# Constraint-Based, Solid Modeling: What do Employers Want Our Students to Know?

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## Abstract
Over the last twenty years, engineers, technologists, technicians and educators have watched the development of three-dimensional modeling go from wireframe to solid. More recently, constraint-based modelers have replaced 2D CAD and constructive solid geometry modelers as the tool of choice for many engineering applications. These modelers place the 3D model at the center of the design process database. Over the last several years, engineering graphics educators have been adjusting their curricula to better prepare students to secure employment in environments where constraint-based modelers are used. One of the big concerns in engineering graphics education is the importance of documentation in the curriculum. How much time should be spent covering multiview drawings, standards for dimensioning and tolerancing, sectional views, conventional practices, auxiliary views, or geometric dimensioning and tolerancing? Do employers want students to know these “drawing” practices? Do they want students to be proficient in constraint-based modeling? What do they expect students to know when they leave the university and what do they want them to learn on the job? This paper will summarize research in engineering graphics education related to constraint-based modeling, present survey results of employers who utilize constraint-based modeling software, and make recommendations related to changes in the engineering graphics education curriculum.

## Introduction
Engineering Design Graphics educators are at a critical point in time relative to curriculum development. Developments in computer technology over the last twenty years have drastically changed the way products are designed and manufactured. Although industry has kept up with these changes, many university programs have been slow to update curricula for a variety of reasons. These discrepancies between industry and education are evident when one examines the topics presented at *EDGD* (Engineering Design Graphics Division) conferences and published in the *EDG Journal* verses those topics published in trade journals, white papers, and other engineering publications. Within the *EDGD* there are still quite a few papers and presentations concerning 2D documentation. Recently, there have even been discussions of a nationally normed test for engineering graphics that is mainly focused on documentation [1].

Part of the problem may be that within the *EDGD* there are a wide variety of educators from institutions that have different goals. The *EDGD* has traditionally focused on preparing engineers to understand graphics. Participants at the last several *Midyear Conferences* of the *EDGD* have been from universities who prepare engineers and technologists and also community college instructors who prepare technicians. There are distinct differences between what these three groups of people should be able to do in a work setting as defined by the Panel on Engineering Infrastructure Diagramming and Modeling (as cited by the School of Technology at Michigan Technological University) [2]. *Engineers* need to be conceptualizers, innovators, planners, designers, developers, decision-makers, formulators of techniques and methods, and synthesizers of information. *Technologists*, on the other hand, should be prepared to be operators of systems, translators of concepts, directors of technicians, implementers, appliers of established techniques and methods, maintainers of systems, and analyzers. Finally, *technicians* should be prepared to be performers of operational tasks, users of proven techniques and methods, builders of components, operators, testers, collectors of data, maintainers of components, and preparers of technical drawings. If engineering design graphics faculty are preparing technicians, then focusing on engineering documentation is appropriate. If faculty are mainly preparing engineers and technologists, then the focus must be on something other than creating documentation. Currently, the status seems to be centered around documentation. In a national survey of engineering and technical graphics educators, Clark and Scales reported that only 16% of engineering and technical graphics faculty evaluate solid models in introductory courses, while 40.9% evaluate 2D CAD drawings [3].

When examining engineering publications, 2D CAD topics are rare. The current topics in recent trade journals, white papers and online journals are data exchange, online collaboration, understanding geometry defects and how to fix them, advanced modeling techniques, behavioral modeling, knowledge-based systems and integration of information throughout the design process, and the need for hybrid employees. If our students are to be successful in the workplace, educators must examine the kinds of topics that students will face.

**Data Exchange**

Exchanging data between two CAD systems and between a CAD system and other engineering applications continues to be a major concern for many firms. This is especially true for the automotive and aerospace industries where hundreds of subcontractors may be contributing to the production of the final design. Companies typically select from direct translators (where files are read and written in their native data sets), international standard file formats such as STEP, IGES, etc., or from various software that runs from a common geometry kernel to produce machine-independent geometry [4]. As CAD systems become more complex, and the need for translating more than just geometry between systems increases, companies will need to have individuals that understand problems with geometry and how to remedy them. In addition, they will need to have individuals who understand how to get data from one application to another with as little data loss as possible. The benefits of exchanging data with third party suppliers are too great to ignore. It is more cost effective to spend money on fixing data than to try to compete without the expertise of these third party suppliers [5].

**Collaboration**
Most CAD vendors are changing their focus from developing only core capabilities in modeling to online collaboration functions [6]. Collaboration software allows individuals at different locations to manipulate engineering documentation and models to simultaneously design a product [7]. The online companies who are developing collaboration software are trying to change the way manufacturers operate. Instead of paying for one system to be located within a company that can handle all design and manufacturing functions, online application service providers (ASP) are developing software that can be accessed on a "pay per use" basis. Companies can even test most of these applications at no cost [8]. What does this mean for educators? Students who can come into a company and collaborate with customers, suppliers, and other employees will be more effective. They will allow their company to surpass the competition by saving time, reducing costs, and bringing products to the market faster [9].

