Taking CAD Integration to the Next Level

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Abstract:
A year ago “Using 3D CAD as a tool to integrate topics across the curriculum” was presented at this forum. \(^1\) That paper discussed the ambitious goal of integrating a 3D CAD tool, primarily IronCAD™ \(^2\), across the curriculum. Integration is continuing, beginning in the freshman year, through the undergraduate program, and into the graduate program. The major challenge presented in the reference paper was to encourage both students and faculty to take the first step to utilize the software in their classes and class work, thereby leveraging the advantages of this powerful and highly visual CAD system. Subsequently, the intent was to encourage widespread use of solid modeling, not only in CAD-based classes requiring creation of technical geometry and/or engineering drawings, but also in other technical classes, non-technical classes or any exercises, requiring tools for geometry, display, animation, and/or web content creation. Based on the initial 4-year plan, ultimate success will be indicated when solid modeling use among faculty and students becomes as ubiquitous as spreadsheet use is now.

This paper constitutes a follow-up report on the continuation of that initial effort and documents examples of both faculty and student integration of modeling-based projects. A faculty survey performed in Fall 2001 indicated strong Purdue University MET faculty support for the direction previously set forth. Of the six CAD software packages surveyed, two packages indicated an increased future utilization, while four indicated decreased future utilization in Purdue University’s MET department.

Examples of this 3D CAD integration using solid modeling will include formal and informal class projects and extracurricular activities, as well as the development and final outputs of a number of open-ended design projects spanning from freshman through graduate level. Other examples include the modeling and animated operation of mechanical assemblies such as an arbor press and a rack mounted stereo system; an independent study team project to develop a Battlebot™ robot; experimental mechanics team projects to develop indestructible football goal posts and to rapidly design, analyze, and visualize stresses in a combined stress experiment; industrial internship projects; a project involving metalcasting design optimization involving metal stream shrouding in pouring large high-alloy steel castings. Two additional courses have had students utilize solid modeling as a result of this effort and these efforts are summarized.

Introduction:
The process of CAD integration was begun at the freshman level with a second semester course entitled MET 102, Production design & Specifications (PD&S). Now in the fourth semester of use, IronCAD™ has seen success in a multitude of projects, both in a variety of class assignments and wholly student initiated applications. As such solid modeling has now migrated into a number of other undergraduate and graduate courses and is well on the way to integration across the whole curriculum. Examples of ways students and faculty are utilizing this powerful tool are discussed below.
To monitor this CAD integration process, a survey was assembled and emailed to all Purdue University MET faculty members in September, 2001 by one of the authors. The CAD software packages included in the survey included: IronCAD™, AutoCAD™, Pro/E, Solid-Edge™, Solid-Works™, and Catia™. This survey requested input on the faculty member’s overall interest level in CAD software relative to their teaching and/or applied research, their present specific CAD software utilization, their future anticipated CAD utilization, any corporate interest in specific CAD software packages expressed to the faculty member, and requested their input relative to which CAD software packages they would recommend if we had to choose two. The number of faculty indicating a “strong interest” was 15 out of 37. Of these “strongly interested” 15 respondents, 60% indicated a desire to utilize IronCAD™, 25% indicated a desire to utilize Pro/Engineer™ and 25% indicated a desire to utilize AutoCAD™ in their future teaching and applied research. The results of this survey show an increasing future interest in both IronCAD™ and Pro/Engineer™, with a declining future interest in the other four CAD software packages included in the survey.

**PD&D Course Applications**

Production Design & Specifications is the second in a two-course sequence on CAD applications and is normally taken the second semester of the freshman year. It is schedule early in the plan of study so that the techniques and knowledge learned can be applied to all subsequent courses as required. The prerequisite to PD&S, offered as a service course by another department, teaches students the rudimentary operational skills of solid modeling. Following that PD&S serves as the core course where students learn to use CAD to apply tolerances, fits, and other design intent specifications in exercises that require construction of CAD models crossing a variety of disciplines and manufacturing processes. These include, castings, weldments, sheet metal parts (flat pattern development) and a variety of machined parts. Because of the prerequisite IronCAD™-based course using a standard textbook⁸, when they enter PD&D, it is assumed that they know the basics of model creation and extraction of engineering drawings from the models.

