Teaching of Parametric Modeling Methodologies for Undergraduate Engineering Students

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Abstract: - In this paper, the experiences of incorporating parametric modeling methodologies in a computer aided design course are introduced. This course aims at sophomore and junior mechanical engineering students. Students are expected to understand the fundamentals of solid modeling, incorporate design intents in modeling processes effectively, and master basic skills of using commercial software for solid modeling. The overview of course design is given, encountered challenges are discussed, and solutions to these challenges are provided. Tentative results from two-year teaching are reported, and some suggestions for further improvement have been identified.

Key-Words: -parametric design, design intents, solid modeling, computer graphics, computer drawing, computer aided design (CAD), education curriculum.

1 Introduction

Due to the saturation of production capability and globalization of the economy, business environment becomes very turbulent and uncertain. The key strategy to keep the competiveness of a manufacturing company is to design and produce new products at a short time and supply them to markets as early as possible [1]. Computer Aided Design (CAD) software becomes essential means for companies to implement the strategy. The ultimate goal of CAD is to relieve designers from low-level or non-creative tasks in designing products, assessing manufacturability of products, and generating all the data necessary to produce them. A large variety of solid modeling software tools are commercially available. They have significantly increased design productivity, improved product quality, and reduced manufacturing and maintenance costs. At the time of the economic recession, engineering companies have a privilege to seek new employees with a high competence, in particular, with a high-level of solid modeling skill [2].

Earlier teaching curricula with computer assisted tools need the continuous evolution to catch up with the advance of Information Technologies (IT). Educators have made their endeavor in integrating modern technologies in teaching. For examples, Mare and Jyri [3] examined the feasibility of digital teaching tools in the education of human factors engineering; they found students evaluated the digital tools very positively in comparison with face-to-face coaching or discussion; a case study of web-based education was introduced for distance learning in agricultural engineering courses; the identified benefits are flexibility, and encouragement of cooperative spirit and individualizes [4]. Viamonte[5] suggested integrating computing tools in exploring mathematic concepts, and transforming concrete experiences to abstract mathematics ideas. Rahamat et al. [6] concerned the perceived satisfaction on e-learning materials and environment; they argued that computer-based materials ensure knowledge is transferred more effectively. Regarding the computer aided drawing; industrial companies have gradually recognized the importance of advanced solid modeling technique to design and manufacturing [7]. Universities and colleges bear the responsibility of training students in solid modeling and preparing them for successful engineering careers.

Educational institutes with engineering program usually offer the courses on engineering graphics and computer drawing. The skills of hand-drawing and basic 2-D drawing on computer are taught. For example, at the Department of Engineering of our university, the course of "ENG120: Graphical Communications and Spatial Analysis" is offered to serve this purpose. In that class, students are trained to dimension parts, create 2-D drawings, and generate isometric and sectional views of objects using a 2-D drawing software tool. Note that 2D hand or computer drawing is imperative but it seems insufficient to today's undergraduates. One of the main reasons is that traditional 2D engineering drawings have been rapidly replaced with advanced 3D solid modeling. The course on solid modeling will introduce some fundamental tools used to design large scale and complicated products and processes, and to integrate solid models with engineering analysis required by applications. In the northern east area of Indiana, the well-trained workers in solid modeling are relatively less in comparison with the available job positions where advanced solid modeling skills are required. Taking an example of our university, the number of engineering students with an enter-level solid modeling skills is less than the number of the internship positions required solid modeling knowledge. As the matter of fact, this is the key driver for the department to develop the solid modeling course.

The necessity of developing a solid modeling course does not imply that a university can place this new course readily in its curricula. Based on a national survey of engineering and graphics educators, only 16% of engineering and technical graphics faculty evaluated solid models in introductory courses, while 40.9% of them evaluated 2D CAD drawings [8]. The idea to develop a solid modeling course is not unanimous. Some suggested that solid modeling skills have to be developed through life experiences. Several studies stated that solid modeling skills cannot effectively be taught through typical instructional methods. Nevertheless, an equal number of studies have found that solid modeling has been improved through instruction [9]. The research was conducted on the effects of solid modeling and visualization to technical problem solving. It was found that visualization was a significant predictor of technical problem solving as defined by successful prototype construction [10]. The subjects of the course should be assessed carefully to avoid being a substitution of training of a specific software tool. On one hand, there are many vendors of solid modeling software tools; all of them provide the training services for their products. On other hand, a university tends to keep classic courses on computer graphics and spatial visualization; this new course must exclusively focus on the fundamentals of solid modeling.

In this paper, the challenges in developing this new course are discussed and feasible solutions to these challenges are provided. The rest of the paper is organized as follows. In Section 2, an overview of this new course is introduced; it includes the list of contents and syllabus. In Section 3, the encountered challenges are discussed and the solutions to overcome these challenges are provided. In Section 4, the results of course development have been reported. In Section 5, some suggestions for further improvement of this course are identified.