While there may be no common answer as to how to accommodate collaboration in the new engineering graphics curriculum, there should be no reason to ignore it. Companies are devoting to many resources to this issue for it to become a passing fad. Communication is stressed throughout most university degree programs, and the techniques provided by the Internet and related technologies have only served to further enhance its coverage. In fact, some graphics programs make communication the platform upon which they operate. At the annual EDGD midyear meeting in San Antonio, Acheson suggested that partnerships between engineering graphics programs and ASPs might be a way to address issues that currently plague our field today. These issues include software costs, integration and installation support, currency of instructor training, and exposure of students to new technologies [10].

**Understanding 3D Geometry**
Current 3D CAD systems incorporate many functions that employees must understand if they are to be successful in the engineering design environment. Feature-based CAD programs now automate many processes that were once tedious to produce, such as fillets and rounds or patterns of holes. Although this makes modeling much faster and easier, when problems arise in the geometry, sometimes the solution is not evident. It is important to understand that these problems may arise from structural defects or violations of the rules of solid modeling, low accuracy or problems with tolerancing, and unrealistic geometry or features that are typically caused by inexperienced CAD operators. These issues with model quality can create larger problems within a company if the models are used for other downstream applications [11].

**Surface Modeling Techniques**
Solid modeling systems have increased rapidly in their capabilities over the last 12 years. Systems have come from having the user apply Boolean operations to create solid models to sophisticated constraint-based modelers that incorporate design intent into large assemblies. For many engineering companies, solid modeling systems continue to meet their needs. There are, however, some industries and applications where surface modeling systems are more beneficial. These

include packaging, footwear, ceramics, toys, and automotive and aerospace components [12]. In the CAD/CAM industry, close to 60% of North American mold makers receive design data electronically in the form of surface models [13]. It is evident when reviewing periodicals related to engineering design that students will need to understand complex modeling techniques and strategies for both solid and surface models in order to be competitive in the workplace.

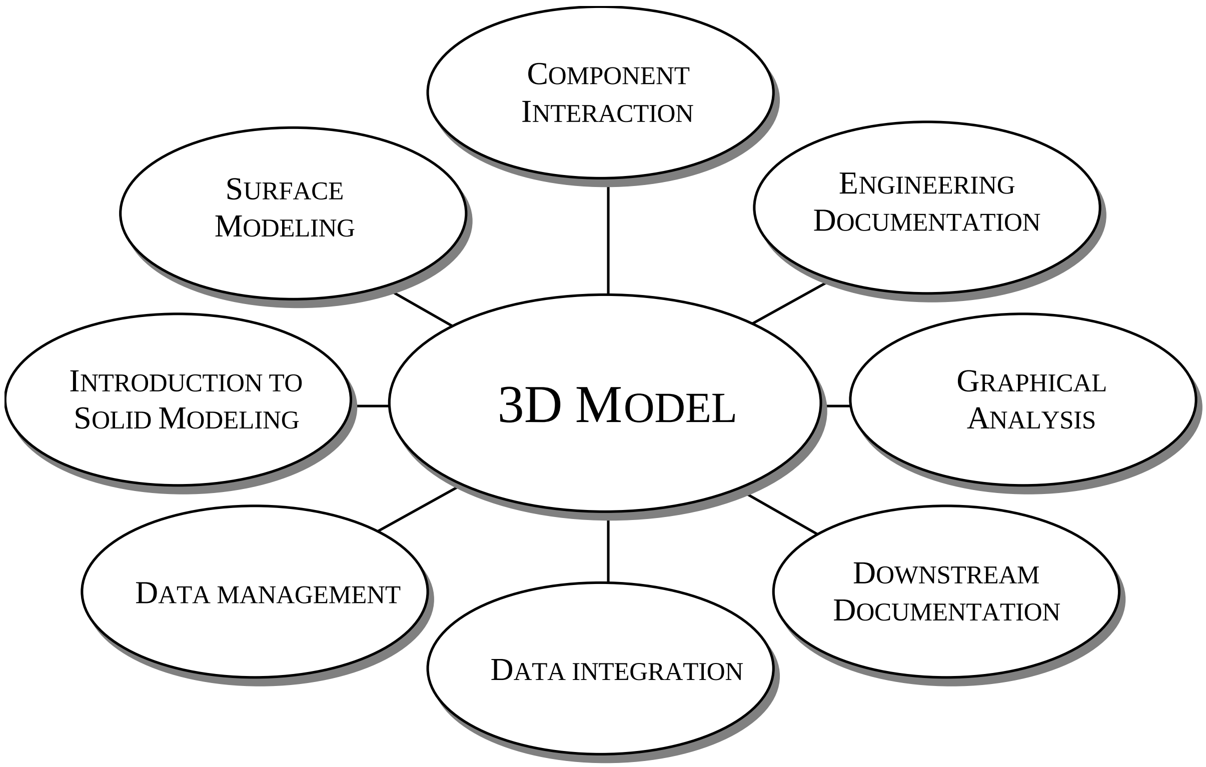
**Behavioral Modeling, Knowledge-Based Systems, and Integration of Information**