While completing the series of increasingly more complex models, students learn how to calculate tolerancing (inch & metric), allowances, limits calculations, geometric dimensioning & tolerancing and fits based on ANSI and ISO standards. They also learn to apply and document open-ended design modifications based on change orders, cost constraints, requirement for use of standard parts (fasteners, bearings, gears, etc.) and adherence to the ISO preferred number system. Figures 1 depicts examples of models generated by students in PD&S and others done independently by students for assignments in other classes. These models are described below start from the upper left corner and proceed clockwise:

- An assembled motor mount used as the final design stage in a PD&S project. After completion of the models, calculating fits, specifying standard parts, resolving a series of engineering change orders, and generating complete engineering drawings, students must animate the parts to simulate the assembly and operation process.
A tooling fixture developed from the stock ASTM structural materials. Students must design the fixture, then specifying the welding processes necessary to build the device. This represents the 2nd project in PD&S.

An assembled arbor press used as a PD&S project. After completion of the modeling, calculating fits, specifying standard parts, resolving a series of engineering change orders, and generating complete engineering drawings, students must animate the parts to simulate the assembly and operation process.

An assembled electronics component box generated using the sheet metal tools in IronCAD™. This was the second project of the semester and required a dimensioned flat pattern drawing from the model.

Figure 1: Examples of student-created solid models from PD&S

Mechanics and Product-Design Independent Study Course Applications
Courses utilizing solid modeling in the mechanics area are: MET 211, Applied Strength of Materials and MET 311, Experimental Mechanics. MET 499, Independent Study for BattleBot™ design also makes use of the software in all areas of product design. In all projects, a design-analysis-test-presentation activity was utilized as shown in the figures. Mechanics applications continue to be an efficient means to have students quickly create geometry that can be modified as design, analysis, and test feedback dictates.
In a sophomore-level mechanics course at Purdue University, this capability was initially demonstrated to the students in the Fall of 2001. The initial demonstrations have evolved into faculty support of students performing their own modeling of homework and laboratory problems as depicted above.

The flexibility with which a solid model can be exported to analysis-specific Computer Aided Engineering (CAE) packages is a key factor in determining the utility of a particular solid modeling software package as a helpful tool. Solid modeling packages that attempt to vertically integrate a plethora of analysis packages often cannot meet the need of integrating cutting-edge CAE tools, in a timely manner, into the design process. Flexible importing and exporting features make are essential to CAD application utility and usefulness. For instance, exporting cleanly to COSMOS DesignSTAR™ requires a parasolid format, which several solid modelers provide and cleanly support subsequent finite element analysis (FEA) study creation including specification of material properties, restraints, and loading defined prior to mesh creation. Several student teams animated their DesignSTAR™ FEA studies and cut-and-pasted the exported animation into a PowerPoint™ presentation.

In the figures below, representative results from three mechanics area projects will be shown.
1) Figures 2 and 3 depict the design of an indestructible goal-post that will meet high school, NCAA, and NFL standards.
2) Figures 4, 5, and 6 depict the design of a BattleBot™ that can successfully be prototyped and debugged, enabling it to possibly compete in BattleBot™ tournaments.
3) Figure 7 depicts the modeling of an experimental mechanics combined stress laboratory C-Clamp to support finite element analysis (FEA) and experimental correlation with theory.

In each of the above three projects, a solid modeler helped the students rapidly develop solid models that met their design communication, FEA, and experimental needs. Future project plans will involve integrating spreadsheets with the solid modeler to be able to exploit both tools’ parametric capabilities more thoroughly.

Figure 2. DesignSTAR™ FEA study of goal post that failed in 1996 utilizing exported geometry from solid modeler and exploration of outside ranges of valid crossbar and upright sizes.
Figure 3. Array of conceptual designs constructed to study ideas for an “indestructible” goal post project in MET Experimental Mechanics class.

Figure 4: Cover page of independent-study project to develop a conceptual design for a Purdue University BattleBot™ along with an animated model of the BattleBot™ Arena.
Figure 5. Progression of BattleBot™ conceptual development using solid modeling.

Figure 6. COSMOS DesignSTAR™ FEA analysis and stereolithography prototype part fabrication using exported solid model geometry.

Figure 7. Model of Experimental Mechanics Laboratory combined stress C-Clamp. Geometry was later exported to DesignSTAR™ for FEA study.
**Example of Metalcasting Application**

MET 535, Optimal Metalcasting, continues to be a strong user of solid modeling software to allow students to rapidly capture design intent and allow rapid design iteration through the interface with application-specific analysis packages. Solid modeling was utilized during Spring 2001 to compare the conventional method of molten metal delivery to the mold cavity with the recently-implemented shroud pouring technique, as depicted in Figures 8 and 9.

