AC 2007-1203: DEVELOPMENT OF A STANDALONE COMPUTER-AIDED TUTORIAL TO INTEGRATE COMPUTATIONAL TOOLS INTO A MECHANICAL DESIGN CURRICULUM

Fernando Class-Morales, Cessna Aircraft Company

Fernando Class-Morales earned his B.S. in Mechanical Engineering from the University of Puerto Rico at Mayaguez in 2002, and his M.S. in General Engineering from the University of Illinois at Urbana-Champaign in 2007. He worked as an intern for UTC – Pratt & Whitney, and is currently a Mechanical Systems Engineer at Cessna Aircraft Company in Wichita, KS. In his free time, Fernando enjoys playing paintball and working on obtaining his pilot license.

Jim Leake, University of Illinois-Urbana Champaign

James Leake joined the Department of Industrial and Enterprise Systems (formerly General) Engineering in August 1999. His educational background includes an MS in Mechanical Engineering (1993) from the University of Washington, a BS in Ocean Engineering (1980) from Florida Atlantic University, and a BA in Art History (1974) from Indiana University. His current research interests include engineering education, integration of CAD/CAE software in the engineering curriculum, spatial visualization, and reverse engineering. Professor Leake's publications include the book Autodesk Inventor, published by McGraw-Hill in 2004 and a CD series, Learning to Use AutoCAD 2D & 3D, published by Thompson Delmar Learning in 2003. He is currently working on an engineering design graphics text to be published by Wiley in 2007. Prior to coming to Illinois, Leake taught CAD and math courses at UAE University in the United Arab Emirates. He is a returned Peace Corps Volunteer, where he served in Tunisia from 1983 until 1986. Leake worked as a naval architect in the Pacific Northwest for 10 years. He is a registered professional engineer in naval architecture in the state of Washington (1990).

Brenton Hall, University of Illinois-Urbana Champaign

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Abstract

Mechanical design courses introduce fundamental concepts in the analysis and design of structural and machine components and assemblies, leaving little or no class time available to introduce students to the latest software developments in this area. In addition, instructors in these courses often lack the tools needed to help students grasp concepts that may be difficult to visualize.

Consequently, the objective of this work was to develop a parallel curriculum tool to provide supplementary instruction in mechanical design. This standalone tutorial is intended for use outside the classroom by undergraduate engineering students. The instructional package provides instruction on the use of the mechanical design and analysis software tools currently available in Autodesk® Inventor™, specifically, the Dynamic Simulation and the Design Accelerator modules. The tutorial provides the user with an interactive overview of different types of simple mechanisms (e.g., four bar linkage, gears) frequently found in mechanical design courses, as well as more complex mechanisms (e.g., scissor jack, cordless screwdriver, differential gear) encountered in everyday life. Virtual working models of the previously mentioned devices are created and subsequently analyzed in the tutorial. Mechanical design topic coverage includes finding the position, velocity, and acceleration of a geometric element on a mechanism, the conjugate action of involute tooth gears, and other illustrations.

The general engineering undergraduate curriculum from the Department of Industrial and Enterprise Systems Engineering at the University of Illinois at Urbana-Champaign was used as the reference for this tool. By integrating the CAE experience into the undergraduate mechanics curriculum, this instructional software package should prove to be beneficial both in academia and to future design analysts.

I. Introduction

Mechanical courses in undergraduate engineering curricula introduce fundamental concepts in the design and analysis of structural and machine components and assemblies. These courses focus on engineering science, fundamentals, and first principles. However, the curriculum is so crowded that there is little or no room for instruction on the computational tools that can be used to design and analyze mechanisms. Moreover, instructors often cannot keep pace with the latest virtual technology software developments.

