Teaching Computer Aided Drafting & Design (CADD) to Undergraduates

Jason A. Evers and John Rogers

This paper was completed and submitted in partial fulfillment of the Master Teacher Program, a 2-year faculty professional development program conducted by the Center for Teaching Excellence, United States Military Academy, West Point, NY, 2008.

Maintaining proficiency in one's profession can be a challenge as an educator, especially in regard to rapidly changing technology. In the realm of engineering, developments in Computer Aided Drafting & Design (CADD) over the past two decades have increased the speed and effectiveness of design through the use of modeling, analysis, and visualization tools embedded in software packages. Engineering graphics instructors have attempted to adapt their courses to keep pace with the rapid changes but instruction on higher-end, industry-standard CADD packages continues to increase in complexity, often causing courses to focus on the intricate series of commands that results in the creation of the model or drawing. The traditional engineering graphics courses tended to focus instead on projections, views, and other more basic visualization concepts. The argument then arises over how much time should be spent on the traditional graphics instruction versus the CADD package specific training such that students are experts in both visualization and modeling. The future of these types of courses looks increasing more complex as the abilities of various software packages increases into the realms of four- (time) and five- (money) dimensional models and CADD begins to morph into Virtual Design and Construction (VDC). This future necessitates a thorough review of current and past practice, which this paper seeks to do; and a look to the future to define the knowledge that our students need to have to succeed.

History of Computer-Aided Engineering Instruction

Engineering graphics instruction has evolved over the past few decades and continues to evolve as software and computer hardware improve. Prior to the advent of computer-aided drafting and design, graphics instruction was done with pencil, instruments and drafting board. Emphasis was placed on documentation practice. The ability to visualize objects in three dimensions from two-dimensional drawings was of primary importance. Two-dimensional computer aided drafting replaced mechanical drawing followed by three-dimensional solid modeling. Over the past 20 years the software has allowed the incorporation of data other than geometry such as material properties, cost, and scheduling information. The solid model can now be viewed as a database with information about a product and its life cycle. Design intent can be embedded in a solid model with the use of constraint-based modeling. [Branoff, Wiebe, Hartman] [Myszka]. Some institutions of higher education and high schools continue to teach two-dimensional documentation at the risk of leaving our students at a disadvantage in the workplace, but best practices are being defined at a national-level [Hartman].

Integration within a four-year curriculum

The integration of CADD within the curriculum is a familiar topic in the literature. Several of the articles summarized in the bibliography of this paper discuss the use of CAD outside of a graphics course [Baxter] [Branoff Wiebe Hartman] [Murphy Jensen] [Harding Szaroletta Tomovic] [McGrann] [Helbling Marriott Gally]. However, it is difficult to generalize from these articles since the structure of curricula at various institutions vary widely. Faculty at each institution must work toward the integration of CADD throughout the curriculum to provide the repetition and breadth of exposure that students need to retain the concepts.

Techniques to consider for implementation at USMA

USMA cadets in the mechanical engineering and nuclear engineering majors are required to take ME370, a course covering computer programming, computer aided design, and engineering analysis. Cadets in the civil engineering major are required to use AutoCAD and Bentley software in their coursework and capstone design project, but are not required to take a CADD course. Several ideas gleaned from the articles are worth considering for implementation at the United States Military Academy.

The concept of embedding design intent can be illustrated by subjecting student solid models to changes and observing the result. Models consistent with the designer's intent will respond properly while poorly constructed models will fail. [Hartman]. The "engineering change notice" and "multiple configurations of a standard catalog part" techniques [Branoff Wiebe Hartman] also are teaching the concept of incorporating design intent. Designing assemblies that incorporate models of purchased components or using on-hand material while solving a set of engineering requirements will give students a flavor of engineering problem solving. [Myszka].

Annotated Bibliography

Barr, R.E. & Juricic, D. (1994) *From Drafting to Modern Design Representation: The Evolution of Engineering Design Graphics*, Journal of Engineering Education, July 1994, pp 263-270.

The paper offers a brief review of the history of engineering graphics' evolution from ancient times. The authors make a compelling argument that during the "ideation" phase of a project, hand-sketching is still an extremely important skill for designers. They offer a proposed outline for a graphics course that is very interesting and comprises many of the aspects taught at our University. While these authors were writing in 1994, it is apparent that they were thinking far ahead to technologies that will span all aspects of design, analysis, production, and maintenance.