**Figure 8** Example outputs of application-specific software based on exported solid model geometry with traditional (left) and turbulence-suppressed (right) metal delivery systems.

**Figure 9.** CFD simulation results for new gating system with turbulence suppressing splashing are well-supported using solid modeling software.
For the above analysis, the model of casting and gating system was generated with a solid modeler and saved as an STL file. The files were imported into the CFD software and the mold was generated around the casting. After the mold is added to the casting geometry, the properties are assigned for each material and the mesh is created. For consistency of the results, all the simulations were run with the same element size and the same pouring conditions as the experimental casting.

In comparing and contrasting the performance of the traditional and turbulence suppressing gating systems, the application of a 3D solid modeler was utilized and was of significant help due to its capability to easily modify geometry, which would be quite involved task in the CFD software package. The strength of all analysis packages is their specific expertise, while in most cases they lack 3D solid modeling or it may be very limited and quite difficult. The capability to easily model and modify the geometry and import it into the CFD package saved a significant amount of time that was spent on analyzing the actual problem and in publishing the results of the study.

**Internal Combustion Engines and Machine Elements Course Applications**
Consistent with the premise of this paper, two additional courses have adopted utilization of solid modeling software to enhance student learning opportunities. Figure 10 depicts a rocker arm assembly and a butterfly valve assembly developed by students in the IC Engines and Machine Elements courses, respectively.

![Figure 10. A rocker arm assembly and butterfly valve developed by students in an internal combustion engines and machine elements course, respectively.](image)

**Conclusions:**
While other solid modelers such as Pro/Engineer™, CATIA™, AutoCAD™ and others have been readily available and in limited use, the adoption of IronCAD™ as a strategic application has proven to be the key decision which increased the propagation of CAD technology across the department. Faculty who in the past would never consider CAD-based assignments, are now doing so. Other departments and other schools as well, are beginning to use IronCAD™, including Freshman Engineering.

As powerful as IronCAD™ is, superceding more entrenched systems such as Pro/Engineer™ is unlikely. Nevertheless, as an easy-to-use but powerful system with minimal learning curve, is tough to find a better solid modeling package than IronCAD™ in an educational environment where the concepts of CAD and 3D modeling matter more than system-specific skills.
Purdue University’s MET faculty survey has shown that the trend towards MET faculty adopting solid modeling software adoption in their coursework and applied research is proceeding very well. We also draw from that survey and our direct, hands-on experience with solid modeling that the expectation for future course adoptions is promising given the increasing numbers of students that will reach the upper division classes with solid modeling training.

Bibliography:

Biography:
BRUCE A HARDING
Harding is a Professor of Mechanical Engineering Technology and an ASEE Fellow. He teaches manufacturing design and specifications related courses emphasizing manufacturability, design for assembly and other quality issues. In 1983 he pioneered the first undergraduate CAD instruction at Purdue. His current specialty is implementation of geometric dimensioning and tolerancing standards. Presently he is a member of the ASME main committee overseeing American National Standards for CAD and engineering drawings, and chairs the ISO technical committee writing the worldwide versions of CAD and engineering drawing standards.

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Professor Szaroletta is an assistant professor of mechanical engineering technology at Purdue University. A member of ASEE, he has 18 years industry experience in engineering and project management positions, with 12 awarded patents. He received his B.S. Degree in Mechanical Engineering from University of Michigan, Ann Arbor in 1977, M.S. Degree in Engineering (Product Design) from Stanford University in 1984, and a Masters in Applied Mathematical Sciences Degree (Computer Science) from University of Georgia in 2000. He has 6 years university teaching experience, where his current applied research interests are rapid product design engineering, experimental mechanics laboratory automation, and optimization utilizing genetic algorithms.

MILETA TOMOVIC
Tomovic is an Associate Professor in the Mechanical Engineering Technology Department, Purdue University. He received his B.S. Degree in Mechanical Engineering from University of Belgrade in 1979, M.S. Degree in Mechanical Engineering from Massachusetts Institute of Technology in 1981, and Ph.D. Degree in Mechanical Engineering from University of Michigan, Ann Arbor in 1991. Dr. Tomovic teaches metalcasting, welding, and manufacturing courses. His research activities include manufacturing, metalcasting, welding, and design.