Interactive Three Dimensional Visualization Based Engineering Technology Education – Modeling and Animation

Mr. Tianwei Wang, Clemson University

T. Wang is with the Mechanical Engineering Department, Clemson University, Clemson, SC 29634 USA

Dr. John R. Wagner, Clemson University

JOHN WAGNER joined the Department of Mechanical Engineering at Clemson in 1998. He holds B.S., M.S., and Ph.D. degrees in mechanical engineering from the State University of New York at Buffalo and Purdue University. Dr. Wagner was previously on the engineering staff at Delphi Automotive Systems and Delphi Delco Electronics (formerly Delco Electronics as a subsidiary of General Motors Hughes Electronics). Dr. Wagner is a Professor and Chair of the Dynamic Systems and Controls Group at Clemson. His research interests include nonlinear and intelligent control systems, dynamic system modeling, diagnostic and prognostic strategies, and mechatronic system design. He has developed the multi-disciplinary Rockwell Automation Mechatronics Educational Laboratory which features hands-on robotic, programmable logic controller, electronic, and material handling experiments. He is a former Associate Editor of the ASME Journal of Dynamic Systems, Measurement, and Control and IEEE/ASME Transactions on Mechatronics, respectively. Dr. Wagner is a licensed Professional Engineer and Fellow of the American Society of Mechanical Engineers.

Mr. Kapil Chalil Madathil, Clemson University
Ms. Melissa Isabel Zelaya, Clemson University

Melissa I. Zelaya is the Program Manager of the Center for Aviation and Automotive Technical Education using Virtual E-Schools (CAAVES). She is also a doctoral candidate in the Industrial Engineering department at Clemson University. Her research interests include the effects of digital learning environments on technology and engineering education, student-centered learning, and human-computer interaction. She received her B.S. and M.S. in Industrial Engineering from Clemson University in 2005 and 2008, respectively.

Mr. Jeff Bertrand
Dr. Kristin Kelly Frady, Clemson University for Workforce Development

Kristin Frady is the Assistant Director for the Clemson University Center for Workforce Development. Prior to joining the team at Clemson, Kristin gained experience in the corporate sector working with Blackbaud Inc., designing and delivering professional training seminars in online, blended, and live environments. She has experience in the educational sector in both live and online environments as an adjunct instructor in computer technology for Greenville Technical College and as a Career and Technology Education teacher for Eastside High School in Greenville County. Kristin earned a B.S. in management from Clemson University and a Master of Arts Teaching in business education from the University of South Carolina. She received her Ed.D. in curriculum and instruction with an emphasis in educational technology from the University of Florida in the fall of 2012.

Dr. Anand K. Gramopadhye, Clemson University
Dr. Sabarish V. Babu, School of Computing, Clemson University

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Abstract: Advanced three-dimensional visualization and virtual reality technology can play an important role in improving the engineering technology education process. These advanced methods offer technical colleges an opportunity to transition student learning from primarily the classroom and laboratory to an approach that includes online educational materials. E-courses allow more curriculum materials to be available for students desiring additional background materials given a perceived subject weakness based on the content delivery method. In this paper, an advanced education method for engineering technology students using the three-dimensional visualization of engineering concepts and object animation based on virtual reality technology has been presented for workforce development. The modeling tool set and selected automotive and aerospace system components were discussed to highlight the development process. A case study was introduced to illustrate the overall conceptualization and creation methodology, followed by the educational materials offered online to the technical college students for interactive learning. The preparation of students for emerging technical careers requires the successful integration of learning materials and channels delivery.

I. Introduction

The background of technical college students may vary from teenagers recently graduated from high school, to adults seeking new job skills and professional credentials. The advent of online educational methods have complemented, or replaced, traditional classroom learning to accommodate individual schedule needs and personal learning preferences. Current methods used in the engineering education process at some South Carolina technical colleges cannot easily contain the complex design details, intricate assembly, and equipment functions which were beneficial for students to understand. The traditional teaching and studying approaches, such as textbooks and two dimensional (2D) drawings or photographs, although acceptable, have limitations which may lengthen a student's learning time[1]. In 2D drawings, only the length and height or a variation with depth was presented which may lead to a lack of details. In addition, if limited to only the 2D drawing and accompany description, students may have difficulty understanding the assembly method since when completed, many of the components were no longer visible. For the study of engineering equipment functionality, traditional methods often cannot provide a full visual representation of the operation with motion. Besides, current teaching methods restrict the time and place of both the instructor and students to the college campus.