2 Overview of Solid Modeling Course

Computer graphics and visualization is the key communication means for engineers to demonstrate design concepts, adopt advanced technologies such as virtual reality, CAD/CAM/CAPP, rapid prototyping, current engineering in their engineering practice. With the rapidly development of solid modeling tools and applications, traditional knowledge on engineering graphics and 2D drawing exposes its limitations to understand complex solid models and master popular solid modeling tools. The possession of knowledge and skills of solid modeling has evolved from ‘better to have’ to ‘must-have’.

Engineering schools and programs have many different considerations in determining how to teach engineering graphics, how many credit hours the course should be, how often the course is offered, and what contents should be covered [11]. The answers for those questions are varied from school to school. Based on a thorough assessment on various factors, the Department of Engineering at the IPFW decided to offer a 2-credit hour core course on solid modeling but open only to Mechanical Engineering students; this new course aims at sophomore and junior students. An instructor and students meet weekly, each meeting consists of one-hour lecture on the fundamentals of solid modeling and two-hour lab for the practice of solid modeling using commercial software tools. An overview of this course is provided in this section.

2.1 Course Goal and Objectives

The goal of the course is to introduce solid modeling methods and integrate solid models with necessary engineering analysis. It will prepare students to identify the design intentions, create and modify part or assembly models productively, and provide students with the essential skills to use a solid model for advanced engineering design.

Solid modeling is an interdisciplinary field that involves a growing number of areas. Its objectives evolved from a deep understanding of the practices and requirements of the targeted application domains. Its formulation and rigor are based on mathematical foundations derived from general and algebraic topology, and from Euclidean, differential, and algebraic geometry. The computational aspects of solid modeling deal with efficient data structures and algorithms, and benefit from recent developments in the field of computational geometry. Techniques for modeling and analyzing surfaces and for computing their intersections are important in solid modeling [2]. To adopt this new course in current curricula of the Engineering Program at IPFW, two objectives of the solid modeling course are (i) to have students to understand some fundamental knowledge about computer graphics for solid models, (ii) to have students to use commercial software tool for solid modeling.

2.2 Course Outline

Traditional computer drawing course emphasized heavily on correct size and style of geometric elements: instead of the underlying problem-solving process used to create the model, the ‘look’ of the graphic model is focused. It has been suggested to use a dynamic modeling approach to provide the opportunities for students to learn about geometry through the embedding of geometric behaviors into models and then testing these behaviors via dynamic change of the model [12].

While 3D constraint-based modeling has been in use in industry for more than ten years, it has only been within the last few years that there has been gradually adoption of these modeling tools at colleges and universities. 3D modeling tools have been identified as a key component of some areas of engineering education for a while [13], but it has only been recently that educators have begun to investigate how the newer constraint-based modeling tools bring a new set of possibilities to instruction [12]. In teaching a solid modeling course, instructors have merged it with many other different subjects such as computer graphics, Computer Integrated Manufacturing (CIM), Computer Aided Engineering (CAE), and numerical calculation. For example, the solid modeling subject is integrated with computer programming at Michigan Technological University, the merged course is taught at the first-year of its engineering program. The motivation is to develop proficiency in solving engineering problems by using computer graphics [14]. For some universities without mechanical engineering, a computer science department often in collaboration with the mathematics department to offer solid modeling knowledge in different courses such as Geometry for Computer Graphics and CAD, Curves and Surfaces for Computer Graphics and CAD, and Geometric Modeling [15]; since the applications of CAD, CAE, and CAM are heavily relied on dynamic properties of solid models, solid modeling has mostly been treated as a core ingredient of those courses [16].

The solid modeling course is required not only to cover sufficient depth and breadth of theory and fundamentals, but also contain a strong emphasis on the application of the technology [17]. Learning from the aforementioned experiences of peer institutions, this new course consists of two modules: theory and CAD practice. The list of selected subjects has been illustrated in Figure 1. It has been organized under four pillars, i.e., 3D modeling fundamentals, part modeling, assembly modeling, and solid models in product life-cycle. It turns out that the objectives for theory and practice can be well balanced.

