AC 2012-4537: INTEGRATING RAPID MANUFACTURING WITH CYBER FACILITY AND TUTOR SYSTEM INTO ENGINEERING EDUCATION

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Integrating Rapid Manufacturing with Cyber Facility and Tutor System into Engineering Education

The objective of this paper is to introduce, implement, and further enhance engineering education in cyber-based rapid manufacturing (CBRM) using a cyber Rapid Prototyping (RP) simulator and a tutor system within the established programs of Industrial, Manufacturing and Systems Engineering and Mechanical Engineering at the University of Texas at El Paso. This paper describes a state-of-the-art cyber rapid prototyping simulator in 3D environment and a tutor system. The purpose of the cyber RP simulator is allowing the users to learn how to operate the Fused Deposition Modeling (FDM) 3000 machine in a virtual environment while the goal of the tutor system is to enhance student learning when the instructor is not available. The paper also aims at developing an effective learning model to facilitate student's learning in rapid manufacturing. Student learning from both real and virtual environment and with and without the support from the tutor system are evaluated and discussed in this paper.

Introduction

This paper is to introduce, implement, and further enhance engineering education in cyber-based rapid manufacturing (CBRM) using a cyber Rapid Prototyping (RP) simulator and a tutor system. The purposes of the cyber RP simulator are allowing the users to get familiar with the basic commands and functions of the real Fused Deposition Modeling (FDM) 3000 facility and learning how to operate the FDM 3000 machine. Currently, globalization has changed the landscape of manufacturing industry. More and more manufacturing companies in US are moving out to oversea due to inexpensive labor cost and other resources. Manufacturing industry becomes sensitive about cost effectiveness issues due to recent economic crisis. Manufacturing companies are cautious about sustainable workforce, particularly in equipment operation. The workers' faulty operations could cause significant damage of the facilities and personal injuries and safety hazards. Moreover, through recent literature survey, the fundamental challenging problem in manufacturing education: (1) How to better educate students online facility training without interaction with instructors[1]; (2) How to improve teaching and learning effectiveness in online course and facility training. Therefore, the 24 hour access intensive and informative training tools are desired.

To date, due to the demand in the market and rapid development and improvement in capability, Rapid Manufacturing (RM) technologies are becoming popular. Several technologies collectively known as additive manufacturing have been developed to shorten the design and production cycle, and have transformed many conventional manufacturing procedures. According to Society of Manufacturing Engineers (SME), RM is a broad term including the use of rapid prototyping, rapid tooling, and the direct use of layer manufacturing technologies to produce final products quickly [2]. Before the production starts, a prototype called Functional Prototype is used as part of design cycle to complete testing of the product. Numerous commercial RM systems for various materials and sizes are now available on the market. Rapid Prototyping (RP) is one of RM techniques. The fast creation of a prototype is known as RP [3]. Layered manufacturing is actually better known as RP where the fabrication of part by depositing or bonding successive layers. The technologies now available include a variety of different processes, such as Stereo Lithography, Selective Laser Sintering, Fused Deposition

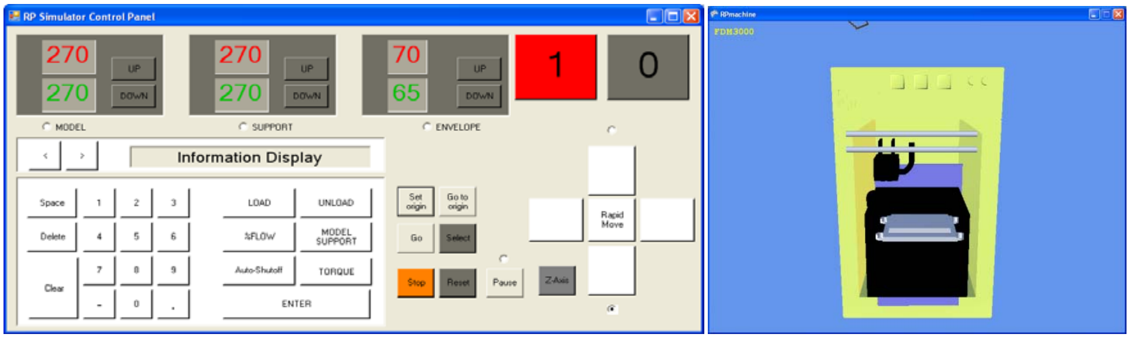
Modeling, 3D Printing, Shape Deposition Manufacturing and Laminated Object Manufacturing. The application of RP methods to the fabrication of customized molds, dies, and tools used to produce parts is called Rapid Tooling [4,5].

The term of "Cyber Facility" (CF) is referring to a facility which is normally in a digital format and able to mimic the real faculty. The main purpose of the use of CF is to allow the user to acquire training, improve operation skills and be familiar with the real facility before actually implementing it. In general, the CFs are fabricated and characterized in the computer systems which make them more safe and cost-effective. The CF is normally developed through programming languages. The characteristics of the CF include but not limited to error free data, innovating testing and evaluating features of a design which in user's perspective can help create ideas [6-8]. Hence, it can optimize the prototyping process, improve part quality, enhance fabrication efficiency, and lower the model making cost significantly.