To remove the constraints of the typical teaching paradigm and education resources discussed above, advanced three dimensional (3D) visualization and virtual reality (VR) technology was introduced which offer several advantages over traditional methods. Specifically, this advanced education approach tends to be more efficient, facilitates standardization, and supports distance learning. Students can directly manipulate the 3D models to rotate them along different axes or scale them in various directions for better viewing. Realistic texture mapping and rendering technology with different materials can give a "real feeling" of the

models so that they resemble the actual object. The third dimension when viewing an assembly was helpful as it offers a spacial perspective and greater understanding as to the connection between different assembly components. With the help of animation and VR technology, the application process for the given toolset may be expressed step-by-step for the end user. Other benefits provided by virtual reality include rapid feedback, greater opportunity for practice, ability to learn in a familiar work environment, and enhanced development of critical thinking skills.

In many educational fields, interactive 3D visualization and VR technology have been successfully used to enhance the teaching experience. Perdomo *et al.* [1] addressed the impact of using 3D teaching as a tool for construction education and its advantages. Lee *et al.* [2] described the creation of a 3D modeling and visualization virtual reality markup language (VRML) tool for the human brain which can be shared on the World Wide Web. Bell and Fogler[3] presented the work of applying 3D visualization and VR technology in virtual chemical plants, virtual laboratory accidents, and a virtual University of Illinois Chicago campus. Ou *et al.*[4] established a learning content management system for engineering hydrology courses with the help of the virtual learning environment. Sampaio *et al.*[5] applied the virtual reality techniques into the civil engineering education which brought new perspectives to the teaching of the civil construction field. Angelov and Styczynski[6] developed learning modules to maintain electrical plants by means of VRML which allows online development and utilization of 3D virtual strategies.

The effective incorporation of technology into meaningful learning experiences can be cumbersome and sometimes appear to create dissonance. However, when technology is judiciously integrated in an instructional design model, it has the potential to positively impact student learning and meet the educational needs in new ways on local levels. As a component of the overall learning design, technology was represented in the Center for Aviation and Automotive Technical Education using Virtual E-School (CA^{2}VES) instructional design model primarily in the form of interactive 3D visualizations. The development of an instructional design model assimilating local industry need, multiple technology systems scattered across various community colleges and high schools, and input from a broad spectrum of stakeholders presented Clemson University's Center for Workforce Development (CUCWD) with a unique challenge. Extrapolation of the various objectives of each resulted in identification of a primary characteristic which became the central focus of the CA^{2}VES instructional design model which represents influence from various leading models[7-8].

The focal point, around which all elements of the instructional design model revolve, was improving student learning and performance for identified module objectives. Each time a module was used, student learning has been assessed in several ways. First, an informal learning analysis may be administered by an instructor where he/she will ask (via a live or online discussion) "orienting questions" designed to gather feedback on present student knowledge in key objective areas as well as to initiate conversations to scaffold student learning. Next, informal assessment was provided by activities interspersed throughout the module which offered students and instructors with learning checks as new information was presented. Finally, formal assessment may be performed in two manners: (1) successful completion of activities in the 3D virtual reality environment (for example entering accurate measurement readings for the precision tools modeled), and (2) instructor selected activities taken from an Assessment Guide which coordinated with module learning activities – assessments were designed to test multiple levels of cognition through providing traditional test questions (e.g., multiple choice and true/false format), design of physical lab activities, use of discussion prompts to extend module learning, and implementation of critical thinking

activities (including paraphrasing, summaries, sequencing, Venn diagrams). The combination of these informal and formal assessments provides a greater understanding of student learning levels before, during, and after completion of e-materials. The remainder of the model interacts in a relational-radial matrix fashion with each component having an equal impact on the overall goal. There are four components in the CA^2VES model, shown in Fig. 1, which include learning design, theories, educational philosophy, technology, and visualization.