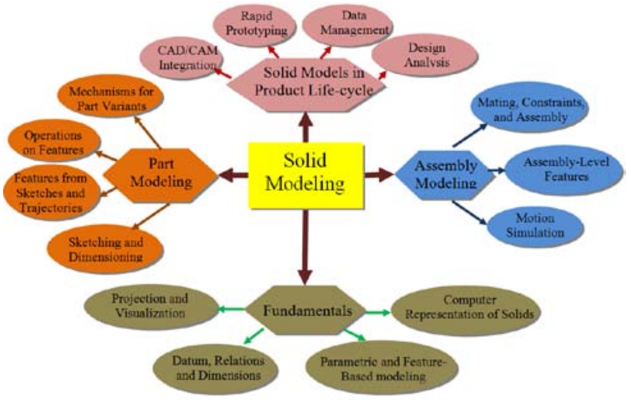


Figure 1. The Contents of Solid Modelling Course

2.3 Course Textbook

Both of fundamental knowledge on solid modeling and the hand-on skills of using CAD tools are covered in this class. Therefore, an ideal textbook would put similar weights on theory and applications. However, no textbook has been found to satisfy our requirements appropriately.

Two types of textbooks are available on market. The first type of the textbooks focuses on fundamental theory of computer graphics. They are focused on the basics of computer graphics and drawing [18, 19]. Taking an example of the reference book by Hoffmann [20], it could be an excellent option for the introduction of graphic theory, concepts, and algorithms needed to design and implement solid modeling systems. However, it is inappropriate to be adopted as a textbook to sophomore and junior ME students; the majority of them lack sound mathematic knowledge and interests for computer graphics. The second type of textbooks focuses on practical skills. These books include little theory but the detailed tutorials about solid modeling. Tutorials in those books are developed for one of commercial CAD software packages, such as Solid Works [21], Catia [22], ProE[23], Solid Edge [24], or Unigraphics[25]. Due to heavy graphical nature of the contents, the second type of the textbooks cannot serve the educational purpose sufficiently [26].

By taking into consideration of 3D modeling theory and applications, it is determined that the class teaching materials consists of the lecture notes on solid modeling theory collected by the instructor and the practice tutorials from a textbook which is written for a specific CAD tool. The textbook by Howard and Musto[21] has been selected for this course.

2.4. Software for Labs

Hand-on skills have to be cultivated from practice in actual design environment. Using a CAD software tool, an instructor can demonstrate the functionality of the software through relevant examples. Students are required to acquire mastery through the completion of specific part and assembly modeling assignments and design projects. Some subjects of practice include sketching functionality, using the relations to capture design intent, create placed features, extrusion, revolution, sweep, loft, and assembly modeling. It was expected that this course would provide students with a solid background to create fairly complex parts and define simple assemblies [27].

The next question is what software fits the purpose of this course well. All of solid modeling tools follow the same principles of solid modeling in the development of their software tool, and there is no a clear winner about what software tools should be taught at a university. It is not critical in terms of the knowledge of solid modeling the students should learn; once a student is familiar to one software tool; it is very easy for him/her to transfer the skill to a new software tool. On other hand, future employers of students do care about the students' skills on a specific software tool. Okudan [28] proposed a methodology that would enable one to optimally select a design software tool for varying objectives. The methodology is developed based on (i) reviewing existing criteria in evaluation of design software, (ii) comparing a number of design software packages based on established criteria, and (iii) running design experiments for testing differences among various software tools. In available tools, the Solid Works has been often selected as the design package for instruction in solid modeling techniques based on the growth in popularity of this CAD package during the past five years. This design package has earned industry-wide recognition and acceptance because of its functionality, ease of use, and wide range of support services offered including partnerships with creators of allied applications for manufacturing and engineering analysis.

2.5 Organization and Evaluation

The course has a weekly meeting. Each meeting consists of a one-hour lecture and two-hour practice. Students are required to complete one or two exercises in class and to complete homeworks and design projects after school. Students are graded based on exercise, homeworks, design projects and exams.

3 Challenges and Solutions

3.1 Diversities of Students

One challenge for this new course is the variety of engineering drawing backgrounds among students. To accommodate mechanical engineering students in class, two prerequisite courses are "ENGR 120: Graphical Communications and Spatial Analysis" and "MA 165: Analytical Geometry and Calculus I". However, computers at engineering labs are equipped with many CAD software tools, some students manage to self-teach a few of CAD tools; in particular, the CAD tools, such as AUTOCAD and SolidEdge are used in other courses. Those students have a very good understanding of solid modeling. On other hand, a few of students have had no chance to be exposed to any CAD software tools, and their knowledge and skills on computer graphics are very limited.

To accommodate these two groups, the period of class meetings has been set as 3-hour instead of 2-hour for other 2-credit courses. The long period allows the students with the limited computer graphic knowledge to complete the required exercises in class, which is crucial for them to build their confidence in learning a new software tool. The lab portion usually consists of the exercises at the basic and advanced levels. The exercises at the basic level correspond to the core theory and knowledge and those at the advanced level correspond to the more sophisticated hand-on skills. The completion of the basic level exercises is mandatory to all of the students and of the advanced-level exercises are optional. However, a student is not allowed to leave classroom early if all of exercises are not completed. The advanced-level exercises do motivate those students who have the good graphic backgrounds and who have strong interests in computer-aided design.