Background of Remote Access of the RM Facility and Development of Cyber Facility

To realize the concept of cyber based rapid manufacturing, **remote access** plays a very important role. Basically, the implementation of remote access can be achieved through the Application Programming Interface (API). In recent years, the authors have developed an Application Programming Interface (API) for a Rapid Prototyping (RP) machine (see Figure 2-a) and a Cyber Facility (CF) called the Rapid Prototyping (RP) simulator (see Figure 2-b) to mimic the real RP machine, FDM 3000 made by Stratasys Inc. Basically, the objective of the API development is to provide a Graphical User Interface (GUI) to allow the user to establish and control communication lines with Web-enabled equipment, for example the RP machine remotely. Therefore, the API allows the user to view or measure or operate the part through Machine Vision Systems (MVS), a Web camera and "remote desktop" provided by Microsoft® Windows. In general, the API should include the following functions: (1) Connect to the RP machine and control it with GUI. With the .sml file which is generated by the Insight® software, calibration can be implemented. Moreover, the software is able to manipulate the part easily from different views and integrate measurement system. It can also provide a clear sight and a feedback during the entire fabrication process; (2) Remotely observe a fabrication process with the MVSs and the Web cam. Moreover, the purpose of the RP simulator development is to provide basic functions and offer students 24 hours access of the virtual machine which is very similar to the **real** FDM 3000 machine. Therefore, students are able to learn more effectively before they operate the real facility. Microsoft 3D Studio Max and XNA framework have been used to model the real FDM 3000 Rapid Prototype machine and simulate the functions of the machine in the 3D environment. There are three different modules included in this self developed software: (1) Control Panel **(**see Figure 2-c**);** (2) Virtual calibration **(**see Figure 2-d**);** and (3) Virtual manufacturing. This function allows students to upload their own part/product design works based on rapid manufacturing. Moreover, the simulator will analyze the input file and display the slices that make up the model. Here, the user is allowed to specify how many slices he or she wishes to have through setting the height of the slice**.** Furthermore, the users can access the user manual through selecting the Help option on the main menu.

a. the API based on FDM 3000 b. The main menu of the RP simulator



c. The control panel of the virtual RP machine d. The simulator performs a calibration sequence

Figure 1 (a-d): The API and the Rapid Prototyping (RP) simulator developed by University of Taxes at El Paso (UTEP)

To date, there is no comprehensive education model fully integrating available Internet technologies and virtual reality into classroom with an emphasis on the improvement of students' skills in problem solving and information seeking [9]. Therefore, the authors propose to use a digital simulator based approach to explore the use of Internet for active learning and problem solving skills enhancement in engineering curriculum. Basically, the RP simulator will serve as a critical cyber facility to achieve the following learning objectives for students: 1) Enhance students for more advanced study of Internet based rapid manufacturing systems; 2) Accelerate the problem solving skills transfer from classroom to practice in real world.

Development of E-Based Tutor System

In this section, the Tutor Systems (TS) which is associated with the real RM facility and the Cyber Facility (CF) is introduced. The purpose of developing the tutor system is to facilitate users in a condition of lack of instruction on site (or using CF for learning and training) and acquiring knowledge to learning and operate the facility. In this paper, we will use Rapid Prototyping facilities called FDM 3000 and Z-corp 3D Printer as examples. **However, it can be used for any types of RM facilities and any associated CAD software.** Basically, the Tutor System can be used for both real facility and CF learning and training. In the Tutor Systems, there are five categories which include nine options. Category #1- *Introduction*: (1) Introduction and (2) Learning about RM facility; Category #2 – *Operation*: (3) Operation demonstrations, (4) Viewing videos based on scenario, (5) Performing online interactive operations; Category #3 –

Software Learning : (6) Learning RM facility associated CAD software; Category #4 – *Evaluation:* (7) Practice exercises and tests; Category #5 – *Help* and (8) FAQ’s on real and virtual FDM, (9) Help manual.

Detailed descriptions about the Tutor System are as follows: **Introduction:** Introduction provides overall description about contemporary RM facilities. **Learning RM facility:** Instructions related to the operation of the RP machines and online commands with the user interface. **View demo videos:** Prerecorded videos of different RP operations will be shown. For example, the RP performing parameter setting and the layer by layer coating operations will be recorded and used for this option. Moreover, the system shows the RP operation manual/instruction with a prerecorded plug-in video showing the movement of RP step by step. **Scenario based videos**: Videos based on different scenarios which include the change in speed of the RP machine or increase in complexity of the parts will be shown to the students. **Online interactive operation**: This option is used to interact directly with the RP and CF online using the user interface, but the system acts as an intelligent tutor displaying the corrective measures to the students in case of any incorrect steps formed by them. **Learning RM facility associated CAD software:** In this module, all multi-media files (i.e., audio and video embedded Adobe Captivate® 5 files) related to CAD software are recorded and posted to facilitate students to learn after hours. **Practice Exercises**: A set of questions are generated from the RP manuals in order to test the basic knowledge of the students in handling them. Then, the results of the students are analyzed and used for further tutoring methods. **FAQ’s:** A list of frequently asked questions is provided with the answers to facilitate the whole process of operation of RP. The set of questions will include the common mistakes made by the students while operating the RP’s and also other general information will be provided using this option. **Help** (**Manual)**: A manual containing the screen shots of the operation by an expert will be provided which can work as an help also. These manual contains the technical information related to the RM facilities. In general, the Tutor System can be enhanced and augment according to students’ needs. Figure 2 depicts the basic structure of E-based tutor system.

