Session 3548

Integrating Solid Modeling Throughout a Mechanical Engineering Technology Curriculum

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Abstract

Over the past few years, the majority of companies involved in mechanical design have been migrating to a solid modeling system as the primary design platform. An broad study was conducted to document the specific details of using a solid modeling system in an industrial setting. As a result of this study, a comprehensive list of benefits was compiled. Also, the major obstacles, which must be faced as an organization adopts a solid modeling system, was documented.

The resulting objective was to propose a structured approach to integrate solid modeling into Mechanical Engineering Technology courses. The plan involves all courses, in the curriculum, that has a design component. This paper reviews the results of the solid modeling study. It also discuses the manner in which solid modeling has been integrated into the Mechanical Engineering Technology curriculum at the University of Dayton.

I. Introduction

The purpose of the study was to identify the specific details of using a solid modeling, CAD system in an industrial setting. The resulting objective was to propose a structured approach to integrate solid modeling into the Mechanical Engineering Technology courses. The work was divided into three phases:

1. The initial phase of the study involved an investigation into the evolution of computer-aided design (CAD). This phase involved investigating and documenting the specific capabilities of the different CAD software packages, both 2-D and 3-D. To accomplish this, numerous training sessions, involving different software packages, were attended.

2. The second phase involved a comprehensive review of the specific uses of solid modeling. To accomplish this, full time employment, in a design engineering capacity, was obtained at an industrial sponsor. The primary responsibility included designing special machines using a solid modeling system. As a result of this experience, a comprehensive list of benefits gained by using a solid modeling system was compiled. The obstacles that must be faced as an organization adopts a solid modeling system was also reviewed.

3. The final phase involved constructing a proposal that specifies the manner in which solid modeling can be integrated throughout the Mechanical Engineering Technology curriculum.

II. Phase 1: Review of Approaches to Computer Aided Design.

CAD modeling is a method of defining a part's shape and dimensions with a computer. Utilizing a computer to document design work has reduced the time required to create designs, along with facilitating design revisions, creation of similar products, and verifying the design intent. It automates the design tasks by providing digital tools that accurately model, analyze, and express physical systems. CAD has become the foundation for a wide variety of engineering, design, drafting, analysis and manufacturing activities.

There are several different types of modeling currently used for machine design. CAD has developed and evolved over the past twenty years from simple 2-D wireframe modeling to today's 3-D solid modeling.

II A. 2-D Wireframe Modeling:

The simplest from of CAD is the two-dimensional modeler. Two-dimensional modeling involves creating views of a part, usually built from lines, arcs and circles. These views are manually constructed to conform to normal engineering drafting practice. The 2-D CAD systems are equivalent to a computerized drafting table. The benefits lie in having a principal database, which records the design information. This is still the most popular manner to model simple parts.

AutoCAD, distributed by Autodesk Inc., is the most popular 2-D design and drafting software. It is used by architects, engineers, drafters, and design-related professionals to create, view, manage, plot and output, share, and reuse accurate, information-rich drawings. The base software package has design modeling features which include sketching tools (line, arc, circle, spline, etc.), modify tools (trim, extend, copy, rotate, scale, stretch, etc.), and measuring features. To provide drawing documentation, the drafting tools allow the placement of dimensions (linear, aligned, diameter, angular, etc.), application of tolerances and the ability to set annotation notes.

Since it is the most popular 2-D CAD package, literally hundreds of add-on modules have been developed, both by Autodesk and third party vendors. Some of the most common include libraries of standard mechanical components, visualization tools, translators for other CAD systems, file managers, factory layout tools, and programs that generate manufacturing tool paths.

Other prevalent wireframe software packages embody the same features as the base version of AutoCAD. Since these packages are not industry leaders, they compete with a price advantage. These packages can be purchased in the range of \$800.$^{\underline{00}}$ to \$1500.$^{\underline{00}}$ per copy. Some of these packages include CADKEY, CADAM, Anvil and MicroStation.

II B. Solid Modeling:

In the mechanical design industry, a major transition is underway in the manner products are designed, tested, and brought to market. With increasing power of computers, today’s engineers and designers are able to create 3-D solid models of their designs on their desktop PCs. These models are often termed virtual prototypes because once the models are created, analysis tools can be used to simulate the operation of the device being designed. The models can also be used to create and manufacturing data.