3.2 Computer Crashes

The problems of computer crashes came to the author with a big surprise when this course was firstly offered; since very rare crashes would happen on a computer with a stand-alone license. When Solid Works were installed and used in class in 2009, computer crashes happened very frequently, and the computers for some unfortunate students crashed in average 5 minutes. These incidents discouraged the students in solid modeling practice. The worse thing was that there was no pattern to be followed for those crashes; they might happen in any occasion. As a consequence, even though students' evaluations for the first two semesters were at the department's average, the majority of students complained about serious computer problems. Crashes had happened frequently when students used some tools such as 'smart dimensions', 'design equations', 'design tables', and when students tried to create a drawing template or customerize modeling environments.

Regardless numerous efforts of IT staff, the actual causes of computer crashes had yet been revealed. Some temporary meanings were applied to retain students’ interests on solid modeling practice: (i) Students are required to download and install a evaluation license of Solid Works on their personal computers. The majority of students possess computer(s) at home, and the stand-along installation can eliminate possible crashes caused by networks. Thanks to the selected textbook, a 6-month free student license of Solid Works is available to students. Therefore, students were encouraged to use their own computers throughout the semester. (ii) Since the practice time in the computer lab was not warranted, it is reasonable to offer more flexibility to students in submitting home works and exercises. Basically, late submissions no more than one week of due date were acceptable. (iii) To encourage students to practice solid modeling after class, the instructor extends the office hours in supporting students. It is worth to mention that the computer crash problems have been addressed satisfactorily after the department updated all of the legacy computers in engineering labs in 2010.

3.3 Balance of Theory and Hand-on Skills

The difficulty to make a trade-off between the theory and skills in teaching a CAD course class has been well recognized. While, the majority of undergraduates show their excitation at learning a 3D software tool, some of them lack genius interests and motivations in learning basic fundamental theory for 3D modeling. For example, vectors and matrices are essential to represent objects in space; students can easily lose their attentions since vectors and matrices are not directly involved in solid modeling process. Another example is the computer representations of a solid model. Mathematically, three basic representations are Constructive Solid Geometrics, Surface Boundary Representation, and the Spatial Decomposition. Students can be easily confused by the set of functional tools in solid modeling such as Extrusion, Revolve Sweeping, and Patterns. These tools are actually the interfaces to access some software functions. They create the features of a solid model, but they are not inside representations of solids.

'Divide and conquer' is the first strategy to integrate the fundamental theory in the solid modeling course. No class entirely covers the theory. In each class, a few of new concepts are introduced and the sufficient time is provided to students for them to refresh these concepts through practice. For example, one class is dedicated to the roles of relations and constraints in 3D modeling. These concepts will be discussed and classified in terms of the number of the entities a relation or constraint can be applied for. The corresponding exercises focus on the usage of relations and constraints are embedded to optimize solid modeling. The second strategy is to inspire students to use creative thinking. For example, Design Intent is a very important concept for solid modeling; it refers to a plan to model a part or assembly optimally by taking into considerations of all possible future changes. In many exercises, students are required to define their design intents and evaluate the easiness of future changes based on various options of design intents. By finding the difficulties of the changes due to an inappropriate selection, students appreciate the importance of design intent concept.

3.4 Design Projects

The advantages of bringing design projects into technical courses have been well recognized by researchers [29, 30]. A CAD textbook usually provides some detailed tutorials for the students to learn new design tools. The positive side of the detailed tutorials is that the students can create solid models without a fully understanding of graphic theory and computer software. Those tutorials are extremely useful to beginners. The negative side of the tutorials is that the students do not get trained to create solid models with their own thinking. It is not uncommon that a student can create a solid model quickly by following a tutorial, and he/she cannot create this solid model again without the instructions from the textbook. From this point of view, the assignments of design projects become an effective way for students to think the solid modeling process independently. The subjects, the scope, and the requirements of design projects are carefully assessed so that students can achieve this objective.

In the solid modeling course, students have the option of defining the subjects of design projects by themselves or given by instructor. The majority of the students decided to define their own design projects. Based on the scope of a design project, it can be performed by individual or a team up to three students. The instructor has the minimal requirements of the design projects: an individual or a team member must create at least ten parts, the animation or simulation of the product assembly or machine must be provided, and further analysis of engineering application leads to bonus at end. Future engineers should also be able to communicate effectively; to enhance the communication capability via solid modeling, students are requested to present their design project orally. The peer of the classmates will grade the outcomes of design projects mutually.