Mechanical design automation technology has evolved from 2D CAD to 3D CAD to solid and surface modeling to feature-based parametric modeling to behavioral modeling. Smart or intelligent models contain information about geometry, processes, applications, and desired model behaviors [14]. CAD modeling has traditionally been used to capture complex geometry and assemblies with hundreds or even thousands of parts. Because companies do not function only on geometry alone, systems have been developed to cut down the time from design to manufacture by including intelligent information along with the model. This information includes specifications, design details, costs, materials, tooling, assemblies, and testing data [15]. These knowledge-based systems are intelligent software that can manage and take advantage of design engineering tasks. They capture design intent, part relationships, standards, and rules that govern product configuration, engineering, and geometry. Knowledge-based systems also allow the product expert, rather than a programmer, to define and write the rules using spreadsheets or the proprietary language within the software [16]. When using knowledge-based systems, new employees must be prepared to work in a *culture of knowledge management* where they understand the rationale for design decisions and are capable of working with systems that proactively support expertise and documentation of best practices [17]. Students need to be ready to use these knowledge-based systems to successfully move engineering information through the design process. Many articles have been written in past ASEE publications regarding incorporation of design principles into classroom activities. These types of modeling systems allow engineering graphics educators to give students meaningful, design-based assignments, and it gives them the ability to assess their students based on realistic solution requirements to problems, rather than tedious minutia.

**Hybrid Employees**

Since more and more engineering and technology applications are happening online, many employers are looking for individuals who not only have knowledge in their content area, but who also can do some level of programming in web-based environments. Traditionally employers have kept designers and programmers separate. Stereotyping employees and keeping individuals separate undermines collaboration efforts. Some of the blame can be placed on educational institutions, but many companies continue to keep design and technology departments separate [18].

To take advantage of this collaborative environment, Branoff and Hartman [19] have suggested the adoption of a curriculum model separated in tiers of responsibility and level of detail. The tiers are the same ones mentioned in the Introduction of this paper: engineer, technologist, and technician. While it is possible that there could be some overlap between these different disciplines, the courses used in the preparation of these individuals would all be conducted within the spirit of the following curriculum model for engineering design graphics. All of these courses contain the majority of the requisite knowledge suggested by industry trends as being important.




There has been an issue raised during past presentations of this model regarding pedagogical approaches to teaching with this model. The engineering student will be given an overview of each of these topics with an exemplary activity to match. The goal is to give them an appreciation of how each of these topics impacts the design process. Unfortunately, most engineers spend little of their time on the job actually doing what most of them would consider "design work". All too often, engineers are tasked with responsibilities, in addition to those mentioned in the Introduction of this paper, relating to field issues and problems, negotiations with suppliers, testing, project management, and other tasks which leave them little time to do any productive design work. Because of these extra responsibilities, it is critical that the technologist and technician be well versed in these topics. Technologists will be immersed in the integration and relationships of these topics. They will spend time creating geometry, managing databases, integrating systems, and exploring down-stream uses for the model. They will be immersed in laboratory exercises to emphasize these topics throughout their formal education. Technicians may not cover the breadth of material that engineers and technologists deal with, but they will explore, with a great deal of depth, several of the topics of the aforementioned curriculum model, such as geometry creation techniques and the use of data management systems. These levels of the engineering graphics curriculum closely correspond to the stages of the engineering design process that already exist, namely concept, development, and implementation.

**Industry Surveys**

During December 2001, several companies in the Raleigh, North Carolina area were surveyed to determine the types of skills that applicants would need to secure a position doing constraint-based modeling. Thirty-five individuals were asked to rank 37 topics and educational experiences for their importance in a hiring decision. Eleven individuals responded to the survey. The highest ranked topics were assembly modeling, constraint-based modeling, modeling strategies, 3D geometric primitives, and orthographic projection. Most companies required people to have associate degrees in engineering technology, one required a 4 year degree in engineering, one required a 4 year degree in a technology area, and one reported only a high school diploma was necessary for employment. All survey respondents worked for companies that did primarily engineering design or manufacturing and worked in either an engineering or design manufacturing department.

In a survey of 28 companies, Cumberland identified areas of expertise necessary for the next generation of engineering graphics technicians. He concluded that engineering graphics programs should include the following topics: macro programming, data translation, file and data management, CAD standards, constraint-based solid modeling, web technologies, simulation and animation, internships, collaboration, and a study of current trends and issues [20].

**Conclusion**

As the EDG educators look ahead to prepare for the future, it is critical that trends in industry be examined so that students will be properly prepared to enter the workforce and make a difference. Currently, industry seems to be looking for individuals who can move data throughout the design process, collaborate online with customers, suppliers and coworkers, identify and fix problems with 3D geometry, use powerful knowledge-based systems to design complex assemblies, and be flexible enough to do design and development work. Is there evidence that companies are having problems because they cannot find employees who can handle these tasks? The United States Navy recently delayed delivery dates on the LPD 17 San Antonio-class landing platform dock ships for many of the reasons stated above. Although the main reason for the delay was the overall design complexity of the ship, other factors included problems with design integration, miscalculating the complexity of the CAD environment, a shortage of qualified designers, and converting 3D design information into fabrication instructions [19].

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