To address this problem, a number of universities are introducing innovative curricula with computer-aided design (CAD) modeling and computer-aided engineering (CAE) analysis tools to help promote a better understanding of engineering basics and fundamentals among students, with the ultimate goal of preparing engineers who can fully integrate computer modeling and design with analytical skills.[1] Researchers at the Department of Mechanical Engineering at Carnegie-Mellon University have found that self-paced and web-based CAE tutorials are a

practical method of complementing traditional engineering instruction on all levels of undergraduate mechanical engineering courses.[2] For example, freshmen complete a web tutorial-led project that introduces them to computer-aided design, finite-element analysis (FEA) and computer-aided manufacturing (CAM) of a specific product. It has been observed through feedback and course enrollment statistics that this experience both motivates the students and introduces available engineering software tools.

The Department of Industrial and Enterprise Systems Engineering (IESE) of the University of Illinois at Urbana-Champaign (UIUC) has also developed instructional software packages aimed at integrating the CAE/FEA experience into the curriculum.[3] This paper focuses on their most recent effort to develop supplementary instructional software packages. *Mechanism Design Instructional Software Using Autodesk Inventor* is a standalone interactive multimedia tool developed to be used outside the classroom by undergraduate students taking mechanical design courses. This tutorial tool provides instruction in the use of Autodesk® Inventor™, and specifically, its *Dynamic Simulation* and *Design Accelerator* modules.

Autodesk Inventor

In general, CAD is used to design, develop and optimize products. As the software becomes more refined and affordable, computer-aided design is an especially important technology with benefits such as lower product development costs and a shortened design time, because CAD enables designers to develop and simulate their work on a computer screen.

Autodesk Inventor, first released in 1999, is one of several 3D parametric solid modeling packages that are commercially available. In the last few years, Autodesk has worked on the growth of their Inventor platform, as evidenced by their acquisitions of MechSoft Technology (*Design Accelerator*) in 2004 and Solid Dynamics (*Dynamic Simulator*) in 2005, and by their partnership in 2006 with ANSYS to provide integrated structural analysis simulation capability to all Inventor Professional users.[4, 5] Competing products on the market include SolidWorks, Pro/ENGINEER, and Solid Edge. Autodesk Inventor is an attractive option because of its increasing popularity in the manufacturing industry[6], and because it offers a series of modules with different functional design capabilities ranging from stress analysis to dynamic simulations.

With *Dynamic Simulation* (*DS*), it is possible to design mechanisms, analyze them and verify that all the components function properly under realistic operating conditions including variable loads and friction, using dynamic components such as dampers and springs. The animated graphing capabilities in DS help visualize the behavior and performance of the design.

The *Design Accelerator* (*DA*) module provides tools that help create mechanical parts like gears, shafts, bolt connections, and more, all based on real-world attributes such as speed, power and material properties. For example, gears are designed based on loads and reduction ratios rather than gear size and placement. DA features an automated component generator and a convenient engineering calculator with standard mathematical formulas and physical theory, as well as the Engineer's Handbook, a design reference library.[7]

II. Tutorial Development

Approach to designing the tutorial tool

This particular tool was specifically designed to meet the needs of the Department of IESE at UIUC. Unlike other documented tutorials, this instructional package is not aimed at one specific course, but is intended more as a parallel curriculum tool that can supplement any of the mechanical design courses offered by the department, including:
- Introduction to General Engineering Design
- Engineering Design Analysis
- Instrumentation and Test Lab
- Component Design
- Senior Project Design

These courses are taught at a Junior/Senior level, so it is expected that the tutorial users have been exposed to and are familiar with the basic Autodesk Inventor application. This is not unreasonable, since all IESE students are introduced to Inventor in their first year engineering graphics course.

To decide the technical content of the tutorial, faculty members were consulted. The final selection of topics covered was determined based on software capabilities and on the relevance of the material and examples with respect to the courses as observed from the professors' experience.