A pilot study was also designed to aid in better quantifying the impact of the learning design and virtual reality modules on student learning. The initial study will contain two groups. The control group which will be taught using materials and face-to-face methods currently utilized in the technical college. In contrast, the experimental group (from the same college) will be taught by the same instructor but instead will use the CA^2VES online learning tools and virtual reality simulations. Learning for both groups will be assessed through standardized pretests, short learning quizzes, and a final formal assessment incorporating questions with varying levels of difficulty. The pilot study results will be analyzed to determine the CA^2VES online learning tool impacts as related to student learning and performance.

This paper presents advanced education methods for technical college engineering by using 3D visualization and VR technology as developed in a collaborative fashion by CUCWD and CA^2VES researchers. The paper has been organized as follows. Section II presents the construction of an instructional design model integrating 3-D visualization. The computer model tools, followed by the virtual reality and online learning strategies, are introduced in Section III. Section IV contains a case study. Finally, Section V presents the conclusion.
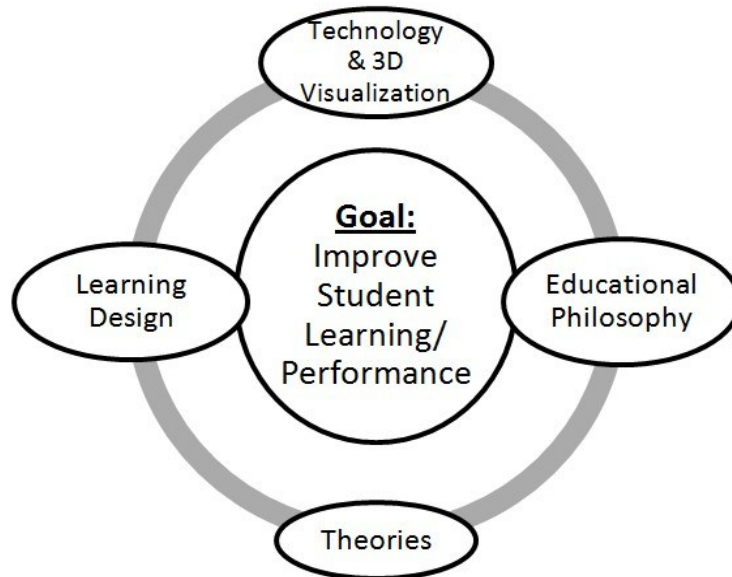

Fig. 1: Four components of the Center for Aviation and Automotive

II. Computer Modeling Tools

For an interactive 3D visualization and VR system, computer modeling establishes the foundation. The virtual world was constructed by various modules created by multi-disciplinary groups of engineers and educators. For instance, the students should be able to understand machines, processers, and/or devices through representative 3D computer based physical models. These computer models may contain geometric, scene, and/or assembly

relationships. After representing the physical entities on the computer, the modules, parts, and/or assemblies were converted into a specified format and saved as a digital resource to share with the development team. In this project, all the modules were converted into a ".dae" (digital assent exchange) format since it offers a convenient method for interactions by the virtual reality team members. This format was defined by COLLADA (Collaborative Design Activity) as an open standard XML (Extensive Makeup Language) schema for exchanging digital assents among various graphics software applications. The converted models may be imported into VR tools for further development.

A. *Software and Hardware Tools*

Early in the development process, several types of computer aided design (CAD) software packages were evaluated to create the engineering systems and technical tools. Some of the software utilities included CATIA, ProE, SolidWorks, and 3DMAX. SolidWorks was selected as the CAD modeling software toolset for several reasons. First, this software package was recognized as a standard CAD tool around world. Second, it has been widely used in diverse engineering fields and was familiar to the project partners and the team members. Third, the individual creating the drawing could use a parametric feature-based approach to create models and assemblies. Finally, using the add-in, the CAD modules file can be easily exported and converted into the ".dae" format with all details then imported into VR tools. For hardware needs, the development team selected standard PC workstations which feature multiple high speed CPUs and a high performance graphics card to meet the demands of the large scale modeling challenges.

B. *Data Library Modules*

In this project, a number of different modules were developed to meet the engineering education requirement. At the highest level, the module library currently contains measurement tools, electronic components, automotive subsystems, aviation subsystems, and safety as show in Fig. 2. The introduction of these modules has been described below to offer insight into the current features.