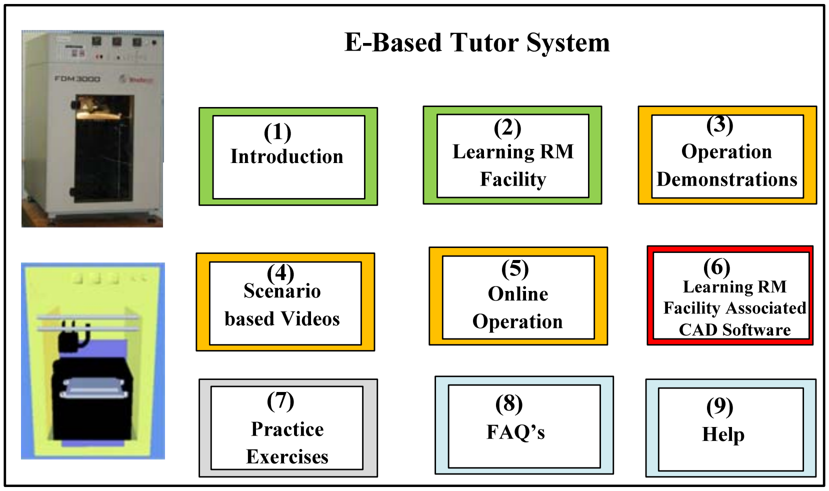


Figure 2. The sketch of the E- based Tutor System

Problem Description

Many engineering courses are pure lecture-based, and do not usually contain components that help student to boost their communication skills within the framework of engineering problems. The limited exposure to this critical success skill has resulted in isolated learning experience. Students lack the broad understanding in other areas of study and oftentimes speaking different languages between the disciplines. Many industries (i.e., automotive, aerospace, electronics, etc.) are complaining about the lack of preparation future engineers are receiving in colleges and universities. The industries pointed out that there exists a huge, yet common deficiency among the engineering students, asking that students should learn how to communicate effectively [10]. This is aligned with the exponential growth of advanced, sophisticated technologies that resulted in an increasing demand for engineers [11, 12]. The report prepared by the Society of Manufacturing Engineers (SME) listed 14 competency gaps that engineering graduates are lacking quality, product/process design [13]. To address this concern, there is a need to develop and incorporate an innovative education model to engineering curriculum to ensure that engineering graduates are equipped with appropriate knowledge and necessary skills in active learning, communication and information seeking.

What is giving added challenges to such education model is the emerging distributed operations in industries. In recent years, the centralized companies of the past have been replaced by geographically dispersed, remotely located companies collaborating on a common project. The technical advances, especially the Internet, have been the major driving force behind this trend. Surprisingly, the full potential of these technologies are not currently used in the classroom settings [14, 15]. There is no comprehensive education model fully integrating available Internet technologies into classroom with an emphasis on the improvement of students' skills in information seeking and communication [16]. In most cases, it is limited to the on-line course delivery, emails and e-bulletin board between students and instructors [17]. Therefore, the authors have implemented **a cyber facility integrated with tutor system approach** to explore the use of Internet for active learning and information seeking skills enhancement in engineering curriculum.

The Cyber Facility Integrated with Tutor System Approach for Effective Learning

The cyber facility integrated with tutor system approach aims at taking advantages of the pedagogical strategies and techniques, to improve students' learning. Basically, asynchronous cyber facility integrated with tutor system approach is self-paced, highly interactive, results in increased retention rates, and has reduced costs associated with student travel to an instructor-led workshop. In addition, this approach allows for easy access to the content and requires no distribution of physical materials. This feature translates into the following specific benefits like (1) *Access is available anytime, anywhere, around the globe*; (2) *Content is easily update*d and (3) *Per-student equipment costs are affordable*.

Despite these potential benefits, empirical studies typically have failed to find statistically significant differences between face-to-face (FTF) and cyber facility integrated with tutor system (CFITS) course performance. The major drawback, when compared to synchronous FTF instruction, is the lack of human contact, which greatly impacts learning. While students can use their Web connection to e-mail their instructors or post comments on message boards, FTF classroom real-time interaction between instructor and students may be still superior. Figure 3 illustrates a methodology of learning effectiveness evaluation for the RM related courses.