Creating the Tutorial

This instructional package covers mechanism design topics found in the typical undergraduate engineering curriculum; it can be used in conjunction with machine and mechanism design courses. In addition, it provides an introduction to mechanism design tools available in the *Dynamic Simulation* and *Design Accelerator* modules of Autodesk Inventor Professional (AIP) version. Particular emphasis is placed upon pin-bar mechanisms and gears, which are frequently covered in undergraduate mechanical design courses. Note that although the *Dynamic Simulation* tool is not included with the basic Inventor series version, students can still download the AIP release for free at http://students.autodesk.com.

In addition to Autodesk Inventor, five other software programs were used to develop the standalone tutorial:
- Macromedia Authorware – Visual authoring software tool for creating multimedia learning applications for delivery on networks or on CD/DVD format.
- Macromedia Flash (now Adobe Flash) – Advanced video encoder that produces high quality animations at a relatively small file size.
- TechSmith SnagIt – Window and client area screen capture software with integrated image editing capabilities.
- Techsmith Camtasia – Professional software for recording, editing and sharing high-quality screen video.
- Jasc Paintshop Pro – Advanced still image editing software.

III. Final Product: <u>_Mechanism Design Instructional Software Using Autodesk Inventor_</u>

The Mechanism Design application is menu-based and it follows a tree-like structure, meaning that it is easy to intuitively navigate the tutorial. Figures 1 through 4 show screen captures highlighting the capabilities of the instructional software tutorial. Among its main features are:

▪ One hundred and fifteen interactive cross-linked slides, sixteen instructional AVI movies, and an additional twenty-seven illustrative embedded flash animations.
▪ Interactive color-coded "hot spots" (hyper-linked text and graphical areas): red highlights for activities initiated by a mouse click; blue for activities triggered by a mouse hover; green for active hot spots.
▪ Helpful pop-up windows with explanatory text or illustrative video.
▪ Clear and accessible navigation buttons. Also, pop-up AVI movies with easy to use playback controls.
▪ Glossary with key terms.
▪ A cross-linked tutorial map that shows the content layout and provides an alternative means of navigating the tutorial.
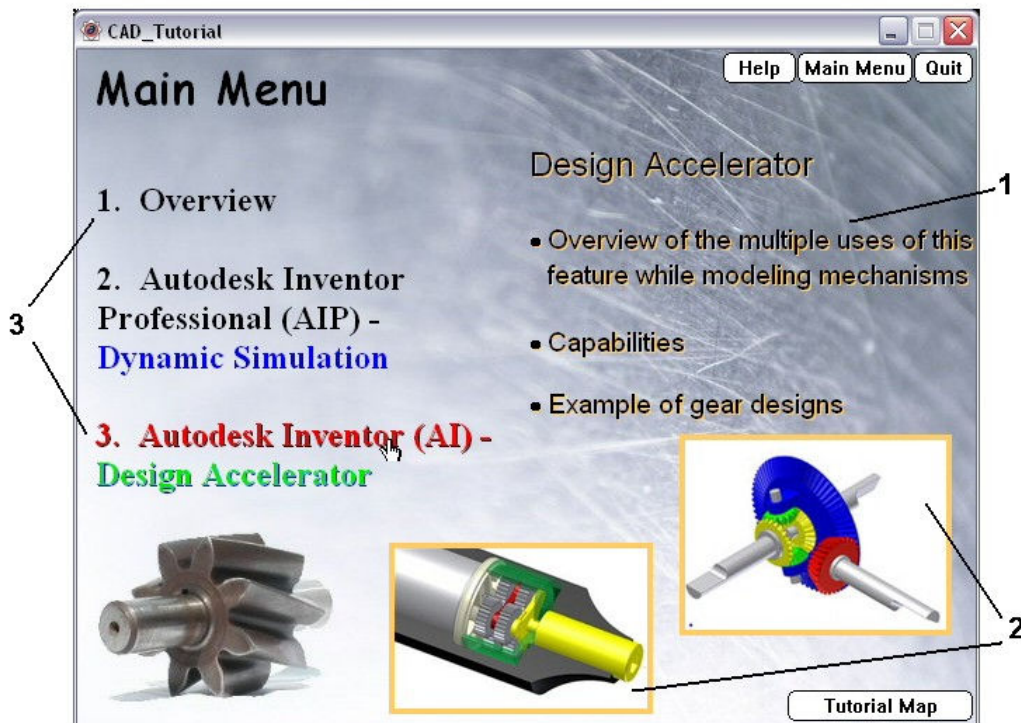