Rani, A., Wahab, A., Shaarani, R. & Aziz, A. (2001) *Facilitating Learning of Engineering Graphics Instead of Learning CAD System*. Platform vol. 2 no. 2

The authors teach a 3 credit engineering graphics course towards a bachelors in mechanical or chemical engineering at the Universiti Teknologi in Petronas, Malaysia. They compare the outline of a course focused on a specific CADD packages with one that trends toward more general engineering graphics instruction and make the case that fundamentals in engineering graphics instruction are being ignored in favor of package specific keystroke training. They make the case that the CADD package must be taught, but only following generalized engineering graphics instruction. Their course features engineering graphics instruction, followed by specific CADD package language, then laboratory "hands-on" learning.

Stiharu, I & Rakheja, S. (2003) *Knowledge, perception and representation in engineering graphics*, International Conference on Engineering Education, July 21-25, 2003, Valencia, Spain.

The authors of this paper make the case that engineering graphics instruction has been largely reduced in favor of specific CADD package command instructions, and that this reduction has resulted in poor communication and design abilities in students. Overall, they believe that CADD has been a positive development, but that it has reduced students' visualization skills and representation abilities.

Helbling, J., Marriott, D. & Gally, T. (2007) *Applied Computer Aided Design Using Aerospace Vehicles for Sophomore Level Students*, 2007 American Society of Engineering Educators Annual Conference, Honolulu, HI, **AC #2007-2701.**

The authors of this paper are using a CATIA CADD class to generate student interest in two other, subsequent areas in their curriculum. Emphasis for the CADD class is placed on the endstate of the design process – the production of a 3-dimensional physical model that can be tested in a wind tunnel to visualize flow streams.

Djassemi, M. (2007) *A Hands-on approach to teaching CAD/CAM for manufacturing and rapid prototyping applications* 2007 American Society of Engineering Educators Annual Conference, Honolulu, HI, AC #2007-1196.

This paper is written about a class in CAD/CAM/CNC, IT445, which is a requirement for an industrial technology program at California Polytechnic State

University. The author's approach to teaching this subject is a hands-on approach which involves several computer exercises in class and group work in labs. Little time is spent on lecture, but the emphasis is placed on using the 3D CAD model as a tool to get to prototyping and production, similar to what civil engineering CAD modeling should emphasize.

Lin, T., Sharif Ullah, A. M. M., & Harib, K. H. (2006) *On the Effective Teaching of CAD/CAM at the Undergraduate Level*, Computer-Aided Design & Applications, Vol. 3, No. 1-4, pp 331-339.

The authors make the case that students need to understand the math behind the generation of curves that become shapes in CAD, because they build CAM modeling input that is typically done behind the scenes for commercial packages. Likewise, the input parameters for cutting speeds and other CNC inputs come from the solution of parametric equations that the authors argue must be understood – through solving them by hand – in order for students to truly understand the material.

Pohl, J., Chapman, A., & Pohl, K.J. (2000) *Computer-Aided Design Systems for the 21st Century: Some Design Guidelines*, International Conference on Design and Decision-Support, Collaborative Agent Design Center, Cal Poly State University.

The authors explain how Collaborative Agent Design Center got started developing Army decision making tools through their work with Intelligent Computer-Aided Design Systems (ICADS). These systems were the pre-cursors to today's four- and five-dimensional design programs. Their paper discusses the operation of their product on an Integraph system and what they deem the essential requirements for a CAD decision-making tool among which are: a high level object representation and an intuitive graphical user interface.

R. F. Hamande, H. A. Artail, M. Y. Jaber (2005) *Evaluating the learning process of mechanical CAD students,* Computers & Education, Elsevier

The authors present a rigorous analysis of student learning in this paper. They distinguish between declarative knowledge, the ability to carry out a series of program-specific commands with procedural knowledge, the conceptual process of analyzing a three-dimensional object and "seeing" it as built-up of features. A power law learning curve model is presented.

It is noted that using fewer, more complex features was a faster way to build a model than a larger number of simple features. The authors review the keystroke-level model (KLM) of the Goals, Operators, Methods Selection (GOMS) rules published in 1980. The study is tailored to learners moving from novice to expert. The total learning curves are decomposed into their procedural and declarative components.