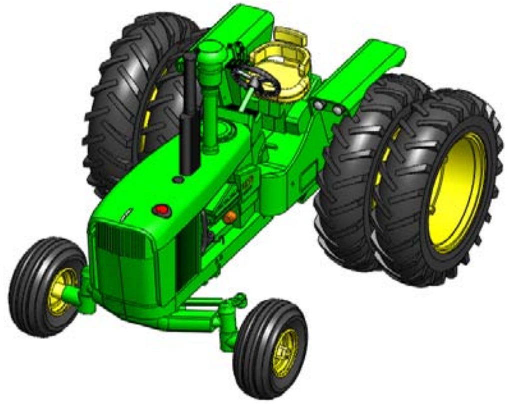


Figure 2. Example of Students' Design Project — A Truck model by Brandon Schumm

Two examples of the students with a full score of the design projects are illustrated in Figure 2 and Figure 3. The example in Figure 2 was made by Brandon Schumm, a junior ME student at IPFW. The model consisted of 37 parts, 4 subassemblies. All of assemblies and mechanisms were functioned appropriately, and the motion simulation was conducted to demonstrate the kinematic chain. The Photoview360 was applied to increase the quality of visualization. He estimated to spend 55 hours on his design project. The example in Figure 3 was made by Jessica Hunnicutt and Conrad Brett, two ME students at the same department. It consisted of 25 parts with reverse-engineered dimensions, 3 subassemblies with a total of 79 parts. The most impressive outcome was the motion simulation of the trigger and bullets. There was not direct tool in the software package to define relative motions of two objects without a joint relation, and it was a challenge to simulate the motion of a bullet.

(a) actual product

(b) model in Solidworks

Figure 3. Example of Students' Design Project — A Gun model by Brett Conrad and Jessica Hunnicutt

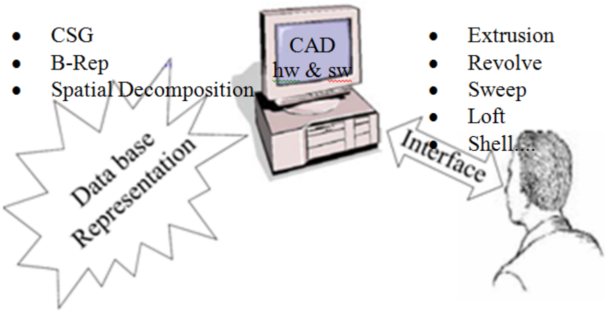


Figure 4. Computer 3DRepresentations

4 Key Concepts in Solid Modeling

In contrast to many traditional courses in Mechanical Engineering, the evolution of solid modeling technologies is very young; many concepts in the discipline of solid modeling are still ill-defined. To teaching these concepts, instructors have to look for the resolutions from recent research publications, presentations and the Internet. A great effort is demanded to refine these concepts. In this section, a few of these concepts are discussed and the experiences in teaching those concepts are briefly summarized.

4.1 Computer Representations and Modeling of Solid Objects

It is important to teach basic data structures used to represent solid models in computers. Since the development of a CAD software tool is not focused, an instructor might not be allowed to teach the systematic methods for data representations. It should be sufficient to clarify the role of data representations in solid modeling. However, when students learn those representations, they are easily confused between the data representations and the solid modeling tools in software. As shown in Figure 4, the confusion can be avoided when the relations among the database, the hardware and software of CAD model, and user/observer are explained. The positions of computer representations and the available solid modeling tools in solid modeling technique can be found readily.

4.2 Parametric Modeling

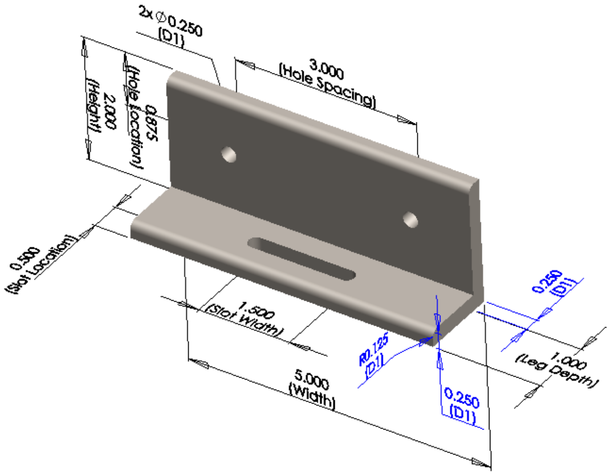
Parametric modeling or feature-based modeling is often treated as an alternative terminology to solid modeling. However, a unanimous definition of parametric modeling has not been found. Through many examples of different parametric modeling techniques including associativity of models, design tables, linked values, and design equations, students are asked to define the concept of parametric modeling by themselves. While the wordings of their statements are different, students tend to use both of 'features' and 'parameter'. Therefore, the further discussions were made on the correlation of 'feature' and 'parameter'. Assume a solid model is a hierarchy tree of 2D or 3D building block, a feature is defined as a building block of the solid model. For each feature, one or a set of parameters are used to define this feature completely. A parameter in solid modeling can be a dimension, a relation, a logical operation, or a variable indicating the status of a feature. In other words, parameters can be anything needed to represent a feature uniquely. To make students aware of features and parameters consciously, exercises in the following aspects are designed:

- Apply relations and dimensions in sketching to maintain design intents
- Use linked values and design equations to define the constraints of two dimensions
- Use design tables for part family
- Observe associativity in the solid model and drawing of a part by changing a dimension in a part file or drawing file.