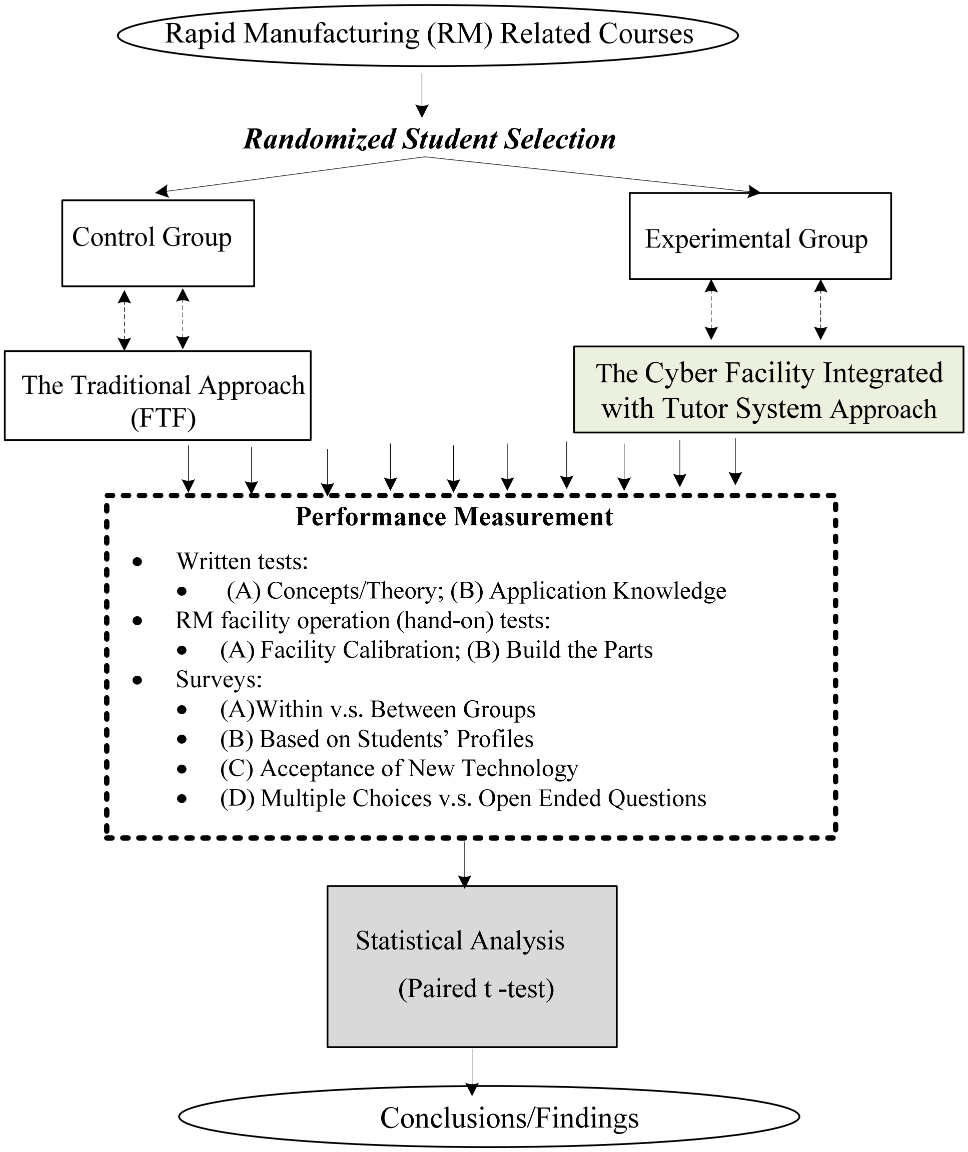


Figure 3 illustrates a methodology of learning effectiveness evaluation for the RM related courses.

Case Study: Comparison of the Conventional Approach and the Digital Simulator Based Approach for Effective Learning in Rapid Manufacturing

XXXX has offered a Rapid Manufacturing related course in Spring, 2011. The course title is Rapid Manufacturing (RM) and Medical Modeling (MM). Basically, the course is an introduction to RM and MM. RM technologies fabricate three-dimensional (3D) parts using layer-based manufacturing processes directly from Computer-Aided-Design (CAD) models. Direct Digital Manufacturing (DDM) is the use of RM technologies in direct manufacturing of end-use parts. Moreover, MM is important in biomedical research and the medical device industry. Medical modeling is used in Visualization and Verification, Measurement and Analyses, FEA and CFD, Implant and Surgical Guide Design, Additive Manufacturing, Reverse Engineering, Surgical Simulation, and numerous other applications relevant to medicine and biomedical research. Using Mimics® to transform 2D data from CT/MRI (medical imaging modalities) to 3D Models is the foundation of the course. Students will learn new applications in 3D modeling for research and medical applications. Examples of past projects are including Cardiovascular Modeling, Hemodynamics Analysis, and Pre-surgical Modeling and Design of Custom Implants and Surgical Guides.

Basically, this class has been collected data/info related to teaching effectiveness through using (1) the Tutor System and (2) the RP Simulator. Particularly, we are interested in exploring if **a non-traditional instruction approach through the Tutor System and the RP Simulator** can compete with and/or substitute to the traditional method (i.e., a face-to-face class). There are two major activities in our data collection plan. **First,** for effectiveness of the use of the tutor system, the instructor used Adobe Captivate® 5 to develop and demonstrate the use of the medical modeling software called Mimics® then saved it as a Captivate file (i.e. .wsf). Then, it was uploaded in the tutor system to allow students to download it. Basically, there are two groups under this activity – Control Group/Group **A** (i.e., using face-to-face instruction) and Experiment Group/Group **B** (i.e., using the tutor system). **Second,** for effectiveness of the use of the FDM operation video and the RP simulator, there are three groups under this activity – Control Group/Group **A** (i.e., using face-to-face instruction), the 1st Experimental Group/Group **B** (i.e., using live video based on face-to-face instruction and video based on the RP simulator posted on YouTube) and the 2nd Experimental Group/Group **C** (i.e., using the RP simulator).

