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.

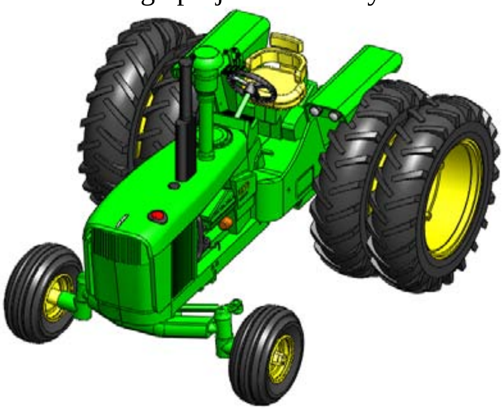


Figure 2. Example of Students' Design Project — A Truck model by Brandon Schumm

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

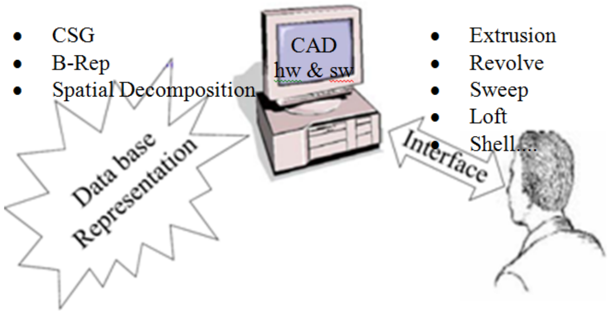


Figure 4. Computer 3DRepresentations

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

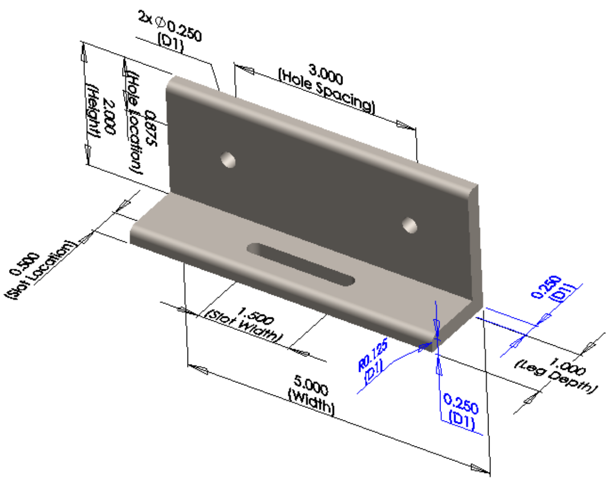
Parametric modeling or feature-based modeling is often treated as an alternative terminology to solid modeling. However, a unanimous definition of parametric modeling has not been found. Through many examples of different parametric modeling techniques including associativity of models, design tables, 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

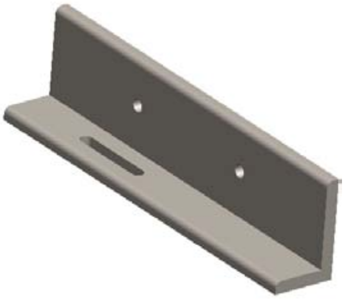
Understanding “design intent” and how to execute it in solid modeling can never be overemphasized. A design is created for a purpose. Design intent is the intellectual arrangements of features and dimensions of a design; design intent governs that relationship between features in a part and parts in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



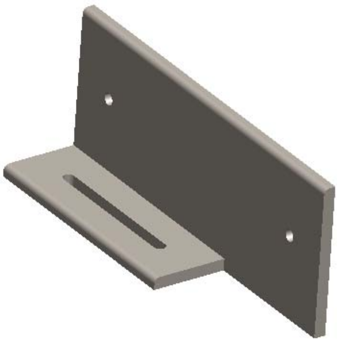
- Height =0.4 (Width)
- Leg Depth = ½ (Height)
- Hole Spacing = Width minus 2 inches
- Hole Location = ½ (Height minus 0.25 inch)
- Slot Width =1/2 (Hole Spacing)
- Slot Location =1/2 (Leg Depth)

(a) Correct model

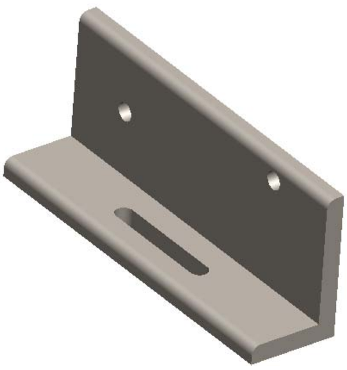


(b) Wrong model caused by missing the constraints of symmetry about a vertical central line of part for the slot

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

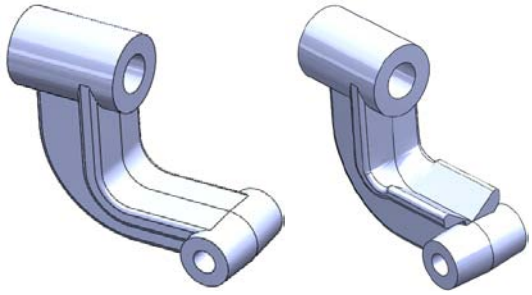


(d) Wrong model caused by missing a collinear relation of an edge in the second sketch with an existing edge in the first extrusion



(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].