Learning is measured by tracking the time it takes to model three-dimensional bodies over the course of a semester. Two sets of bodies are assigned: an easy set and an intermediate set. Each set consists of four bodies of comparable difficulty.

Nathan W. Hartman (2004) *Defining Expertise in the Use of Constraint-based CAD Tools by Examining Practicing Professionals*, Purdue University, Proceedings of the 2004 American Society for Engineering Education Annual Conference and Exposition

The author opens with a discussion of how education and the proficient use of CAD have not kept pace with technological change. Effective strategies for the use of constraint-base CAD need to be developed. The purpose of the research is to examine the development of expertise by observing practicing professionals. Hartman discusses what it means to be an "expert" and summarizes the associated literature.

Five expert participants were engaged and two methods of data collection were employed: think-aloud modeling, and knowledge mapping. Each participant was given the task of creating a solid model given a written problem scenario, a part drawing and drawings of associated assembly parts. The goals were to determine modeling procedures common among experts and to find a common mental model of the knowledge domain of constraint-based CAD. The transcripts of the think-aloud modeling sessions were analyzed to document common modeling considerations. There was much variation among the participants, but all considered potential changes, feature order, parent-child relationships, and sketched geometry. Modeling strategies were developed to capture design intent, embedded relationships, and critical dimensions.

The knowledge mapping task involved placing index cards with common terms and phrases in relation to one another with respect to their importance and interrelationships. The experts all considered the model in the context of the whole design process, and also considered use of the model for other purposes such as strength analysis.

Expertise appears to develop from authentic engineering activities and immersion in constraint-based CAD during the educational process. Classroom activities should provide a clear engineering context for computer aided design. Modifying models according to specific criteria is important. Such activities will help students adjust to the complexity of design. For example, students might make changes to one-another's models get practice with geometry interrogation.

Complete constraint without overconstraint of the geometry should be the instructor's focus. Instructors need to asses student work by examining desired behavior and feature relationships.

Hartman recommends the use of written, open-ended problem scenarios that force the student to develop a modeling strategy that will capture design intent. The notion that CAD is not simply for display purposes needs to be gotten across. Using models to create prototypes and CNC code are examples. The student's model should be subjected to unforeseen design changes.

David H. Myszka (2004) *Putting the Design in Computer Aided Design*, Proceedings of the 2004 American Society for Engineering Education Annual Conference and Exposition

Myszka discusses the history of CAD course development and common topics covered in CAD courses.

Six short, detailed, open-ended design assignments are presented. In these assignments the student is typically required to create geometry to connect a base and a catalog component, a bearing or motor for instance. Each student is given unique parameters (dimensions and specific component catalog numbers).

Students are required to think more than they would if given a specific part to build. The author documents improvements in student ratings of the course. One

drawback is that the author could not find a text with such exercises and has spent many hours developing them. Another drawback is the student frustration arising from the effort it takes to understand what the instructor is looking for.

Abhishek Seth, Shana Smith, Mack Shelly, Jiang Qi (2005) *A Low Cost Virtual Reality Human Computer Interface for CAD Model Manipulation*, Proceedings of the 2005 American Society for Engineering Education Annual Conference and Exposition? Iowa State University

The authors document difficulties manipulating 3D CAD models with 2D devices such as mouse and keyboard, and some of the attempts to develop 3D devices such as data gloves that respond to hand gestures as well as stereo vision. The solid modeling design community has not widely adopted VR interfaces.

The system presented is implemented in C++. An off-the-shelf data glove device and a stereo display with off-the-shelf LCD shutter glasses are used to manipulate and view solid models created with ProEngineer or other CAD software. The Data glove recognizes hand gestures such as pointing by sensing finger joint flexure and hand tilt. Global hand movement is ignored for simplicity.

Object manipulation tasks were performed by subjects who then completed a survey. Subjects took longer to accomplish the manipulation tasks with the glove device than with a mouse and keyboard, probably because they were experienced CAD users with mouse and keyboard.

Radha Balimuralikrishna, Clifford R. Mirman (2005) *Adopting a Systems Approach to Design a Freshman Course in Technical Graphics—Meeting the Societal Need for Articulation*, Proceedings of the 2005 American Society for Engineering Education Annual Conference and Exposition

The motivation for the study described in the paper is "articulation," defined as the ability to transfer college credit within and between 2-year and 4-year colleges. A survey of freshman graphics revealed a wide variety in terms of offering, content, and structure. Five domains are identified to characterize courses: technical content, teaching method, medium of practice (pencil and paper vs. computer only), 2D vs. 3D design paradigm, and finally the specific graphics software used.