The Use of the Tutor System

The students were separated into two groups. Group A is using the Tutor System (Experimental Group) while Group B is using traditional instruction (Control Group). Basically, the group determination is based on separating similar background students to avoid statistical bias. Here, 14 students are formed in Group A while there are 15 students in Group B. Student were required to conduct the semester project and the final project scores were used to appraise group performance. This project consists of building a four-part assembly using 3D printing technology. The assembly must be extracted and assembled using Mimics® software. Abdominal and cranial datasets will be provided. The assembly must be edited and colored using Z-Edit. The assembled part should be limited to more than 4-inches on a side (so a max. of 4-in by 4-in by 4-in part). As a result of this restriction, the part will most likely need to be scaled down. Figure 4 illustrates students working on their term projects and the instructor providing a lecture using Mimics® software.

Figure 4: The students working on their term projects and the instructor providing a lecture using Mimics® software

Some sample projects from students are illustrated in Figure 5 and students' project grades are listed in Table 1. Here, the best project is based on completion of the part and with the most detail (i.e., the foot part)

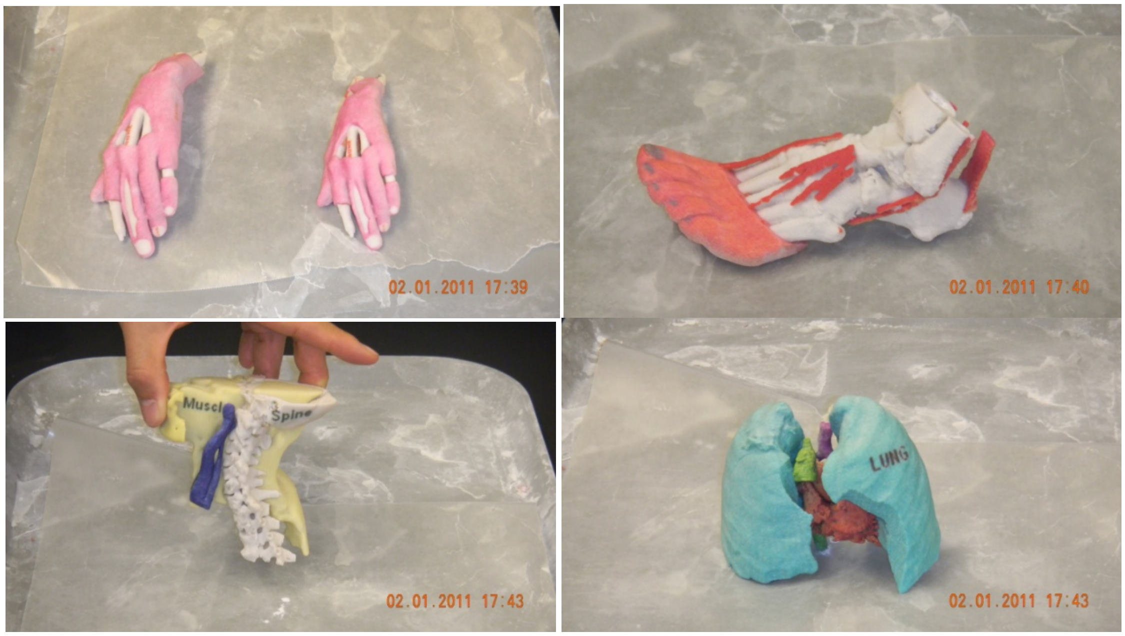


Figure 5: Student projects using 3D printing technology (clockwise) – (1) Posterior view of the **hands** showing soft tissue and exposed metacarpals and phalanges; (2) Dorsal view of the **foot** showing soft tissue and tendons as well as tarsal and metatarsal bones; (3) Lateral view of the base of the **skull** showing cervical vertebrae, trachea, esophagus, and soft tissue and (4) Anterior view of the **lungs**, heart, trachea and aortic arch

Table 1: Project grades from Group A and Group B

Group A **(Control Group)**		**Group B** **(Experimental Group)**	
No	Grade	No	Grade
1	95	1	95
2	90	2	95
3	100	3	95
4	100	4	100
5	100	5	95
6	100	6	100
7	95	7	90
8	95	8	100
9	90	9	95
10	100	10	100
11	95	11	90
12	95	12	100
13	100	13	95
14	95	14	90
15	95		
Total	1350		1340
Average	96.42		95.71

Here, we assume the null hypothesis is that difference between the two sample means is not significant. We assume α = 0.05 and Statistica® software was used to calculate two sample t-test. The results are shown as follows:

Table 2: Two sample t-test

Group 1 vs. Group 2	T-test for Independent Samples Note: Variables were treated as independent samples							
	Mean Group 1	Mean Group 2	t-value	df	p	Valid N Group 1	Valid N Group 2	Std.Dev. Group 1
Group A vs. Group B	96.42	95.71429	0.452338	27	**0.654639**	14	15	3.851644

Group 1 vs. Group 2	T-test for Independent Samples Note: Variables were treated as independent samples		
	Std.Dev. Group 2	F-ratio Variances	p Variances
Group A vs. Group B	3.518658	1.198225	0.739252