Solid Modeling derives its name from the fact that a solid modeler creates an object called a solid, or body, representing a part. A solid is a model that clearly identifies any point in space as either inside or outside of the model. This sounds simplistic, but has powerful ramifications. It allows a solid modeler to automate many of the decisions that a 2-D modeler relies on the user for, such as which sections of a part to keep and which to trim away.

A solid modeler starts with the creation of a simple body. This body might be a sphere, a cube, an extrusion of a shape, or be created from a surface. The basic operation is to "add", "subtract", or "intersect" another body, resulting in the creation of a new body. No user input is required to determine the sections to leave or remove. The solid modeler automatically trims off unneeded portions, or adds new portions, handling all faces. A face is any single side, or surface of a body. This single operation may create any number of new faces on the body, but the users are not exposed to that level of detail.

The advantage of solid modeling is that each body is represented as a single object, not as a complex collection of shapes. It greatly simplifies the specification of intricate design details of complex parts. Without great exertion, all the details of a telephone handset can be created.

A solid model can be used for creation of related parts. For example, when the handset model is complete, it can simply be "subtracted" from a square block, creating a mold base cavity.

Unlike 2-D CAD, there is not a standard solid modeling platform[7]. The industry is primarily separated into two categories, high-end and mainstream software packages. High-end packages were the first generation of solid modeling systems, primarily written for the aerospace and automotive industries. These are powerful systems that have features that model complex geometry. These package provide integrated capabilities for creating detailed solid and sheet metal components, building assemblies, designing weldments, and producing fully documented production drawings and photorealistic renderings and even create animations of the product operation. Design analysis and data sharing capabilities are also powerful and set these systems apart. The cost of these packages is in the range of $10,000.00 to $30,000.00 per copy[5]. The primary high-end solid modeling systems are Pro/ENGINEER (used at aerospace firms such as Allied Signal, Rockwell and ITT), I-Deas Masters Series (used exclusively at Ford), Unigraphics (used exclusively at General Motors) and Catia (used exclusively at Chrysler and Honda)[7].

Mainstream software packages claim to offer solid modeling power and performance to get any job done, while being intuitive enough for every engineer and designer to learn. These systems were designed for users migrating from 2-D systems, as well as those with 3-D modeling experience. However, it may be difficult, or impossible, to use mainstream software products to model complex parts. A fender for an automobile, and a turbine blade, are examples of components that may push a mainstream solid modeler. Also, the analysis capabilities are somewhat limited with the mainstream packages. However, many third party vendors supply products that integrate analysis capabilities into these mainstream packages. Cost of these packages is in the range of \$3000.$^{\underline{00}}$ to \$5000.$^{\underline{00}}$. The primary mainstream solid modeling systems are SolidWorks, and SolidEdge. Specialty equipment manufacturers and tool/ die shops have been the largest adopters of the mainstream packages[7].

III. Phase 2: Industry usage of Solid Modeling

Phase 2 of the study was to investigate the implementation of solid modeling in industry. Information from a 1998 Simmons Market Research Bureau study[9] of design engineering shows that 3-D solid modeling is an important design tool for engineers working in most job functions.

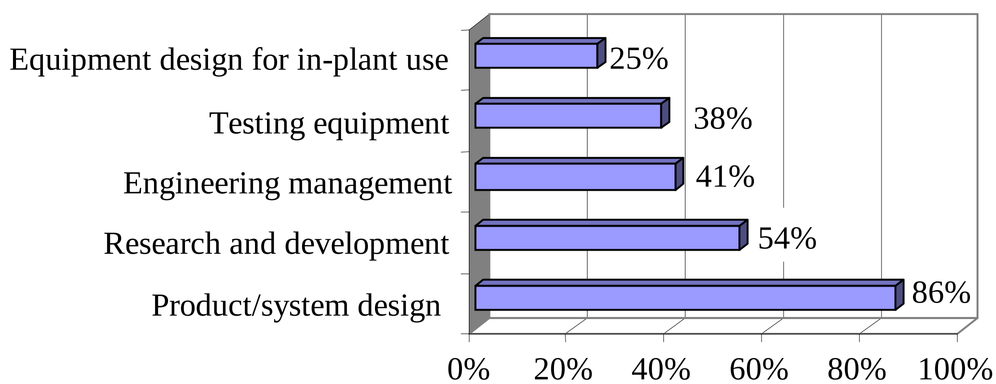

Figure 1 Adoption of Solid Modeling

As surmised from figure 1, many companies are investing significant capital to transition from 2-D CAD to solid modeling. The justification for this capital investment is the promise of increased productivity and a reduction of design errors. During the study, I spent eight months, at an industry sponsor, working full-time on the design of special machinery using solid modeling software. From research, and this experience, the following benefits and observations were compiled.