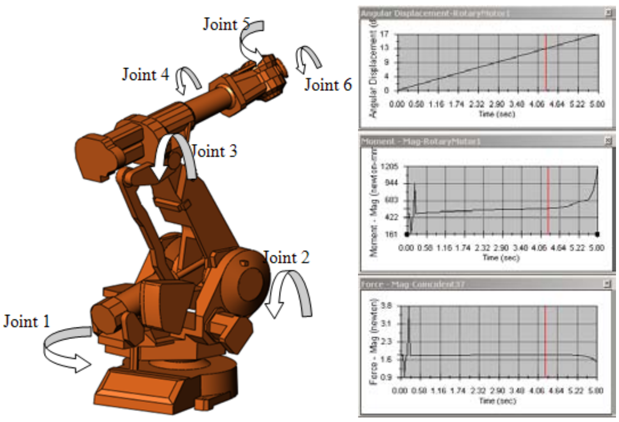


Figure 7. Example of Machine Simulation Using Solid Works

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.

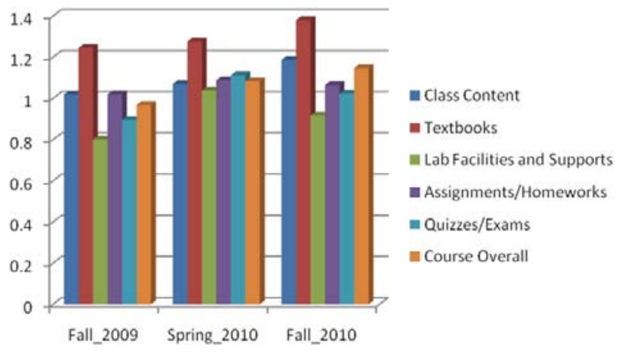


Figure 8. Trend of students' evaluations with respect to the department's average

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.

Acknowledgements. The author would like to thank all of IPFW students in his ME 160 Solid Modeling course for their enthusiasm, engagement, and suggestions to the course. Especially, thank Mr. Brandon Schumm, Mr. Brett Conrad, and Miss Jessica Hunnicutt for their excellent Solid Modeling projects.

References
[1] Z. M. Bi, S. Y. T. Lang, W. M. Shen, L. Wang, Reconfigurable Manufacturing Systems: the State of the Art, *International Journal of Production Research*, Vol. 46, No. 4, 2008, pp. 967-992.

[2] Jarek R. Rossignac, Aristides A. G. Requicha, "Solid Modeling", http://www.gvu.gatech.edu/~jarek/papers/sm.pdf, 1999.

[3] Teichmann Mare, I. V. JyriJr, Human Factors Engineering: Digital Teaching Tools and Paper-Free Handouts for Lecture Notes, *WSEAS Transactions on Advances in Engineering Education*, 2012, Vol. 9, No, 2, pp. 31-41.

[4] K. G. Arvanitis, G. Patelis, D.Papachristos, Application of a Model of Asynchronous Web based Education (WbE) in the Agricultural Engineering Sector, *WSEAS Transactions on Advances in Engineering Education*, 2012, Vol. 9, No.1, pp. 12-22.

[5] Ana J. Viamonte, The Computer in the Mathematics Teaching, *WSEAS Transactions on Advances in Engineering Education*, 2010, Vol. 7, No. 3, pp.63-72.

[6] R. Rahamat, P. M. Shah, R. Din, S. N.Puteh, J. A. Aziz, H. Norman, M. A.Embi, Measuring Leaners' Perceived Satisfaction Towards e-Learning Materials and Environment, *WSEAS Transactions on Advances in Engineering Education*, 2012, Vol. 9, No. 3, pp. 73-83.

[7] J. Hutchinson, Re-Thinking the CAD Course: Design, not Drafting, http://www.tiesmagazine.org/archives/dec_2002/pdf/dec_2002_CadCourse.pdf, 2002.

[8] A. C. Clark, A. Y. Scales, Assessment Practices in Engineering/Technical Graphics, *Engineering Design Graphics Journal*, Vol. 65. 2001, No. 3, pp. 13-24.

[9] Shawn Strong, Roger Smith, Spatial Visualization: Fundamentals and Trends in Engineering Graphics, *Journal of Industrial Technology*, 2002, Vol. 18, No. 1, pp. 2-6.