After calculating the two sample t-test statistic and the p-value equivalent to 0.654639, we could conclude that the difference between Group A (Experimental Group) and Group B (Control Group) is **not significant** due to the p-value is greater than the α-value. Therefore, **the use of the tutor system is equally effective to face-to-face instruction.**

The Use of the FDM 3000 Operation Video and the RP Simulator

FDM operation instruction was given to the **Group A** by the instructor of IE 4395/5390 and MFG 5390 class. The Group A was constituted of 10 students. They received instructions related to FDM 3000 machine operation, calibration and its applications. For the **Group B**, two articulated videos were shown to demonstrate how the FDM 3000 machine works. One video was taken from instruction of the instructor while the other one was developed based on the use of the RP Simulator posted on YouTube. The size of this group is about 10 students as well. The last group (i.e., **Group C**) with 9 students involved was directed to use the RP Simulator to learn FDM operations and other applications. At the end of each activity corresponding to each group, a written test comprised of 10 multiple choice questions was taken to evaluate students' knowledge of the FDM 3000 operations and applications. The test scores from three groups were tabulated and illustrated below (see Table 3):

Table 3: Comparison of student performance based on Group A, Group B and Group C

Group A (Live Instruction)		**Group B (Video)**		**Group C (The RP Simulator)**	
S. No	For 10	S. No	For 10	S. No	For 10
1	4	1	8	1	6
2	5	2	9	2	6
3	9	3	10	3	6
4	9	4	9	4	7
5	10	5	9	5	8
6	8	6	10	6	7
7	6	7	7	7	8
8	10	8	10	8	6
9	9	9	9	9	6
10	7	10	9		
Average	7.7		9.0		6.6

The following analysis shows the results obtained from statistical tests. Note that three two-sample t-test (i.e., groups AB, groups AC and groups BC) were performed.

Table 4: Two sample t-test (Groups AB)

Group 1 vs. Group 2	T-test for Independent Samples Note: Variables were treated as independent samples							
	Mean Group 1	Mean Group 2	t-value	df	p	Valid N Group 1	Valid N Group 2	Std.Dev. Group 1
Group A vs. Group B	7.7	9	-3.08607	18	**0.00637**	10	10	1.59513

Group 1 vs. Group 2	T-test for Independent Samples Note: Variables were treated as independent samples		
	Std.Dev. Group 2	F-ratio Variances	p Variances
Group A vs. group B	1.286684	1.536913	0.532155

Table 5: Two sample t-test (Groups AC)

Group 1 vs. Group 2	T-test for Independent Samples Note: Variables were treated as independent samples							
	Mean Group 1	Mean Group 2	t-value	df	p	Valid N Group 1	Valid N Group 2	Std.Dev. Group 1
Group A vs. Group C	7.7	6.6	0.957024	18	**0.351233**	10	10	1.595131

Group 1 vs. Group 2	T-test for Independent Samples Note: Variables were treated as independent samples		
	Std.Dev. Group 2	F-ratio Variances	p Variances
Group A vs. Group C	3.265986	4.192140	0.044122

Table 6: Two sample t-test (Groups BC)

Group 1 vs. Group 2	T-test for Independent Samples Note: Variables were treated as independent samples							
	Mean Group 1	Mean Group 2	t-value	df	p	Valid N Group 1	Valid N Group 2	Std.Dev. Group 1
Group B vs. Group C	9	6.6	2.792654	18	**0.012024**	10	10	1.286684

Group 1 vs. Group 2	T-test for Independent Samples Note: Variables were treated as independent samples		
	Std.Dev. Group 2	F-ratio Variances	p Variances
Group B vs. Group C	3.265986	6.442953	0.010548

According to Tables 5 -7, we can conclude that only comparison between AB and BC are significant. In other words, only **the group using the video** (i.e., instruction video and YouTube video) has the best performance in this test.

Survey Results from IE 4395/5390 and MFG 5390 - Introduction to Rapid Manufacturing and Medical Modeling

Pre-course and Post-course Questionnaires: Pre-course and post-course questionnaires were developed in order to know the initial opinions of the students about distant education, the technologies involved, and if there was any change in their opinion after getting exposed to the new method. The pre- and post-course questionnaires were given to three categories. The compiled responses for the pre-course questionnaire are tabulated as shown below. Responses were tabulated for undergraduate and graduate students separately in order to know if any difference in opinion existed.

Pre-Course:

Pre course questionnaires are to survey what background students have in the content of the IE 4395/5390 and MFG 5390 - Introduction to Medical Modeling course. The data collected for undergraduate and graduate students are shown below: The final results of the questionnaires for pre-course survey are shown in the histograms. The graph is drawn with the question number IDs on the X-axis and percentage of responses on the Y-axis. The following figures show the histogram for undergraduate and graduate students in the pre-course survey.