III A. Benefits of Solid Modeling:

The specific capabilities and benefits, to a company, of solid modeling include the following:

- Parts are designed in three-dimensional space as shown in figure 2. The solid model exactly replicates the design, leaving no ambiguities of part details. The part can be viewed from any angle eliminating assumptions. Users of the two-dimensional CAD drawings must be able to visualize the part from the given drawing views. Spatial visualization is a key skill for drawing interpretation. These skills must be learned and developed over a period of time.

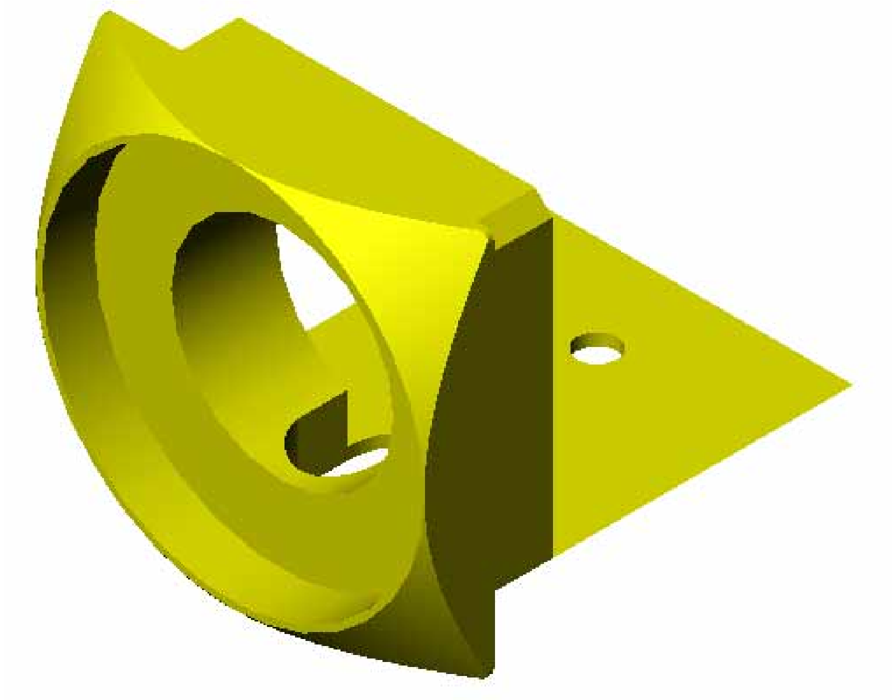

Figure 2 Solid Model

- Engineering drawings with multiple views can be automatically generated. The actual placement of dimensions, tolerances and notes can be easily modified to conform to customer specifications. Views are associative and will always be consistent. As shown in Figure 3, isometric views can be inserted into a drawing for enhanced visualization. In 2-D CAD, three-dimensional parts are represented by two-dimensional views. The engineer must make sure that the views are consistent and valid.

- Solid models contain complete volumetric information about a part. Cross sectional and mass properties can be readily calculated.

- Parts are parametrically designed. A change in one dimension automatically updates any dependent part features. All associated files, such as the assembly model and the engineering drawings, are also updated.

- Engineering analysis, primarily finite element analysis, can be efficiently accomplished. Having the part configuration modeled as a solid eliminates any redundant creation of geometry. Automatic mesh generation packages have direct access to the original part model.