(1) Measurement Tools: The measurement tools that have been virtually modeled include a caliper, micrometer, combination square, oscilloscope, and multimeter. All of these items have been described as 3D CAD modules based on real tools with full details and functionality. These modules may be operated by the students in the virtual environments to help them learn the basic knowledge of metrology and develop specific skills. To work with these measurement instruments, the geometric dimensions of standard parts, such as gears, bearings, and valves were also modeled.

(2) Electronic Components: The electronic components module contains basic electronic devices such as resistors, capacitors, breadboards, batteries, and lamps. These electronic components have been created according to the developed requirements and allow students to assemble them to into different electronic circuits. These components may have individual properties and values that can be adjusted.

(3) Automotive Subsystems: The automotive elements include the engine block, vehicle frame, drive line, disk brakes, transmission, drum brakes, suspension, and steering. These systems were modeled as individual assemblies with full details including the assembly relationship of the parts and the governing physical laws which describe their dynamic motion. The parts

should be developed so that they may be controlled and operated by the students separately. From the assembly relations, the students can also get full information of how the parts connect and integrate into a vehicle.
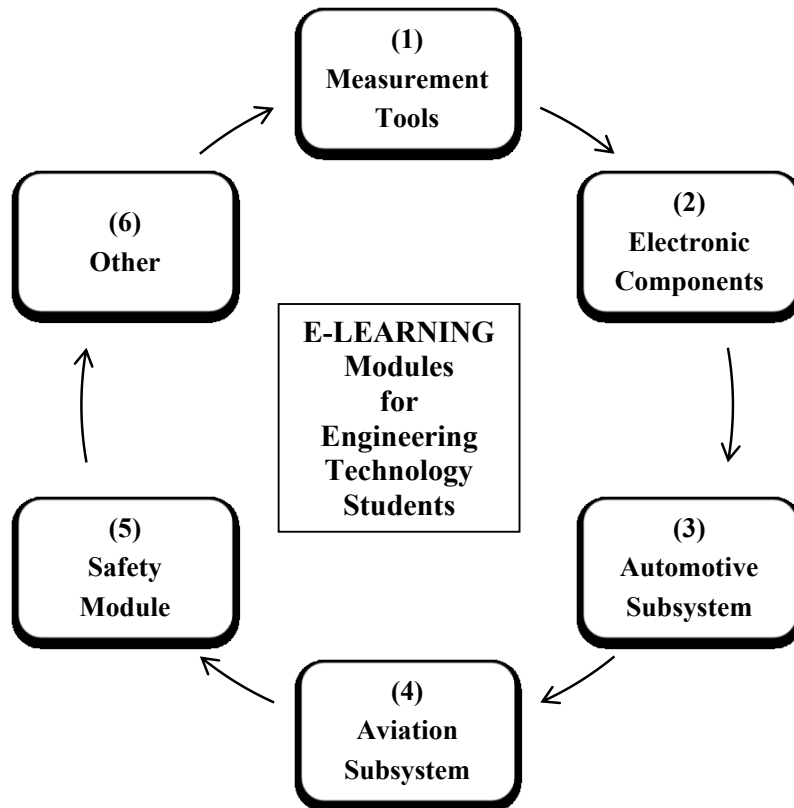

Fig. 2: CAD module library with content ranging from measurement tools to safety

(4) Aviation Subsystems: The aviation subsystems include a gas turbine, aerospace vehicle frame, and flight surfaces. The gas turbine was modeled as an assembly, including the blades, combustor, compressor, fuel tubes, and shaft. The internal combustion propulsion engine, in addition to the other system components, provided an overview of the basic turbine operation and aircraft maintenance concepts for students.

(5) Safety Modules: An assortment of machines and robots were available within the safety module to allow students to virtually interact with these system elements. All of these machines should be operated with full functionality and realism. Particularly, in this part, the safe operation was the main priority so that participants can understand the health/safety aspects. As a result, the correct operation method must be considered when modeling the members.

(6) Other: As the project evolved, a variety of additional modules were added to the library to support the learning process. A representative sampling of the module elements have been compiled in Fig. 3.

