Cyber Based Layer Manufacturing with an On-line Testing System

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Improving engineering education has become a major concern for universities. There is a need to change the engineering curriculum and create courses that will give future workforce engineers the skills that manufacturing companies are searching for. One of the concepts that are trying to be utilized is creating online courses[1, 2] ; for the objective presented here the online technology is used but with a different approach than just a regular online course. In this paper, the idea is to explain, implement, and further enhance engineering education with a different program for the Industrial, Manufacturing and Systems Engineering department and the Mechanical Engineering Department at the University of Texas at El Paso. This program has the goal of building up engineering education in Cyber-Based Rapid Manufacturing (CBRM) by using a cyber-Rapid Prototyping (RP) simulator. The cyber RP simulator will be introduced and described in a 3D environment. The main goal of the cyber RP simulator is to give students the opportunity to learn how to operate the Fused Deposition Modeling (FDM) 3000 machine; this learning will occur in a virtual environment with different steps explaining how to use the FDM machine. This paper aims at explaining the RP simulator and its effect on students' learning in a real and online environment; the success of the RP simulator and the program will be measured in the evaluation of the students using the RP simulator with online and without online testing, and Face-to-Face (FTF) instruction.

Introduction

Manufacturing has changed over the years, and as more industry challenges appear, the education of the future workforce needs to step up and change the teaching ways in order to satisfy the skills that the manufacturing industry is searching for. It is of great importance that the upcoming workforce has the necessary skills in science, technology, engineering, and math (STEM) [3]; this knowledge is necessary because the industry believes that the new workforce lacks skills in problem solving, social interaction and teamwork[3]. Several companies state that they are not moving their manufacturing processes oversea because of the lack of workforce skills, but the numbers state something different[3], most companies are moving their industries off-shore. Current manufacturing industries need a workforce that will understand how to operate and maintain manufacturing equipment. Workers should have the skills and once they are properly trained, they should be able to correctly work with the machines without faulty operations that could cause machine damage and economic loss to the company. Education is trying to improve the integration of online courses but specifically to engineering the integration of technologies such as robotics, and advanced machines[3]; it is necessary that students learn how to use manufacturing machines, in order to have some kind of manufacturing process experience[4]. In a recent literature review, two challenging problems in education were presented which are: **How to better educate students in online facility training without interaction with instructors, and how to improve teaching and learning effectiveness in online course and facility training[5].**

As the manufacturing industries want faster production, additive manufacturing is becoming more popular throughout the years. The implementation of additive manufacturing involves

Rapid Prototyping (RP) and Rapid Manufacturing (RM) technologies. It has been stated that additive manufacturing techniques print material layer by layer to form a part, and one of the reasons for its design is to accelerate product design and production cycle[6]. Besides having additive manufacturing several companies are trying to involve Cyber-Enabled Manufacturing (CEM), this system allows to continuously monitor the final products through sensors and the equipment state[6]. The CEM system can be used as an example of why involving online technology is necessary in the teaching of manufacturing courses in order to get the next generation of workforce involved with the necessary skills in the working environment. RP and RM technologies have helped reduce the cycle and cost of product development and it is of great importance in developing different tools, and improvements in manufacturing technologies. As previously stated, RM includes rapid prototyping, rapid tooling, and uses different layer technologies depending on what is being developed, but now the innovation is the use of the internet to enhance design and manufacturing productivity by having a remote integration[7, 8]. There are several additive technologies such as Ultrasonic Consolidation, PoyJet 3D Printing, Stereo Lithography, Micro-Stereo Lithography, Inkjet printing, and many more[6, 9-11].

Rapid Manufacturing and Rapid Prototyping technologies are trying to be adapted to cyber technologies such as internet and virtually connect the different manufacturing equipment and be able to know production outcomes and equipment maintenance through a network[7]. In this case, the term of "Cyber Facility" (CF) describes the idea that is presented in this paper, which is having a virtual facility that will be able to teach students in a way that a real professor will do. The CF has several characteristics some of them include error free data, innovating testing, and evaluating design features which can help develop different ideas[12-14]. The CF will serve as a kind of practice in a virtual facility, and with this practice it will train user to use the real facility when it is time. In this case more than a facility it will be getting familiar in using and how to operate the commands of the Fused Deposition Modeling (FDM) 3000 facility.