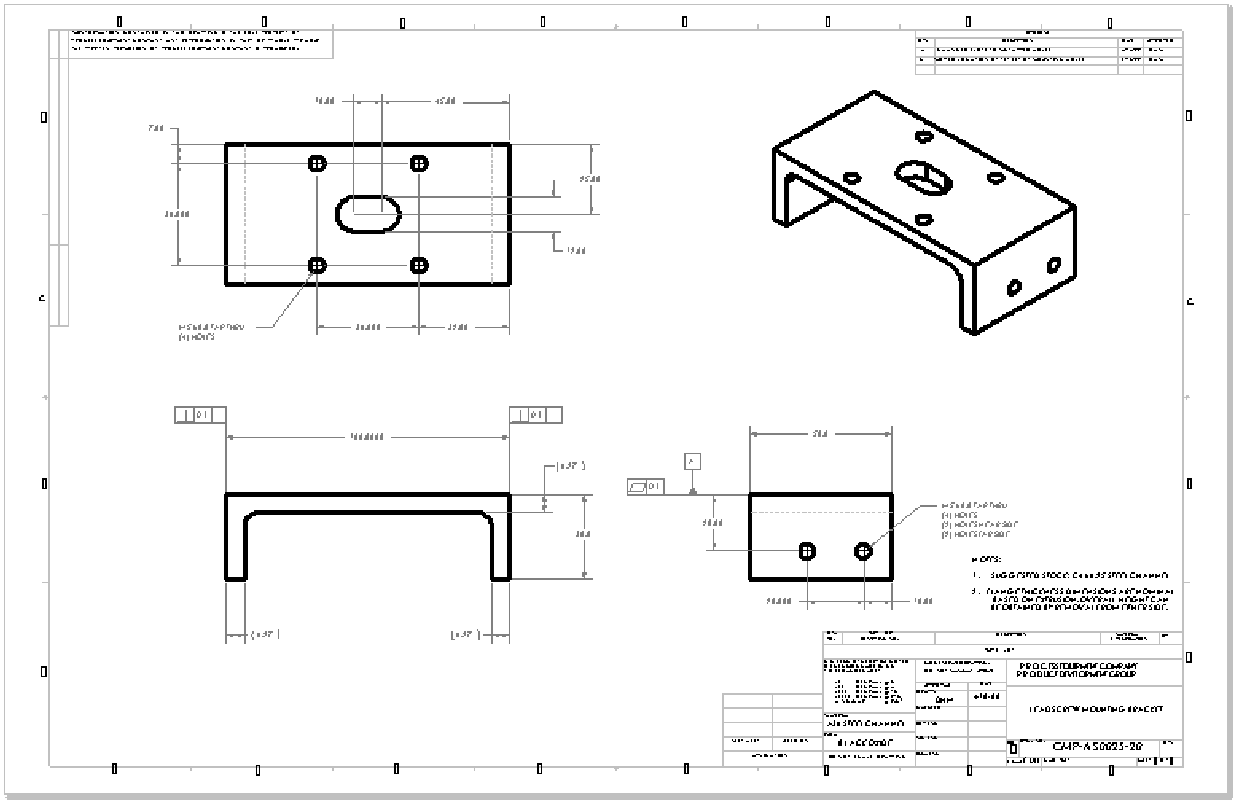

Figure 3 Detailed Drawing with Isometric View

- The individual parts are assembled in a manner that simulates the actual construction process. Parts are “mated” according to physical connection used (bolts, dowels, etc.) Interference and location misalignments are readily detected. An assembly is shown in Figure 4.

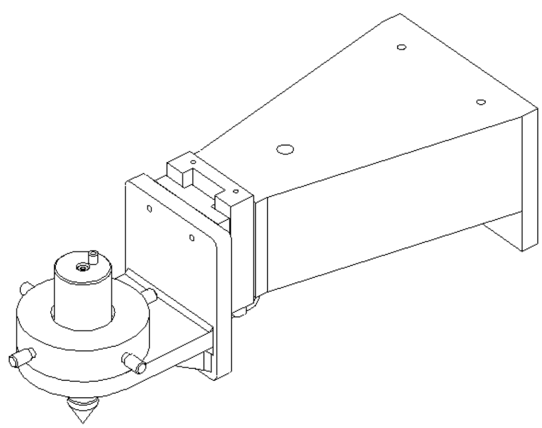

Figure 4 Assembly of Component Solid Models

- Pictorial views of the shaded parts or assembly can be effectively used for marketing materials. Such a pictorial view used for marketing is shown in Figure 5.

Figure 5 A Marketing Pictorial

- Animations of the machine motion can be done to assist in understanding the design, detect interference, and for marketing materials.

- Exploded assembly drawings with an associated bill of materials can be automatically generated. This greatly simplifies assembly of the machine when compared to cross-section, or hidden-line assembly, drawings. An exploded assembly drawing is shown in Figure 6.

III B. Obstacles to Implementing Solid Modeling

Obstacles for a company to implement solid modeling include the following:

- A migration from 2-D systems to solid modeling will involve training of engineers and designers. A learning curve will hinder design productivity in the short-term. The cost of training can also be significant.