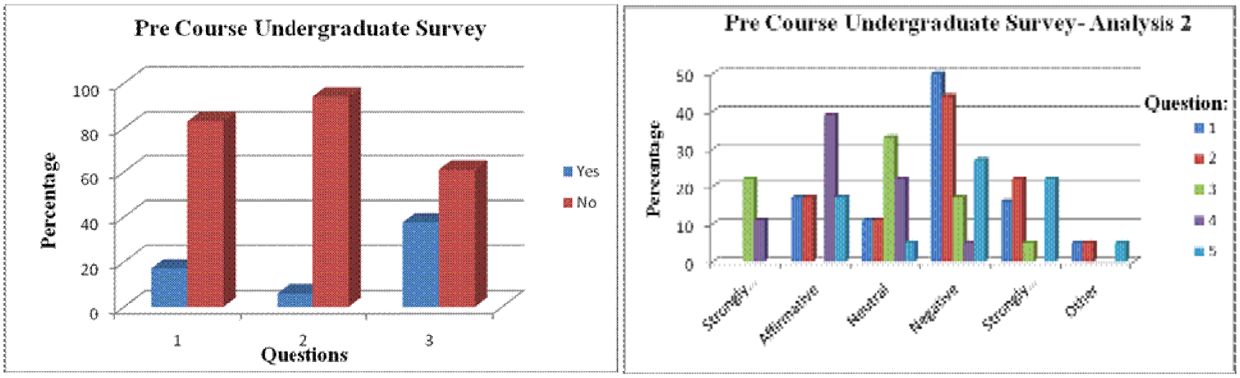


Figure 6: Pre-course survey for undergraduate students

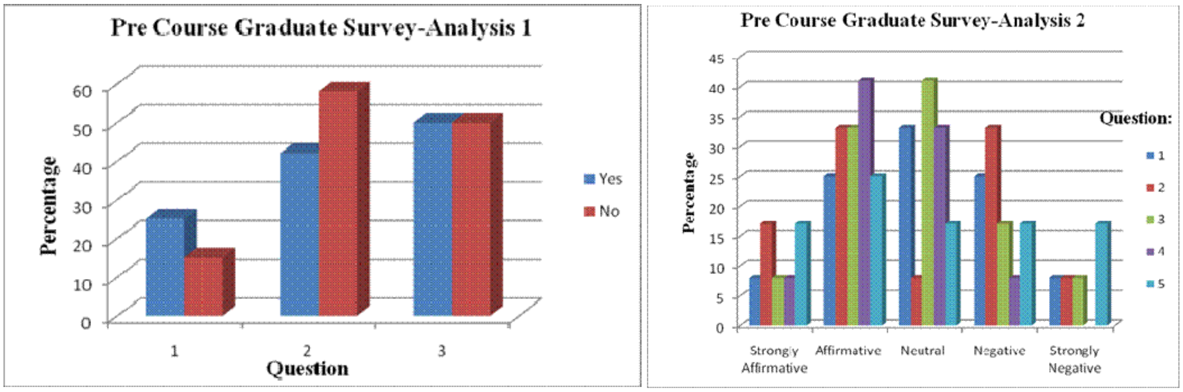


Figure 7: Pre-course survey for graduate students

Post-Course

Post-course questionnaires are a way to survey the student's perceptions after they took the IE 4395/5390 and MFG 5390 - Introduction to Medical Modeling course. The data was collected for undergraduate and graduate students and the results of the survey are illustrated below: Final results of the questionnaires for post-course survey are also shown in the histograms. The graph is drawn with the question number IDs on the X-axis and percentage of responses on the Y-axis. The following figures show the histogram for undergraduate and graduate students in the post-course survey.

