding, during the design process. This methodology, which we call “problem avoidance,” is one of the primary uses for Moldflow simulation technology. What constitutes an ineffective design for molding may be apparent to a seasoned processing engineer looking retrospectively at a poorly performing tool, but how can Mechanical Engineering Technology students use the CAE tools to visualize, diagnose and solve molding related problems ahead of time—without 20 years of molding experience. Students can go further and use the information that cannot be seen in the real molding process but is revealed via simulation.

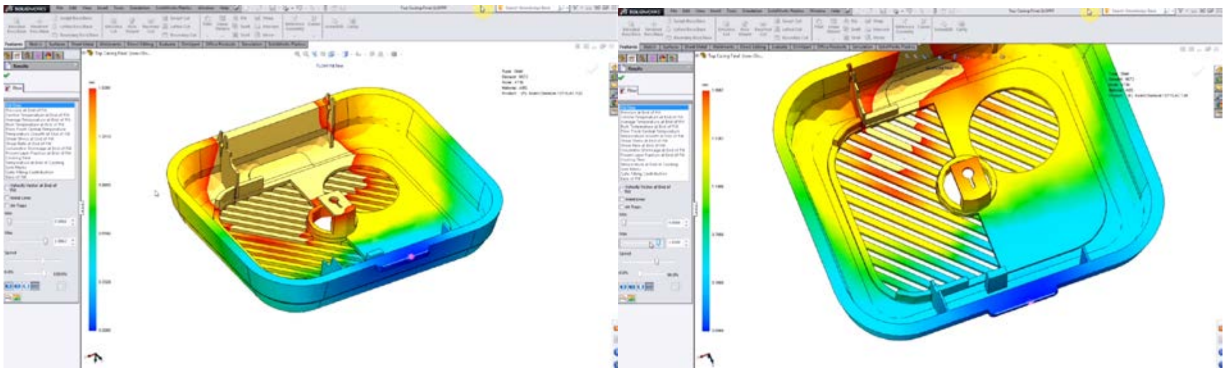


(a) (b) (c) (d)

Figure 3. Samples of Moldflow analysis using software embedded tutorials[8]. (a) Runner and gating design (b) Warpage analysis (c) Volumetric shrinkage analysis (d) Cooling circuit analysis

Tutorial Development for MET407 Students using SolidWorks Plastics CAE Tool

SolidWorks Plastics comes in three levels, Standard, Professional and Premium. Engineering Technology department currently has thirty educational seats of SolidWorks premium package which comes with SolidWorks Plastics Standard[9]. SolidWorks Plastics Standard enables students to optimize parts for manufacturability in the early stages of design. Easy to learn and use, it is fully embedded within the SolidWorks CAD environment so one can analyze and modify designs at the same time optimize for form, fit, and function. Professional and Premium versions allow mold designers to lay out multiple cavity molds and design runner systems, among other things. So in that sense, the Standard package is somewhat limited in the capabilities compared to Autodesk Moldflow insight nevertheless very easy to learn and apply what if scenarios to find out the effect of design parameters in processed parts quality.



(a) (b)

Figure 4. Mold flow analysis using SolidWorks Plastics Standard software[9]. (a) Cavity fill analysis (b) Weld line analysis.

Since Drexel Engineering Technology students are very familiar with SolidWorks CAD modeling from previous courses, modifying designs such as changing wall thickness or using different raw materials on the quality of the molded products is very easy to demonstrate and accomplish without physical tooling.

Integration of Cambridge Engineering Selector (CES) EduPack and SolidWorks Sustainability to ET Courses

As we teach engineering materials and manufacturing process courses prior to capstone senior design projects, it is imperative to introduce ET students with advanced tools to impart skills that will guide design decisions that minimize or eliminate adverse eco-impact. Embodied energy and carbon footprint, recycle fraction and toxicity have obvious eco- connections that require careful considerations for Product Lifecycle Assessment (PLA) combined with mechanical, thermal, and electrical properties that have the greatest role in design to minimize eco-impact. During the 2014-15 AY authors used two software packages: Cambridge Engineering Selector (CES-EduPack 2013) and our existing SolidWorks® packages with Sustainability "**addin**" function invoked to provide tools to meet complex product and process design requirements, helping students to explore and learn the underlying science of eco-design in a sustainable environment. While CES EduPack Sustainability database package provides a computer-based resource for assessing articulations of sustainable technology and the place of materials in them, SolidWorks sustainability evaluates the environmental impact of a design throughout the life cycle of a product. Students are required to compare results from different designs to ensure a sustainable solution for the product and the environment[15].