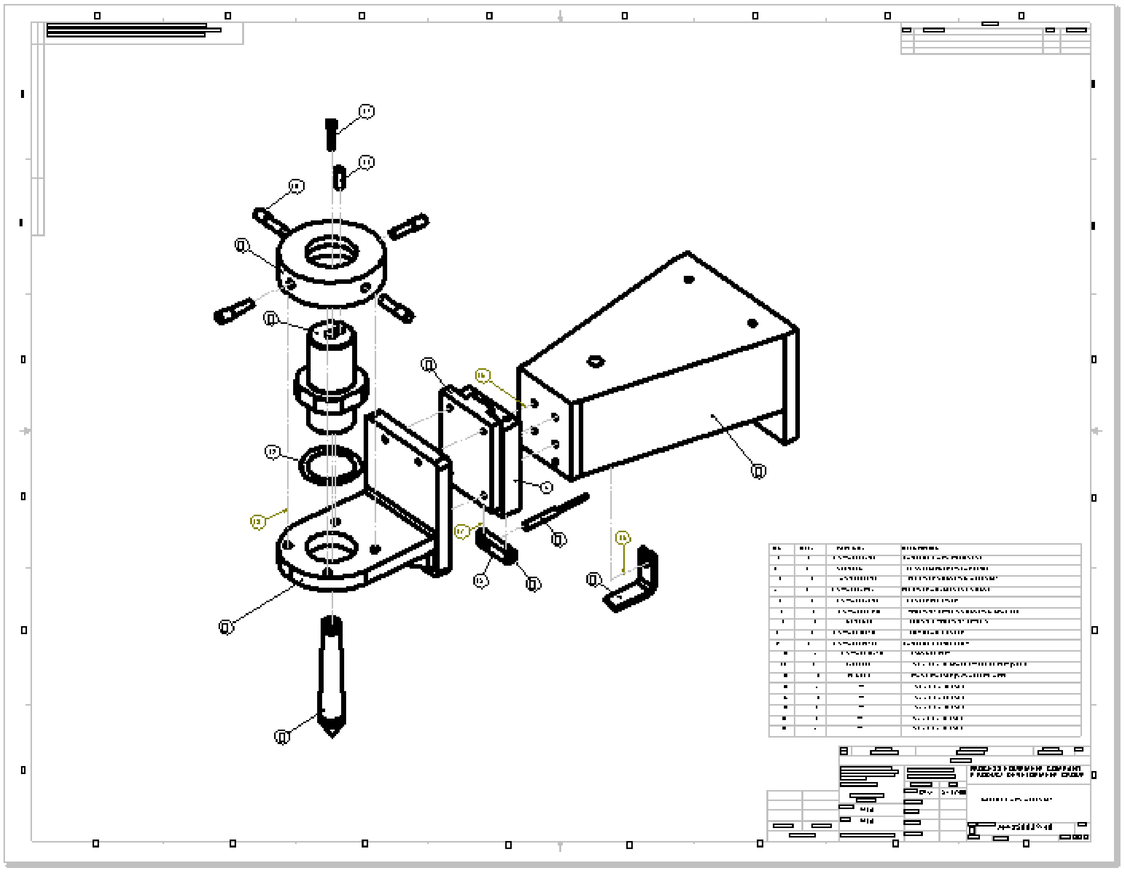

Figure 6 Exploded Assembly Drawing

- The computer systems needed to run solid modeling software must be upgraded. The mainstream packages require at least a Pentium 100 with a minimum of 128 MB RAM, 90 MB of disk space and graphic processor with OpenGL acceleration. High end packages require even more powerful computers.

- Libraries of 2-D components, which may have been compiled over the years, will become obsolete.

- Data exchange with other companies (vendors and customers) may not be reliable. Being the dominant 2-D CAD system, all data exchange is done according to the AutoCAD format. Since there is no leader in solid modelers, no standard exists for data exchange. Many third party companies offer specialized solid model exchange software, but this industry is in its infancy.

IV. Phase 3: Incorporation of Solid Modeling into the Mechanical Engineering Technology curriculum

Phase 3 of the study was to develop a proposal, which outlines a process for incorporating solid modeling into mechanical engineering technology courses. Companies are discovering that the benefits of solid modeling are outweighing the obstacles and are making the transition. Without a major concern over loss of component libraries and data exchange difficulties, a transition to solid modeling in an educational institution is even more convincing. Further, in order to meet the needs of industry, graduates from the mechanical engineering technology program must be fluent in solid modeling practices.