Development Background of the Cyber RM Facility

The conceptual framework of the cyber RM system (see Figure 1) consists of three main parts: (1) the RP simulator, (2) application server and (3) network setup. The following section described more details.

a. RP Simulator

The RP simulator is the main part of this project. We use 3D studio Max to model the real FDM 3000 Rapid Prototype machine, and simulate the functions of the machine in the 3D environment using XNA framework. It's the beta version of the Rapid Prototyping Support Systems (RPSS). Its basic functions can be controlled by the users. Users can rotate, zoom in/out, turning on/off the machine. The purpose of the beta version is let the users get familiar with the RPSS. When users move their mouse to a certain area on the 3D virtual machine, the description/introduction of the function/control will popup to teach the user how to operate that part on the real machine. And user can practice calibration of the machine in its virtual calibration environment, so that users can operate the virtual machine like operating a real one.

b. Application Server

The application server contains all the course materials, student account/information such as their score, operation level and uploaded .STL files. Also, it contains a database to organize all the materials and information which can also be accessed and maintained by the teacher/administrator.

c. Network Setup

The RP Simulator also connects with the real machine through API. In the future, users may import their own .STL file into the RPSS and simulate the whole procedure of manufacturing, check/fix if there is any problem, then, send the file to the real machine and remotely build it right away.

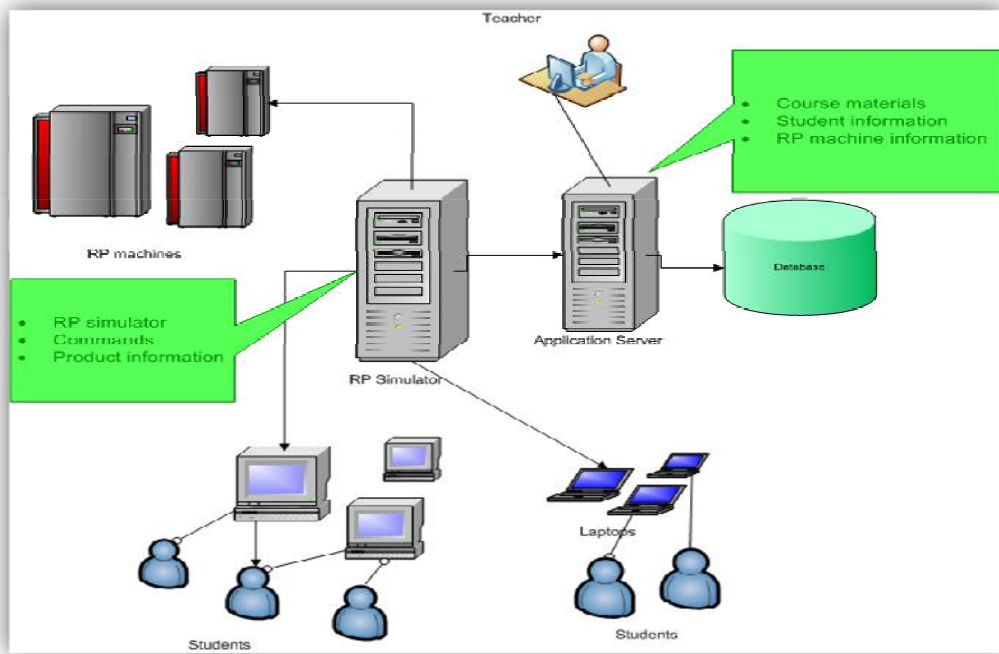

Figure 1: The conceptual framework of the cyber RM facility

Development of the RP Simulator with an On-line Testing System

In this section, the RP simulator with an on-line testing system is introduced next. In the current on-line testing system, it only covers (1) basic functions of the FDM 3000 (see Appendix) and (2) calibration of the FDM 3000. The virtual manufacturing part is still under development. In general, the operation system of the testing system is running on Windows 7 operation systems, and will be further launched on web. This system is self-contained product, which means that it doesn't need any other software components or applications with which it must coexist. The flowchart of the on-line testing system and the snapshot of the virtual test module are illustrated in Figure 2 and 3 respectively.