C. Reference Materials

The reference materials, including documents, photographs, drawings, have been collected from various sources to support the creation of the e-learning materials. Some of these sources

include Clemson's Department of Mechanical Engineering, the college machine shop, on-campus laboratories, government agencies, and extensive industrial and academic interactions. The CAD modeling team regularly identified materials and then evaluated the resources to create the 3D CAD modules.
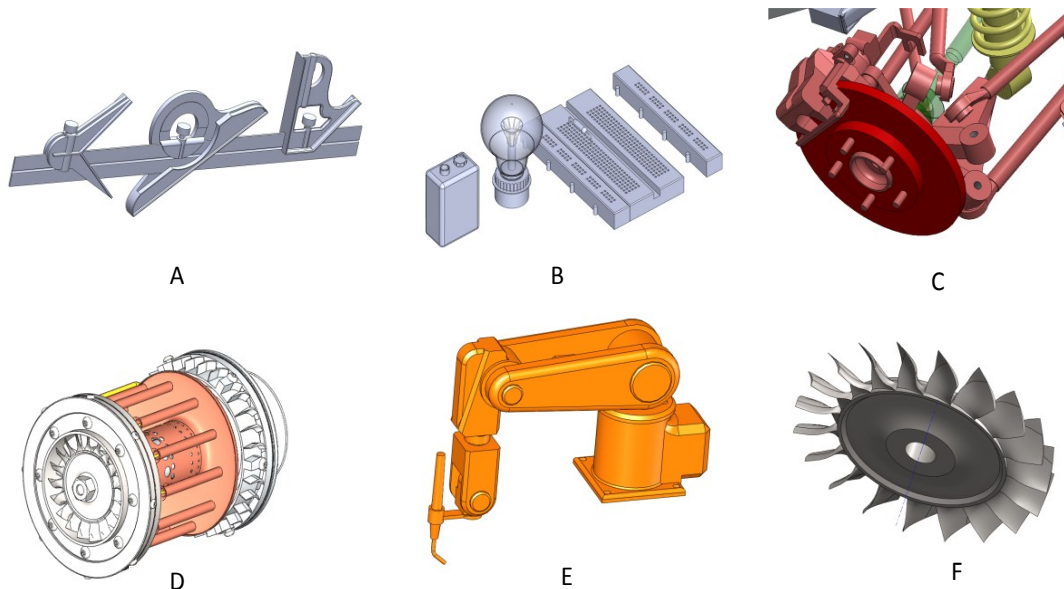

Fig. 3: CAD module examples - (A) combination square , (B) electrical components, (C) automobile subsystem - disc brake, (D) gas turbine combustor, (E) 6 degree-of-freedom robot arm, and (F) gas turbine fan assembly

D. CAD Modules Creation Process

The CAD modeling research team (i.e., Department of Mechanical Engineering at Clemson University) received the 3D module requests from CUCWD. The customer requested various 3D module types based on the education needs; they also provided detailed instructions. The team members collected the materials from available resources. After evaluation, the CAD models were developed and preliminarily reviewed before conversion into a 'dae' format as a digital source to submit to the VR team. The team provided feedback so that the CAD modules were modified until they satisfy the requirements; Fig. 4 displays a flow chart for the task. When developing the CAD modules, the designers should create the features based on the following the working process.

- Draw Sketches: Sketches are the starting point for creating 3D solid part features in SolidWorks. A sketch tends to be a 2D profile, or cross section, which is made up of such basic geometry such as a line, rectangle, circle, arc, etc. With provided menus and speed tool buttons, the designer can easily create sketches, specify dimensions, and add geometric relationships among the components.

- Generate 3D Solid Features: After the sketches are finished, the designers may extrude, rotate, loft or sweep sketches to create the desired 3D part features. They may then specify the necessary dimensions to define the 3D part features.

- Assemble Body: Once the individual 3D solid part has been created, the designer should

assemble these parts together into the complete body. Using the geometric constraints (e.g., coincident, distance, parallel, and/or concentric), the position of each part and the relationship between them may be identified.

• Save Part Feature: The created 3D CAD module must be saved by the designer to a feature database and then converted into a specified digital resource.

III. Virtual Reality and Online Learning

The virtual reality technology and accompanying online learning concept was heavily utilized in this educating program. The CAD modules were imported in the virtual reality system and then VR tools applied to develop an immersion study system. The advent of online learning, or e-course, has helped to create a new method of flexible distance education.