Figure 1 - Mechanism Design Instructional Software screen capture. Features: 1) Dynamic explanatory text; 2) Flash animations of examples included; 3) Menu-based structure.
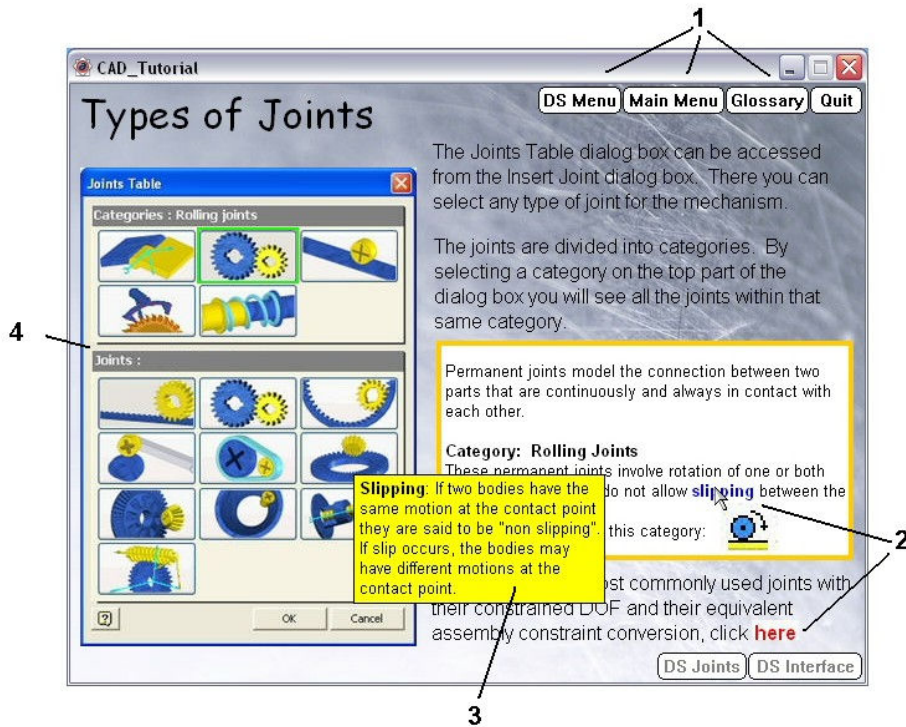
Figure 2 - Mechanism Design Instructional Software