Douglas H. Baxter, Michael J. Guerci (2003) *Automating an Introductory Computer Aided Design Course to Improve Student Evaluation*, Proceedings of the 2003 American Society for Engineering Education Annual Conference and Exposition

The authors present their automated grading system for a large-enrollment graphics course. Solid models are submitted by students and evaluated automatically by a macro program written in Visual Basic that interacts with the SolidWorks models and provides feedback to the students. In addition to automated grading, the system provides early warning to instructors about lagging students.

Douglas H Baxter (2003) *Expanding the Use of Solid Modeling Throughout the Engineering Curriculum,* Proceedings of the 2003 American Society for Engineering Education Annual Conference and Exposition

The author discusses the use of solid modeling for teaching concept in courses other than graphics. Topics using solid modeling include vector properties, structural optimization, and differentiation applied to shape optimization. For example, a solid model of a vector and its orthogonal components helps in visualizing the equivalence of a vector and its components. Minimal knowledge of the CAD program is required to manipulate the vector in three dimensions.

Ted J. Branoff, Eric N. Wiebe, Nathan W. Hartman (2003) *Integrating Constraint-Based CAD into an Introductory Engineering Course: Activities and Grading Strategies,* Proceedings of the 2003 American Society for Engineering Education Annual Conference and Exposition

The paper includes a brief discussion of the evolution of graphics education over the past 50 years. The importance of using CAD tools to build intelligence into solid models is emphasized. The authors offer several techniques for the graphics instructor that teach the concept of constraint-based CAD. The engineering designer's intent for the part or assembly can be embedded into a solid model by incorporating three dimensional mathematical relations (e.g. hole centers are placed at 1/4 and 3/4 of the width of a part and automatically update when the part width is changed) and constraints (tangent, parallel, etc). Activities outlined include Engineering Change Notices, Reverse Engineering, and Modeling Multiple Configurations of a Standard Catalog Part. This approach requires the instructor to interrogate the solid model in order to evaluate a student's ability.

Michael D. Murphy, Daniel D. Jensen (1999) *Integrating CAD into an Already Packed Curriculum: Is another Class Necessary?* 1999 ASEE Annual Conference & Exposition: Engineering: Education to Serve the World; Charlotte, NC; USA; 20-23 June 1999.

The authors present a study of three options for teaching CAD at the US Air Force Academy where the engineering curriculum is constrained. The strategy of incorporating CAD in sophomore-level design courses and dropping a dedicated CAD course is promoted.

Alexander Lee, David Anderson, Karthik Ramani (2003) *"Toying" to Learn for 21st Century Product Development Environments: Computer-Aided Design, Collaboration, and Rapid Prototyping,* Proceedings of the 2003 American Society for Engineering Education Annual Conference and Exposition

The authors describe the development of a course at Purdue University in which the students design and build a working prototype of a toy. Students use a laser-based rapid-prototyping machine to create the prototype for a project fair. The project provides excellent motivation to learn CAD skills.

B. A. Harding, W. K. Szaroletta, M. M. Tomovic (2002) *Taking CAD Integration to the Next Level,* Proceedings of the 2002 American Society for Engineering Education Annual Conference and Exposition

The paper outlines the effort to include the use of solid modeling in technical and non-technical courses from freshman year through graduate school at Purdue University. Freshman graphics instruction includes a CAD course the first semester and a product design course second semester. Solid modeling is utilized in core mechanical engineering courses, mechanical engineering independent study, a metallurgy and casting course, an internal combustion engines course, and a machine elements course. The selection of a single CAD software package proved to be the key to propagating the use of solid modeling in the curriculum.

Roy T. R. McGrann (2008) *Assessing the Effectiveness of a Mechanical Engineering Computer-Aided Design Course,* The American Society for Engineering Education Zone I Conference, West Point, NY 2008

The author describes the assessment of a CAD course in the context of ABET accreditation. It is a good example of the place of a graphics course in a four-year mechanical engineering program. The assessment and improvement of CAD education over a six-year period is done by means of a “marker” problem, an assignment that is repeated with modifications from year to year. The marker project is the design of a landing gear system which employs a four-bar linkage.