4.3 Design Intent

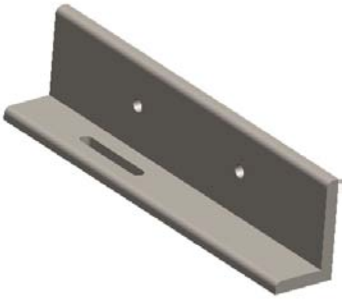
Understanding “design intent” and how to execute it in solid modeling can never be overemphasized. A design is created for a purpose. Design intent is the intellectual arrangements of features and dimensions of a design; design intent governs that relationship between features in a part and parts in assemblies.

While students usually follow the tutorials of solid modeling to create solid objects, they are encouraged to plan the modeling procedure independently based on selected design intents. Students are asked to test the easiness of changes based on different selections of design intents. For a solid object, designers often have many different ways to create a solid model; the performance of a 3D model can be evaluated for a large number of choices for design intents. As shown in Figure 5, a simple part is provided to illustrate the importance of design intent. The outcome of the design must maintain all of the symmetries of the part, the relations of the variables for dimensions are defined in the given equations. Figure 5a, 5b, 5c, and 5d have shown four cases of a wrong model with the possible reasons.



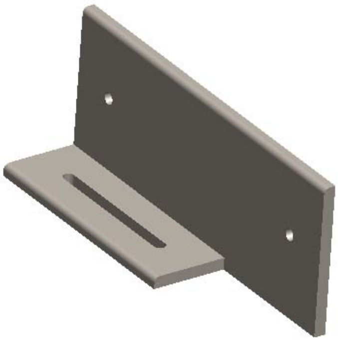
- Height =0.4 (Width)
- Leg Depth = ½ (Height)
- Hole Spacing = Width minus 2 inches
- Hole Location = ½ (Height minus 0.25 inch)
- Slot Width =1/2 (Hole Spacing)
- Slot Location =1/2 (Leg Depth)

(a) Correct model

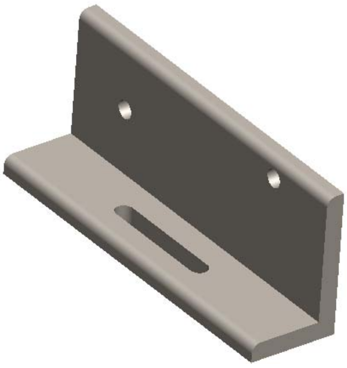


(b) Wrong model caused by missing the constraints of symmetry about a vertical central line of part for the slot

(c) Wrong model caused by lacking the symmetric plane of the part

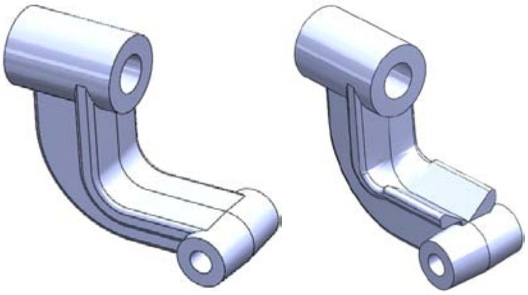


(d) Wrong model caused by missing a collinear relation of an edge in the second sketch with an existing edge in the first extrusion



(e) Wrong model caused by missing missing the constraints of horizontal central lines of two holes

Figure 5. The Importance of Design Intent



(a) correct sweep (b) incorrect sweep

Figure 6. Example of Software Intelligence

4.4 Intelligence of CAD Software Tool

The primary goal of a CAD software tool is to relief engineers from tedious routinely design activities. A software tool must possess a certain level of intelligence to reach this goal. Intelligence might be measured by the efficiency of the tool to interpret the minimized input into a correct solid model. Take an example of an Extrusion tool in the Solid Works, the minimized input from a designer is a valid 2D sketch, and the depth of the extrusion. The intelligence of the software tool is illustrated that the software defines the direction of extrusion and it creates all of the boundary surfaces including side walls and two end surfaces [31].