screen capture. Features: 1) Accessible navigation buttons; 2) Color-coded "hot spots"; 3) Interactive informational pop-up text; 4) Colorful graphics - Autodesk Inventor screen capture.
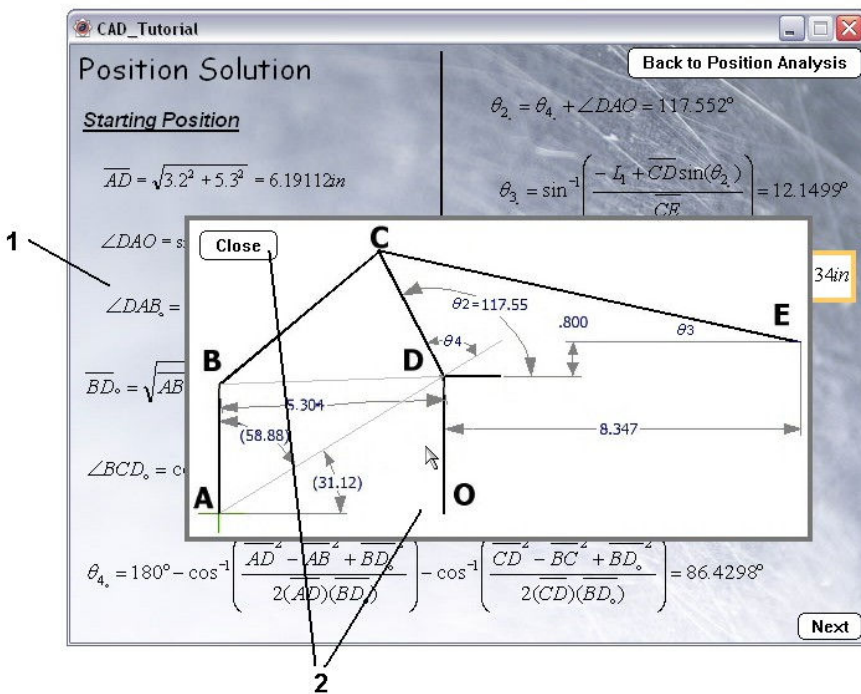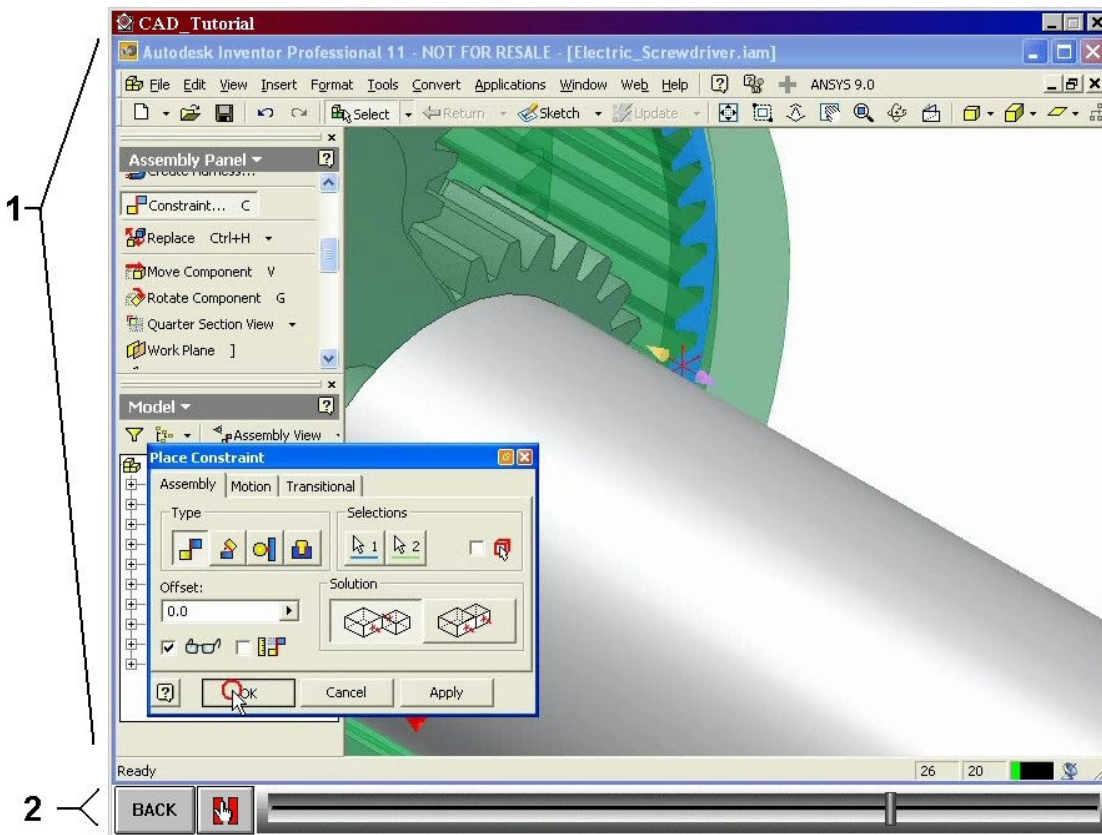