[10] D. S.Koch, The Effects of Solid Modeling and Visualization on Technical Problem Solving, *Ph.D. Thesis, Virginia Polytechnic Institute*

and State University, Blacksburg, Virginia, 2006.
[11] R. Jerz, How CAD Forces Changes to Engineering Graphics Education, *Proceedings of the 2001 American Society for Engineering Education Annual Conference & Exposition, American Society for Engineering Education*.
[12] Eric N. Wiebe, Ted J. Branoff, Nathan W. Hartman, Teaching Geometry through Dynamic Modeling in Introductory Engineering Graphics, *Engineering Design Graphics Journal*, 2003, Vol. 67, No. 2, pp. 12-20.
[13] R. E.Barr, T. J. Krueger, T. A.Aanstoos, J. Moore Horan, Industry-Sponsored Design Projects for Freshmen Engineering Graphics Students, *the Gulf Southwest Section Meeting, American Society for Engineering Education*, March, 2003.
[14] Norma Veurink, J. Hertel, Integrating Solid Modeling and Computer Programming Through a Freshman Design Experience, *38th ASEE/IEEE Frontiers in Education Conference*, October 22 – 25, 2008, Saratoga Springs, NY, pp. S1D-3 - S1D-7.
[15] HanspeterBieri, Teaching Solid Modeling within a Non-Specialized Curriculum", http://static.upillar.com/pictures/resources/93313/scaled/Springfield_photo.jpg?1266079158, 1996.
[16] J. Pan, Syllabus for IME 335 Computer-Aided Manufacturing I, http://www.calpoly.edu/~pan/teaching/ime335_syllabus.pdf, 2004.
[17] K. S. Lee, M. L. H. LowEngineering Visualization and Modeling: Teaching and Management Using the IT Approach, *International Journal of Mechanical Engineering Education*, 2005, Vol. 32, No. 2, pp. 160-180.
[18] G. R. Bertoline, Introduction to Graphics Communications for Engineers,*McGraw Hill Higher Education*, ISBN-10: 0073522643, 2008.
[19] F. E. Giesecke, A. T.Mitchell, H. C.Spencer, J. T.Dygdon, J. E. Novak, S. D. Lockhart, I. L.Hill, M.Goodman, *Modern Graphics Communications* (4th Edition), Prentice Hall, ISBN-13: 978-0135151037, 2009.
[20] Christoph M.Hoffmann, Geometric and Solid Modeling, http://www.cs.purdue.edu/homes/cmh/distribution/books/front.pdf, 1989.
[21] W. Howard, J.Musto, J. *Introduction to Solid Modeling Using SolidWorks 2010*, McGrwa-Hill, ISBN-10:0073375438, 2010.
[22] Sham Tickoo, S. Ekbote, S. *CATIAV5R17 for Designers*, CADCIM Technologies, USA, ISBN: 193270924X, 2007.
[23] A. Adewale, Solid Modeling Using Pro/Engineer Wildfire, *the 1st Edition, Thomson Delmar Learning*, ISBN-10: 1-4180-0564-9, 2006.
[24] Sham Tickoo, D. Swapna, *Solid Edge ST2 for Designers*, CADCIM Technologies, ISBN-10: 1932709797, 2010.
[25] Randy H. Shih, *Parametric Modeling with UGSNX6*, SDC Publications, ISBN: 978-158503-486-4, 2008.
[26] Yong S. Suh, JohnathenMcCasland, Interactive Construction of Solids from Orthographic Multiviews for an Educational Software Tool, *Computer-Aided Design & Applications*, 2009, Vol. 6, No. 2, pp. 219-229.
[27] R. Balamuralikrishna, Clifford R. Mirman, Infusing Manufacturing Analysis in the Manufacturing Engineering Technology Curriculum Using CAD, *2003 IL/IN Sectional Conference*, April 4-5, 2003 – Valparaiso University, Valparaiso, IN, American Society for Engineering Education.
[28] Gul E. Okudan, Selecting a Solid Modeling Software for Integration to Engineering Design Teaching: A Proposed Methodology & Its Application Results, *Proceedings of the 2004 American Society for Engineering Education Conference & Exposition, American Society for Engineering Education.*
[29] K. Lapin, S.Ragaisis, Integrating Team Projects into the SE Curriculum, *WSEAS Transactions on Advances in Engineering Education*, 2008, Vol. 3, No. 5, pp. 104-110.
[30] D. M. Viana, M. F. S. E. Silva, A. C. Santana, H.Abdalia JR., Including Integrating Projects in Engineering Curricula, *WSEAS Transactions on Advances in Engineering Education*, 2008, Vol. 3, No. 8, pp.73-82.
[31] Dimonte Group, Curvy Stuff 101, http://www.dimontegroup.com/Tutorials/CurvyStuff102.htm, 2011.
[32] Davis S. Nobes, K. K. Duke, P. Mertiny, On the Influence of Solid Modeling on Design Innovation in Junior Mechanical Engineering Design Courses, *Proceedings of the 2010 Canadian Engineering Education Association*, http://library.queensu.ca/ojs/index.php/PCEEA/article/viewFile/3125/3063.

[33] ABB Inc.,IRB4400 CAD Model, http://www.abb.com/abblibrary/DownloadCenter/, 2011.
[34] Y. Aoshima, K.Nobeoka, Y. Takeda, The Impact of 3D-CAD on New Product Development, kdea.re.kr/event/aoshima.doc, 2005.
[35] Theodore J. Branoff, Nathan W. Hartman, Eric N. Wiebe, Constraint-Based, Solid Modeling: What do Employers Want Our Students to Know? *Proceedings of the 2002 American Society for Engineering Education Annual Conference & Exposition*, *American Society for Engineering Education*.