Course Assessment

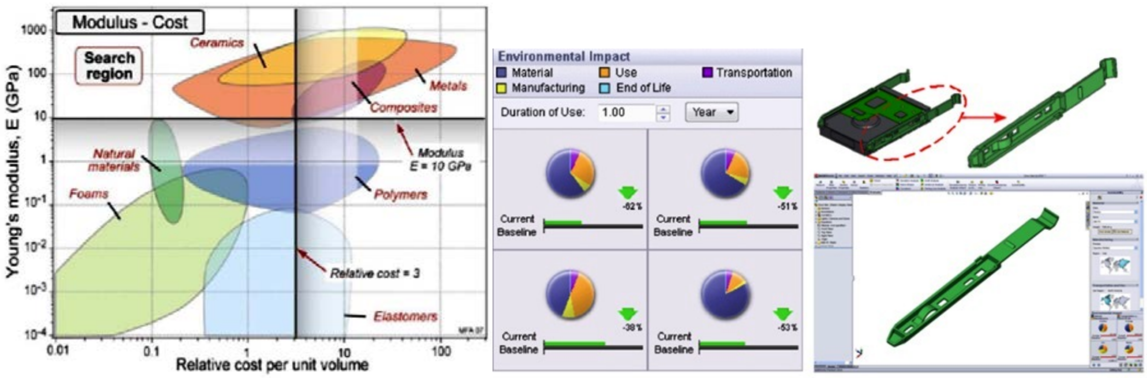
MET407 Manufacturing Process course objectives are listed as follows:

Course Level Student Learning Outcomes:

Upon completion of this course, the student will:

1. Know the parameters influencing product quality of a variety of manufacturing industries operation.
2. Analyze complex manufacturing processes using modern simulation tools and understand the direction in which manufacturing operations are evolving.
3. Become acquainted with the terminology and techniques used by industry in the manufacturing of a part.

4. **4.** Develop the ability to think and solve practical problems concerning the selection of manufacturing materials and processes.
5. **5.** Develop an understanding of manufacturing materials and processes in a series of practical, progressive and easily understood lessons.



(a) (b)

Figure 5. (a) Constraints of modulus greater than 10 GPa and relative cost less than 3 plotted on a graph, (b) SolidWorks Sustainability analysis using a plastic part.

In addition to Student Outcome d, above course level outcomes support two more of the ABET-ETACs Student Outcomes as listed below:
a. *an ability to select and apply the knowledge, techniques, skills, and modern tools of the discipline to broadly-defined engineering technology activities.*
b. *an ability to select and apply a knowledge of mathematics, science, engineering, and technology to engineering technology problems that require the application of principles and applied procedures or methodologies.*[3]

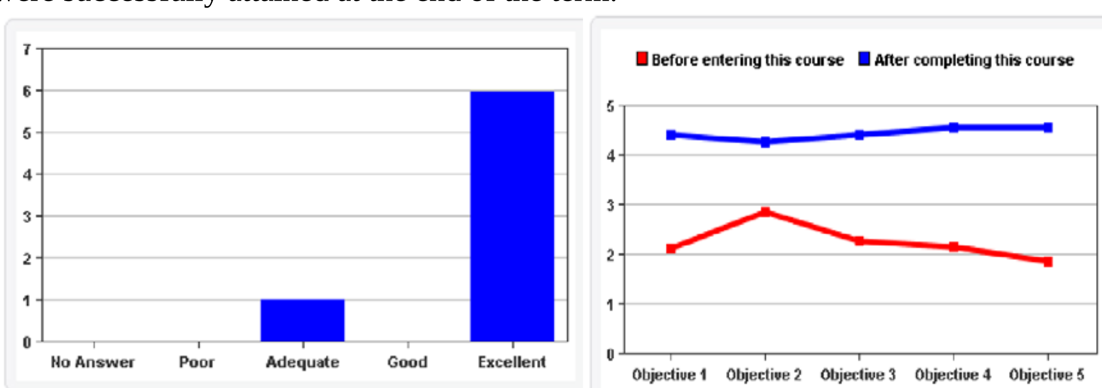
Tutorial development is still an ongoing process and authors are in the process of collecting student feedback at the end of the winter quarter of AY2014-15. Please see the survey questions and student responses on software tools in Table 2. In addition, end of course assessment data which is linked to course level outcomes are provided in Figure 6.