Figure 3 - Mechanism Design Instructional Software screen capture. Features: 1) Detailed analytical solutions to complement CAD solution; 2) Pop-up supplemental images.
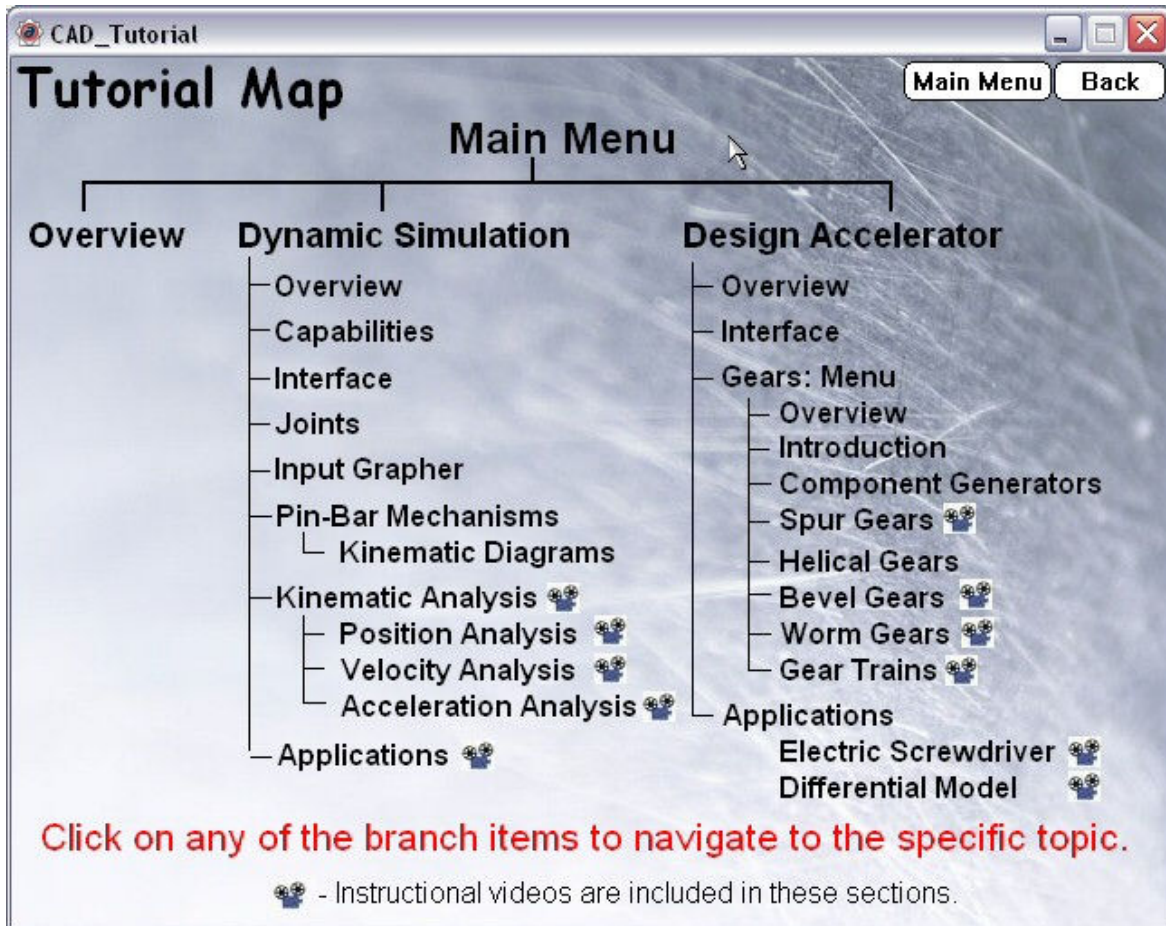
Figure 4 - Mechanism Design Instructional Software screen capture – AVI video. Features: 1) Screen video recording of a real-time solid model construction in progress using the Autodesk Inventor Professional – Design Accelerator environment; 2) Easy to use video playback controls.