Students can be discouraged when all of the inputs are taken in place but the result of a solid model in Solid Work is not the expected one. These cases are commonly seen when some advanced part modeling tools such as 'sweep' or 'loft' are applied. As shown in Figure 6, the corrected solid model is in Figure6a where a loft feature connects two ribs at two ends smoothly. However, if the sketches are not fully defined even with all correct dimensions, the software tool might have a wrong interpretation of the design intent and result in an incorrect model in Fig 6b. Students should appreciate the limitations of existing software tools, and they should be able to consider an alternative plan to the software, so that all design intents can be implemented appropriately.

5 Solid Models in Product's Life Cycle

One significant advantage of a solid model is that it contains complete data for engineering analysis. Students can benefit from the integration of a solid model with various engineering analysis. In addition, most of the commercial software tools provide the interfaces to users to conduct engineering analysis after the process of solid modeling. In this proposed course, the following applications of solid models are covered.

5.1 Simulation and Machine Design

Modern computerized tools are now regularly used across all scales of industry. In mechanical design, solid modeling not only allows virtual building of a component but also analysis and optimization. An opportunity is now available to allow students to innovate on an unprecedented level using solid modeling [32]. Within manufacturing industry, the usage of kinematic analysis is common-place. Therefore, undergraduate students in this area must have a knowledge base in the applied areas of kinematic design, dynamics analysis, and implementation of systems that provide motion, such as cams, gears, and mechanisms [22].

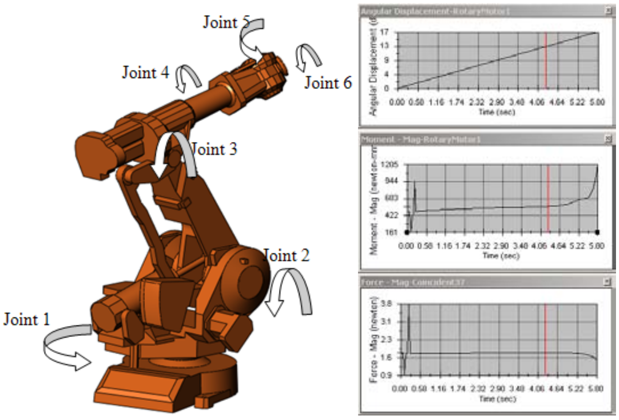


Figure 7. Example of Machine Simulation Using Solid Works

After an assembly model of a machine is created from its parts, kinematic and dynamic behaviors of the machine can be simulated in the CAD software tool, e.g. the Motion Simulation tool of Solid Works. Students can define rotary or translational joints and take into consideration of friction and gravity for a motion simulation. All of the simulation results, such as velocities and accelerations of the objects, the reaction forces/torques at joints, can be displayed and exported. As shown in Figure 7, an assembly model of the ABB robot has been used as a case study during the course of its motion simulation. The ABB robot has six degrees of freedom whose motion directions are specified in Figure 7. The 3D models of parts were downloaded from the ABB website [33]. Students are required to edit the original CAD models and insert extra datum to assembly these parts appropriately. The motion simulation of the assembled robot should be performed, and the engaged forces in all of active joints have to be exported to see if the robot meet the functional requirements of the task.

5.2 Finite Element Analysis

Solid modeling technology has now been advanced to a stage where it has become the precursor to a wide array of engineering analyses including finite element analysis. These recent developments suggest that we can make a case for a mandatory course in solid modeling enabled manufacturing analysis for all manufacturing engineering and technology majors [27]. The purpose of the introduction of finite element analysis is to inform students that a solid model provides the great convenience for engineering analysis. Geometries and boundaries of the objects have been defined in a solid model, and dynamic properties of the object, such as volume, weight, moments of inertia can be evaluated easily in solid modeling tools. The general procedure of applying a finite element analysis is introduced. Students conduct the finite element analysis and optimization for the created part based on some given criteria such as the minimized weight or dimension. By all meanings, the fundamental theory of finite element analysis is out of the scope for the solid modeling class. The tutorial in on-line helps of Solid Works seems an appropriate source for students to learn the integration of solid modeling with finite element analysis.

5.3 CAD/CAM Integration and Rapid Prototyping

The completion of a solid model is not the destination of a design process. Students can benefit from a basic understanding of manufacturing processes, by which the conceived product can be fabricated and assembled. The technologies discussed in this course to materialize design concepts are CAD/CAM integration and rapid prototyping.

CAM is generally an ideal outlet of CAD. Today, over three-quarters of new machine tools incorporate CNC technologies. These tools are used in every conceivable manufacturing sector, including many that affect building technologies. Initially, CAD software tools had little effect on computer numerical controllers (CNCs) due to the different capabilities and file formats used by drawing and machining programs. With the advances of recent technologies, many CAD software tools including SolidWorks and Unigraphics have incorporated CAMs. Students can appreciate the efficiency of CAD/CAM integration.