A. Virtual Reality (VR)

The virtual reality component, contained within learning modules, provides students with an opportunity to engage in high-impact, hands-on, authentic learning. This tool contributes new flexibility to educational experiences through immersion in real-world scenarios where students manipulate multiple variables, use tools, and develop skills. Research suggests that implementation of this type of tool with its highly interactive and learner-centric approach has the ability to impact learning and retention.[9,10] In this project, two groups worked on the 3D interactive and virtual reality application, the Southeastern Institute of Manufacturing and Technology, Florence, SC, and Clemson University's School of Computer Science. After the CAD modules were converted into the ".dae" format, the digital source was sent to these two groups to be imported into the VR tools so that the properties and functions were introduced.
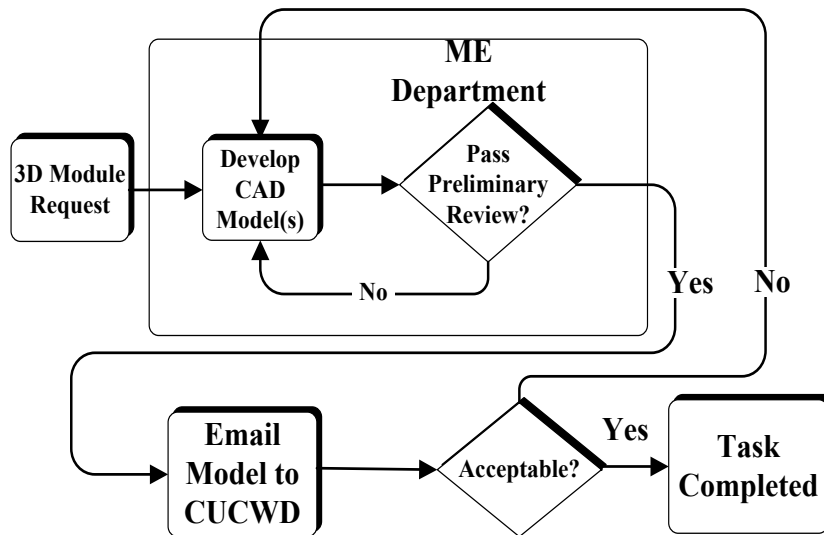

Fig.4: Flow chart for CAD module creation process

B. Online Learning

The instructional design model driving the online learning design of CA^2VES strives to incorporate leading research outlining best practices in the implementation of online learning tools. One element of the CA^2VES online learning tool design was a virtual reality component,

contained within learning modules, providing students with an opportunity to engage in high-impact, hands-on, authentic learning. This tool contributes new flexibility to the educational experience through immersion in real-world scenarios where students can manipulate multiple variables, use tools, and develop skills. Research suggests that the implementation of this type of tool with its highly interactive and learner-centric approach has the ability to impact learning and retention.[11] Other benefits provided by virtual reality include rapid feedback, more opportunity for practice, ability to learn in a familiar work environment, and greater development of critical thinking skills.

IV. Case Study - Measurement Module

A case study illustrates the application of the e-learning modules to the topic of measurement tools. The team started the overall project with the measurement devices given their widespread usage in automotive and aerospace systems. The metrology CAD modules were created and the interactive features designed in the virtual world. The objective was to help the learner understand the basic functionality and the appropriate operation method of the caliper. The 3D visualization and virtual reality was seamlessly integrated into the courses and modules incorporating course plans, exercises, quizzes, exams, and laboratory manuals resulting in an integrated assessment approach.

In the virtual environment, each module contains four sections - introduction, guided practice, exercise, and assessment as shown in Fig. 5. First, the introduction offers basic information about the instrument and how to interact with the simulation. It also includes information on how to interpret the caliper measurement correctly. Second, the guided practice engages the user in a step-by-step process to ensure that they understand each step required in taking a proper measurement. For example, they are presented an abstract solid object and requested to take measurements. Instructions are displayed and after the user completes the instruction, the next step was displayed. Third, the exercise section asks the user to take a measurement of a real world object and convert the measurement between different units. Once the measurement has been taken, the real world object was randomly scaled and the user requested to perform the new measurement. Finally, the assessment section consists of randomly scaled measurement tasks identical to the exercise section where the assessment measurement tasks may be graded and the final score both displayed for the student and sent to an instructor. Users may navigate to each section at any time by clicking on the tabs at the top of the screen. The virtual environment was designed to mimic the physics of the real world and users interact with the simulation by clicking and dragging the instruments into place and recording their measurements. Special interactions such as zooming are represented by icons.
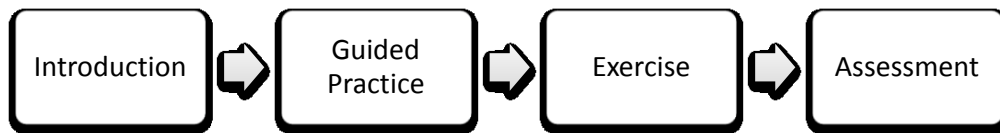