Figure 7 illustrates the mechanics and design sequence in the Mechanical Engineering Technology (MET) curriculum at the University of Dayton. Most MET programs have similar sequences.

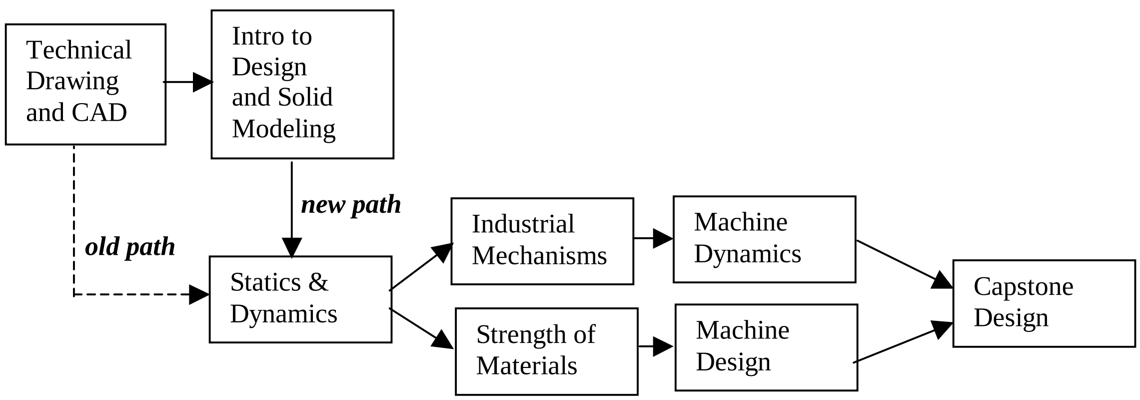

Figure 7 Mechanical Design Sequence at U.D.

Technical Drawing and CAD, is required by all MET students and focuses on the preparation of engineering documentation. Students are introduced to orthographic views, and standard drawing representation. Two-dimensional CAD, using AutoCAD, is a principal component in this course. Even with a transition to solid modeling, understanding view projections, and familiarization of AutoCAD is still considered valuable knowledge. Therefore, this course will remain committed to 2-D CAD.

Intro to Design and Solid Modeling (IDSM) is also required by all MET students and introduces the design process. Technical Drawing and CAD serves as a prerequisite to the IDSM. In the mechanical design process, CAD is a major element in developing the form and fit of the components that comprise a device. Therefore, CAD is a major component of this course. Solid modeling, using I-Deas Master Series, has been adopted as the CAD software platform used in this course. Prior to the study, this is the only course where solid modeling was utilized. To truly transition to solid modeling, I-Deas must become the principal design platform in the upper-level design courses.

Currently, transfer students can receive credit for the IDSM if they've completed courses in design and solid modeling. Since proficiency in I-Deas will be expected in the upper-level design courses, this policy has been altered. In addition to completing of appropriate courses, students wishing to receive credit for the IDSM must also complete tutorials in part modeling, building assemblies, and drawing creation. These tutorials will provide instructions on the details of using the I-Deas software.

Three design courses served as prime candidates for implementing solid modeling into the design process. These courses are required for all MET students, with other students only rarely enrolling. They include:

Machine Dynamics: This course focuses on the force analysis of machinery. Design implications are thoroughly discussed. Throughout the semester, an original design of a complex machine is developed. An assembly drawing and detailed drawings of original designed components are required. In the past, AutoCAD was used for this task. To reinforce the capabilities of solid modeling, I-Deas should be adopted as the required CAD system for this design process. In addition, I-Deas can be used to analyze the mass properties of components. These are required properties when performing dynamic force analysis of the machines components.