The complete instructional package is more than just the *Mechanism Design* application. It also comprises original Autodesk Inventor models to accompany the tutorial examples, designed and constructed by the tutorial developers. The application disk includes a folder with over 50 supplementary Inventor assembly, sub-assembly, or part files. These files allow the user to reproduce the CAD activities demonstrated in the tutorial videos. This feature enhances the interactive experience for the user, since the student can build working models of actual mechanisms as he or she goes through the tutorial.

The package also contains installation files for the necessary video decoders.

Technical Content

The *Mechanism Design* application is organized into two main sections – one that deals with Dynamic Simulation and another with Design Accelerator. General overviews of the Mechanical Design tutorial and of the Inventor software are included as well. Figure 5 shows a screen capture of the Tutorial Map, which accurately outlines the tutorial content.

Figure 5 - Mechanism Design Instructional Software screen capture – Tutorial Map slide, outlining the tutorial layout.

The mechanical design courses at the IESE Department at UIUC cannot devote a significant portion of a crowded syllabus to the design and analysis of pin-bar mechanisms (and their kinematics), and to the design and analysis of specific mechanical components, such as gears and shafts. Professors and instructors in these courses have expressed a need for more illustrative models to show the full motion of pin-bar mechanisms and gear systems, and to reinforce the student's understanding of their analysis and design. Therefore it was decided that these mechanisms would be featured in the tutorial.

The Dynamic Simulation (DS) module is used to study linkages. This part of the tutorial offers four introductory sections that mainly describe the capabilities of the DS module and introduce interface features that are specific to this module. These are: Overview, Capabilities, Interface, Input Grapher, and Joints. Careful instructions on the correct use of the DS module are presented. The tutorial then transitions to the scientific/engineering content with the subsequent sections: Pin-Bar Mechanisms and Kinematic Analysis. These latter sections include basic concept definitions and detailed background theory on five different categories of joints (standard, rolling, sliding, contact, and force joints), pin-bar mechanism classification (function generators, path generators, and motion generators), degrees of freedom, and 4-bar linkage types (crank-rocker, crank-crank, rocker-rocker, and slider-crank). Furthermore, the tutorial goes into

great detail on how to generate kinematic diagrams and how to perform position, velocity and acceleration analyses. It is worth mentioning that the kinematic analysis section is supplemented by both video animations of the DS-assisted solution and a detailed analytical solution to aid the students in understanding how the results are obtained and verified. Also, each kinematics example is for a distinct problem, which is solved with a custom-generated DS model. Finally, a scissor jack application model (see Figure 6) is fully analyzed with DS, providing an example of intermediate difficulty that students can follow and understand. This example was inspired by an actual IESE design project assignment from previous years.
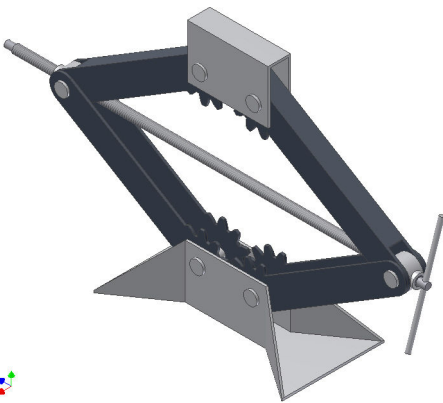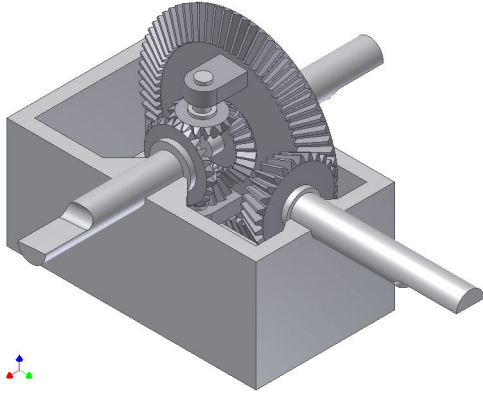