Fig. 5: General categories of the virtual environment user interface

The Vernier caliper and relevant measured parts were modeled in the CAD software package. The research team measured the caliper dimensions and modeled it as a parts assembly including the main scale part, Vernier part, retainer, and the stop block. Further, a gear with holes and an integrated bearing may also be created in a standard measurement. After modeling both the caliper and the measured parts, these modules were saved and converted, and then

submitted to the School of Computer Science with an instruction document. The texture (including the material property and the print markers) were mapped on the CAD modules. After the visualization part was finished, the school of Computer Science added module functions. The overall working process has been shown in Fig. 6.
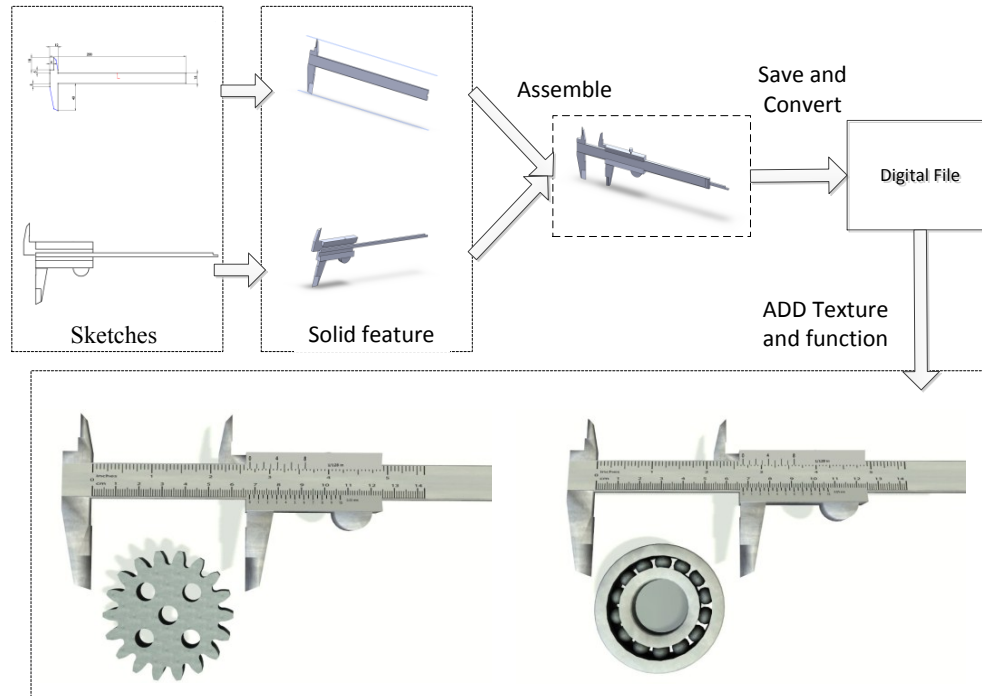

Fig. 6: Working process (from CAD modules to virtual environment) for the caliper in the measurement tools module in Section II

V. Conclusion

The rapidly evolving education environment for engineering technology integrates electronic learning with traditional classroom and laboratory experiences. This paper outlines the recent efforts undertaken in the development and application of advanced interactive 3D visualization based technical engineering education. The division and cooperation between different departments, CUCWD, CA^{2}VES, and other departments have been introduced. A series of learning modules have been created including measurement, electronic, automotive and aviation subsystems, safety modules, etc. The research team modeled these components using a commercial 3D software package. The standard model development process, from concept to digital file, flowing from modules independent work group through the concept to the application of online learning, was established. Finally, a measurement tool case study was presented to demonstrate the overall concept and methodology.

VI. Acknowledgement

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