Design of Machine Elements: This course focuses on the design and selection of machine components. Similar to Machine Dynamics, an original design of a complex mechanical device is developed. An assembly drawing and detailed drawings of the original designed components are required. In the past, AutoCAD was used for this task. To reinforce the capabilities of solid modeling, I-Deas should be adopted as the required CAD system for this design process. Also, utilizing I-Deas facilitates the determination of the weight of the design. Often, the weight of a product is an important customer criteria. When 2-D CAD is used as the design platform, the machine assembly weight is a rough approximation

Capstone Design: This course is entirely focused on an original design project. Industrial partners typically sponsor the projects. Many of the sponsors already adopted solid modeling software, and were expecting the students to utilize similar capabilities to complete their work. Solid modeling must be adopted as the required CAD platform for the design activities. However, without multiple design experiences, using solid modeling skills, students are reluctant to use I-Deas. In the past, they tended to revert to 2-D modeling using AutoCAD. This deficiency has been eliminated by incorporating solid modeling throughout the curriculum.

The main obstacle for integrating solid modeling into these three courses revolves around faculty training. All full-time faculty members are not all proficient with I-Deas. Also, it is extremely rare to identify part time instructors, whose expertise revolves around the primary course material and are also competent with I-Deas. To overcome this obstacle, solid modeling consultants, who can assist students with questions and problems related to I-Deas, have been identified.

Other courses serve as secondary candidates for implementing solid modeling into the design process. These courses are also required for all mechanical engineering technology students, but other students commonly are involved. These secondary candidates include Statics and Dynamics, Strength of Materials, and Industrial Mechanisms. Similar to the primary candidates, these courses also include a semester project, which typically focuses on a design experience. Since not all students have had an introduction to solid modeling, implementation is difficult. To utilize I-Deas in these courses requires either of the following strategies:

a) The projects could be developed as teams. Portions of the projects could be discipline specific (industrial, manufacturing, electrical, mechanical). The mechanical students would be responsible for solid modeling and drawing preparation.

b) Remedial instruction, similar to the tutorials that would be required for students receiving transfer credit for the IDSM.

The final category of courses that can benefit from utilizing solid modeling include the those that focus on specialty skills. Finite Element Modeling already utilizes the analysis capabilities of I-Deas. Computer aided manufacturing course could utilize the automated tool path generation capabilities in the numerical control module of I-Deas.

V. Conclusions

Over the past few years, mechanical design has been shifting from 2-D CAD to solid modeling. This paper documented the reasons why that shift is increasing design productivity. To meet this demand, many Mechanical Engineering Technology programs have implemented stand-alone courses in solid modeling. However, few have taken advantage of using this skill throughout the curriculum.

The purpose of this study was to fully understand the intricacies of using solid modeling for actual design tasks. Using this knowledge, a plan for integrating solid modeling throughout the curriculum was formulated and documented.

The plan for the prime candidate courses has already been implemented. The details of incorporating the plan into the secondary candidate are being finalized. Students have profited from the experience with design experiences, similar to those being adopted and utilized in the field. This has been especially well received in the Dayton area, with its strong manufacturing base. The students will be better educated in a design process, which is in high demand.

Bibliography

1. Altidis, Paris, “One Engineers View on Ease of Use”, *The Design News*, Penn Engineering, June 19, 2000.
2. Berardinis, Lawrence A., "Models of Success", *Machine Design*, January 11, 1996, p54.
3. Dvorak, Paul, "Guidelines Show a Better Way to Solids", *Machine Design*, May 22, 1997, p52.
4. Howell, Steven, *Mechanical Desktop: Parametric Solid and Assembly Modeling*, Autodesk Press, 1st Ed., 1998
5. Lamit, L., Gary, *Pro/Engineer 2000I*, Brooks/Cole Publishing Co.,1st Ed. 1999.
6. Lueptwo, Richard, M., Minbiole, Michael, *Graphical Concepts Using SolidWorks*, Prentice Hall, 1st, Ed., 2000.
7. Sorby, Sheryl A., Manner, Kim J., *Solid Modeling With I-Deas*, Prentice-Hall, 1st Ed., 1999.

8. Teaque, Paul, “Why Engineers Seek Solid Ground”, *The Design News*, Penn Engineering, January 18, 1998.
9. Versprille, Ken, Which CAD is Right for You?", Integrated Manufacturing Solutions", *Society of Manufacturing Engineers*, March 1999.
10. Williams, Robert, “Solid Modeling : The Competitive Edge in Design”, *The Design News*, Penn Engineering, July 6, 1998.
11. Witney, Lee, "Transitioning to 3-D", *Manufacturing Engineer*, Society of Manufacturing Engineers, August 1999.
12. Wysack, Roy, L., Wolfe, L., Stephen, *Designing Parts With Solid Works*, CAD/CAM Publishing, 2nd Ed., 1998.

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