Figure 6 - Scissor Jack

The Design Accelerator (DA) module is used to handle the gear analysis. Again, introductory overview and interface sections are included. The comprehensive Gears section describes the "Component Generator" capabilities of DA and explains in detail how to use the Generator to model spur, helical, bevel and worm gears, as well as more complex gear trains.   The DA tutorial selection also presents in-depth gear design theory and terminology, including the use of the involute profile. Again, precise instructions on the proper use of the DA module are presented. Finally, two thorough and fully functional gear applications are modeled using DA: an electric screwdriver, and transmission differential. Figures 7 and 8 respectively show these models. Both application examples were custom-developed for this tutorial, to present the students with realistic and stimulating working models that they could replicate.
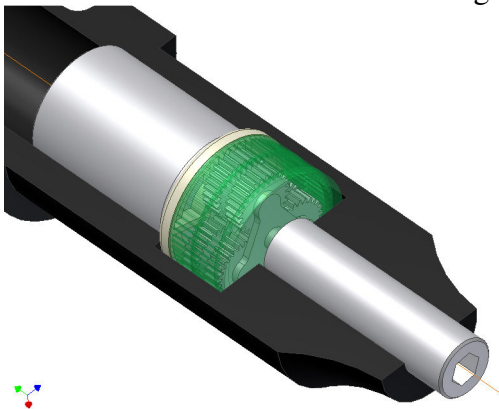
Figure 7 - Electric screwdriver

Figure 8 - Transmission differential

It is expected that the *Mechanism Design* tool will encourage students to more actively use Inventor software in class design projects such as the scissor jack and similar assignments.

System Requirements

- CD-ROM
- Intel Pentium processor or higher
- Microsoft Windows 98 SE, Windows 2000, and Windows XP (Windows XP preferred)
- 64 MB free available system RAM (128 MB recommended)
- 800 x 600 monitor resolution and higher
- If DivX codec needs to be installed, 1.7 MB hard disk space

IV. Conclusions and Recommendations

The goal of this undertaking was to develop a parallel-curriculum software tool to aid in the instruction of mechanical component design courses. The *Mechanism Design Instructional Software Using Autodesk Inventor* tool and its accompanying package successfully combine mechanical engineering design fundamentals with computer-aided engineering. This highly interactive, standalone application uses Autodesk Inventor's Dynamic Simulation and Design Accelerator modules as the solid modeling platform software. It covers in detail the basics of important mechanisms, specifically pin-bar mechanisms and gears, and it provides examples with original, functional Inventor models that are chosen to be relevant and interesting to students, along with careful step-by-step instructions on the use of the DS and DA modules as a design aid. The tutorial is comprehensive and easy to navigate, and it can be used as a supplementary teaching aid in an introductory mechanism design course, but also as a tool to learn to use advanced design modules available from Autodesk Inventor.

The main challenges in developing these types of tutorial packages are: 1) frequent releases of updated versions of the featured program (in this instance, Autodesk Inventor Professional) make it challenging to keep the tutorial current, and 2) the development of a high-quality custom-designed instructional tutorial requires that the developer(s) be both knowledgeable in the technical content of the tutorial and proficient in a number of different software packages. Therefore, in the long run, this project might be more efficiently undertaken by a permanent

development team, or by a semi-permanent development team of students with overlapping tenure.

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