5.4 Product Life Cycle Management

The rapid advancement of information technology has influenced the process of product development in many manufacturing companies [34]. One practical issue of solid models is how to exchange data with other engineering systems. As the CAD systems become more complex, 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. 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 [35]. Other two covered aspects in this course are mold design and metal sheet design.

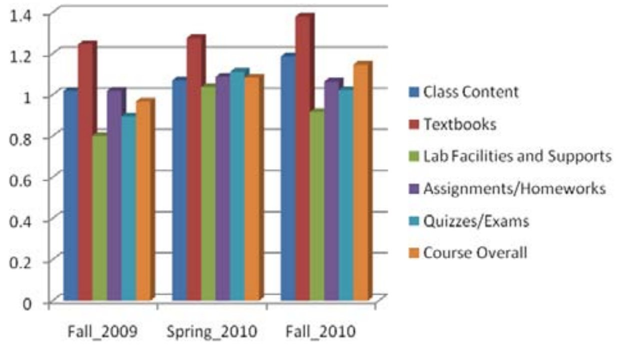


Figure 8. Trend of students' evaluations with respect to the department's average

6 Results

The evaluations from the students are very encouraging to the department. Students have been very interested and engaged in this new class; most of them are willing to put their extra efforts in accomplishing home works and design projects.

The feedbacks of the students' evaluation forms have been summarized in Figure 8. The feedbacks to six questions related to this course are included and the average performance of the offered courses in the department is used as a benchmark. The data are normalized with a ratio of the individual's score and the department's average score. It implies that a value over 1.0 implies the performance of the solid modeling is above the average of the department.

Overall, this new course has received very positive response from students, and the trend of the improvement is obvious. The only index below the average in the Spring Semester of 2010 was on 'lab facilities and support'. The main reason was that not all of the lab computers are installed with Solid Works and students experience some problems to use software tools after class; another reason was probably that new computers at the labs still use old-fashion mice with three press buttons; they are without a rolling wheel in middle and very inconvenient for solid modeling.

The followings are some typical comments from the students:

- The assignment were fun;
- The program is fun to learn very interesting and practical;
- I thought the motion simulation part is cool;
- (I like) everything;
- It is diversity, interesting subject;
- I wish it was offered earlier…

7 Further Improvements

The new solid modeling course at the IPFW has been proven to be very successful. Two primary objectives have been well achieved and students enjoy in attending this course. There is an increasing pressure from the department's standpoint to open the course to the students with other engineering programs. However, it has been seen that this course can be improved from the following aspects.

7.1 Labs for CAD/CAM Integration

Shortening the development time of a new product is the key factor to the success of many companies. Efficient design contributes significantly to this shortening. The CAD design tool can contribute to this shift. A solid model can be directly applied to analyze the performance of product virtually, and the performance of product can be verified before the final product is materialized. Moreover, a solid model can be directly utilized to generate programs for manufacturing and assembly processes. Two or more labs on how to integrate CAD models with CNCs machines or rapid prototyping systems will be very helpful. It is desirable for students to access the rapid prototyping machine or CNC machine and experience the whole process from design, to manufacturing, and to assembly.

7.2 Task-Oriented Product Design

Taking into consideration of time constraints, design projects for students are confined to reverse engineering some existing products. Students' knowledge and skills on the design activities of entire products have not been fully exploded. Generally, designs can be classified into top-down design and down-to-top design. For the assignment of design projects, it might be feasible to specify a theme of design scope, and provide the students to experience the whole design procedure from design idea, concept design, detail design, verification, and implementation.

7.3CSWA Practice

It is desirable for the students to possess the certificates after they possess sufficient knowledge about the usage of a specific software tool such as Solid Works and ProE. It is advantageous in a curriculum which can cover some information on the basics of the qualification tests and master key concepts and knowledge to increase the success rate of tests. This can challenge some motivated students.

7.4 Tips to Learn a Solid Modeling Tools

There are so many software tools available on market, it is impossible to introduce every one of them in class. However, it is possible to find some common things about those software tools, and summarize some guides and tips to help students to learn new software tools quickly once they become available to students.

7.5 Integration with Other Machine Design Courses

Solid Modeling is a very powerful tool to support other courses such as robotics, design of machinery, and design of machine elements. At the IPFW, some paramilitary studies have been conducted to use solid modeling tool for design projects in ME361 Kinematic and Dynamic Design of Machinery and ME360 Design of Machine Elements. Students agreed that solid modeling tools have helped them understand the mechanism, visualize machine motions, and facilitate the analysis procedure of engineering design. It is possible to integrate solid modeling methodology as a practical means for design of machines and machine elements.

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