At the end of the course students were surveyed using a Likert-type scale to assess how much the course contributed to their understanding of the software tools and topics. The rubrics used were 1 = "None" and 5 = "A great deal". Ten out of 13 students responded. The questions are shown in Table 1, together with average scores and standard deviations for each. Eight of the ten students responded, with an average score of 3.0 (σ = 1.5) for questions 1 through 11. The average score (3.33, σ =1.80) for Question 11 (Do you recommend keeping term project in this course?) was better than grand average (3.23, σ =1.34) of all scores for all other questions. This is a good indication that students had a positive experience using tools and applying to term project assigned at the beginning of the quarter. When we look at the student responses for CES and Moldflow tools, students felt that they benefitted more using CES tool compared to Moldflow.

Table 2. End of course survey questions and student responses.

	Question:	**Average**	**STDDEV (σ)**
1	How much did this course contribute to your understanding of how CES (Cambridge Engineering Selector) worked?	3.22	1.30
2	How much were you able to incorporate CES in your term project?	4.11	1.05
3	How much did this course contribute to your understanding of how MoldFlow Adviser worked?	2.22	1.56
4	How much did you benefit CES experience in the course?	3.44	1.33
5	How much did you benefit MoldFlow Adviser experience in the course?	2.00	1.58
6	How much did the term project contribute to your ability to work in teams?	2.89	1.54
7	I want more hands on use of CES software in this course.	3.22	1.33
8	I want more hands on use of Autodesk Moldflow systems in this course.	3.67	1.12
9	Do you recommend keeping CES software application in this course?	4.33	0.71
10	Do you recommend keeping MoldFlow Adviser software application in this course?	3.11	1.45
11	Do you recommend keeping term project in this course?	3.33	1.80

However, student's score for keeping Moldflow adviser in the course (question 10) was greater than the target level of 3.0 (σ = 1.45), which is consistent with scores for other questions. Students still felt that more case studies and homework studies are needed to improve their understanding of the tools and will be more used to these modern tools. The recent course evaluation of the course outcomes indicates (Figure 6) that students felt that the course objectives were successfully attained at the end of the term.



(a) **(b)**

Figure 6. Course evaluation results from Drexel's Academic Evaluation, Feedback and Intervention System (AEFIS) by 7 students: (a) Overall course rating (b) Graph indicates student response to

question: Please rate your perceived performance or understanding of the following course objectives, according the scale provided. 1 = No Understanding - 5 = Complete Understanding

Conclusions

Teaching manufacturing processes courses using software simulation tools will increase the comfort, competitiveness, and confidence of the students not only qualitatively, but also quantitatively[6]. It is also observed that the software tools provide a positive impact on student's simulation skills that will minimize time spent on the job training in the industry. The design as well as material and process selection experience develops the students' lifelong learning skills, self-evaluations, self-discovery, and peer instruction in the design's creation, critique, and justification[11-12]. The experience of teamwork gives the students a sense of satisfaction and accomplishment that is often lacking in many engineering courses, not including projects. Furthermore, process simulation motivates student learning and develops skills required in industry. The students will able to make more accurate and satisfactory estimations and calculations of these processes. We hope to see that their projects and case study results reflect that they have understood well all the basic ingredients of the complex engineering systems.

Acknowledgement

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