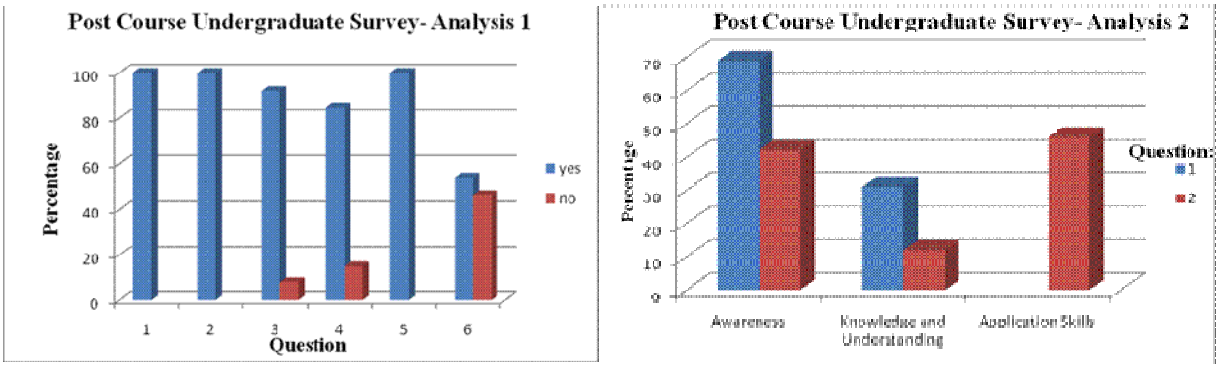


Figure 8: Post-course survey for undergraduate students

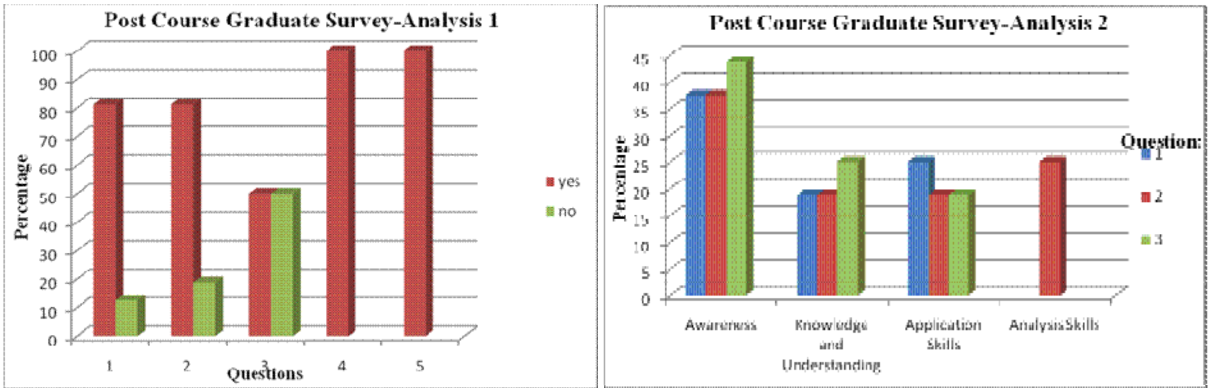


Figure 9: Post-course survey for graduate students

Conclusions

Based on the **pre-course** survey analysis, it is summarized that graduate students had more understanding than undergraduate students regarding **rapid prototyping technologies** and **remote operations**, and most of undergraduate and graduate students thought that high quality learning can take place without face-to-face interaction which is a positive sign for upcoming technologies to be implemented in the education environment. Moreover, students' responses were positive to the use of 3D devices for effective and active learning. Through the same pre-course survey, it was revealed that most of the undergraduate and graduate students agreed with the proposed course outlines are suitable for them to learn, particularly, developing a CAD model then fabricating it through a 3D printer in the medical field application. Furthermore, most graduate students felt comfortable learning technical information over the Internet. Both graduate and undergraduate students thought that the multi-media approach will enhance student learning better due to course materials could be more available and easy access at any time.

According to the **post-course** survey, students are comfortable and more inclined towards to web based education because they could access instructions, manuals and other documents online. Other observations were that student could understand better since he or she has a chance to rewind media materials. Also, it is very helpful for those whose have to work and do not have time to attend school. Most of the undergraduate and graduate students agreed that "through using Mimics® to transform 2D data to 3D models could enhance student learning since it provide insight into the medical field." Also, they can understand better geometry of the human body. Based on knowledge and hands-on experience with the simulator as well as the FDM 3000 machine and 3D visualization, the following insights can be indicated: (1) Most of students seem to agree that they could learn more effective using multi-media to enhance their professional skills; (2) Both undergraduate and graduate students found some advantages regarding the use of the tutor system. They concluded that students could get assistance on/off campus by using the tutor system. The students could repeat the video several times and work at their own pace. The survey also indicates the students' responses were affirmative in relation to the use of remote operation and the enhanced perception using 3D visualization. They support the statement that multimedia systems like 3D and the simulation can definitely enhance student learning.

Acknowledgement

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Appendix

Also, to introduce this state of art software and increase publicity, eight and a half minutes video have been professionally made and posted on YouTube (http://www.youtube.com/watch?v=QMR5WaodGFA) on 12/21/10.

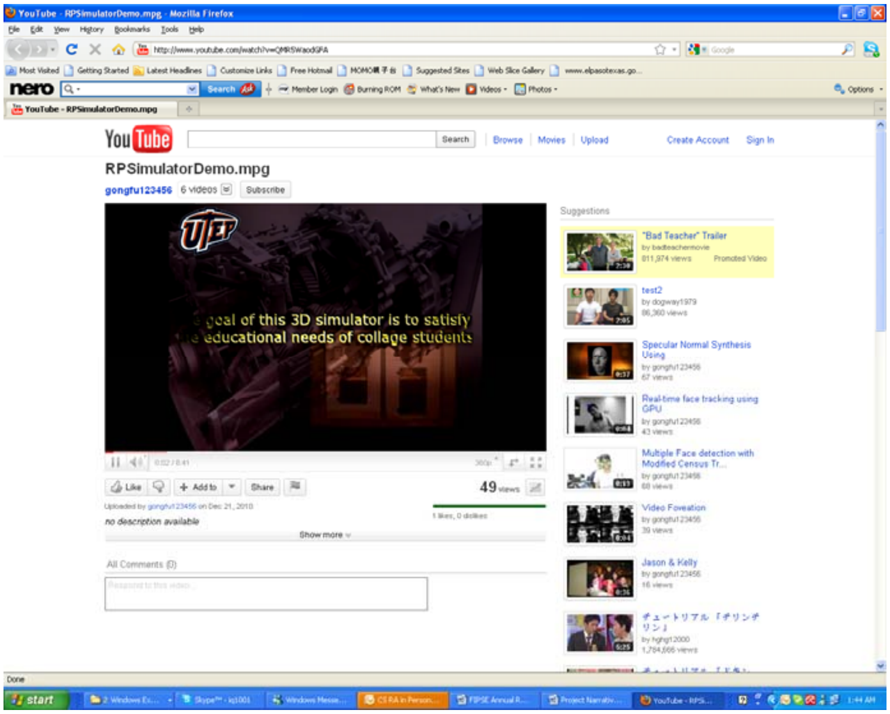

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Figure 10: Introduction of the RP Simulator video posted on YouTube on 12/21/10