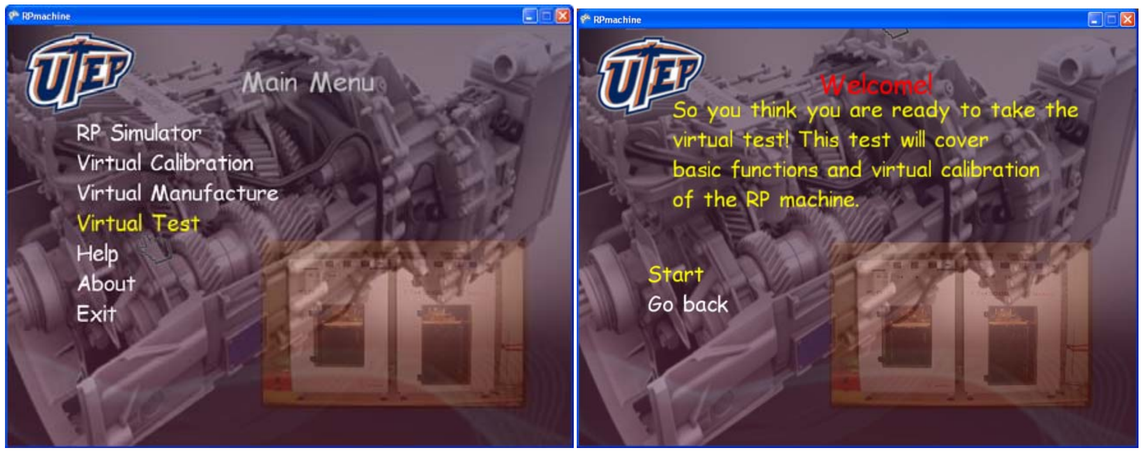

Figure 2: (a) The virtual test module developed by University of Taxes at El Paso (UTEP) and (b) Welcome screen

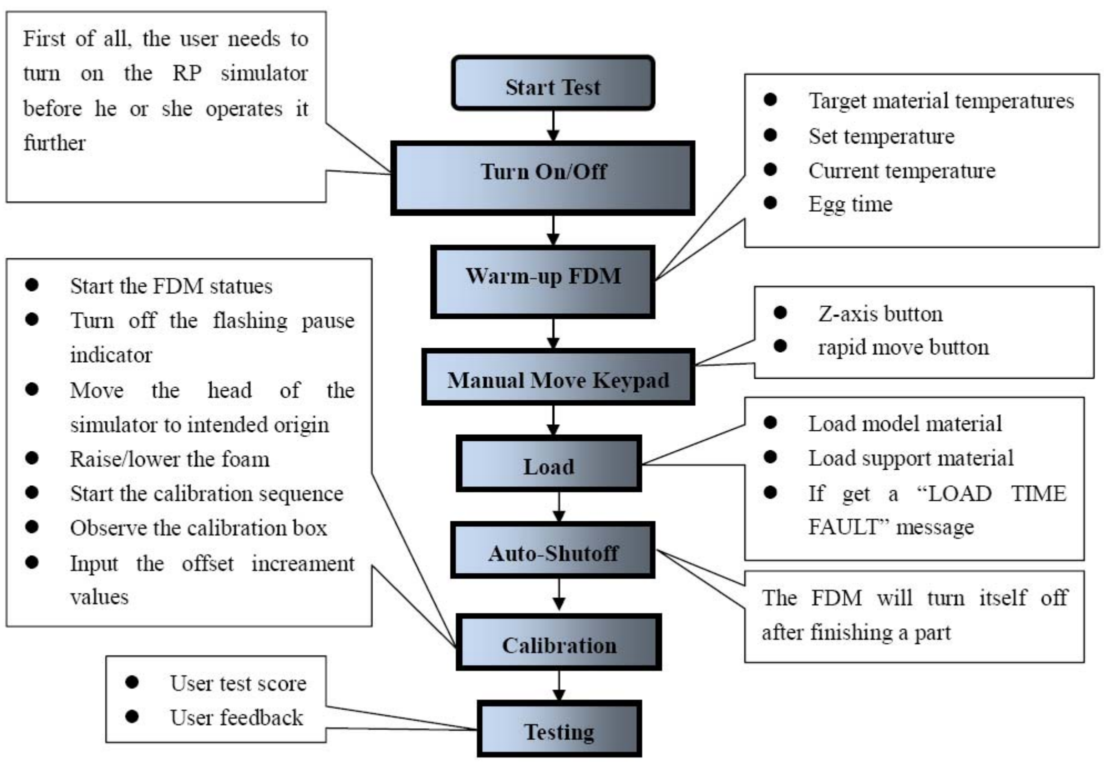

Figure 3: The flowchart of the on-line testing system

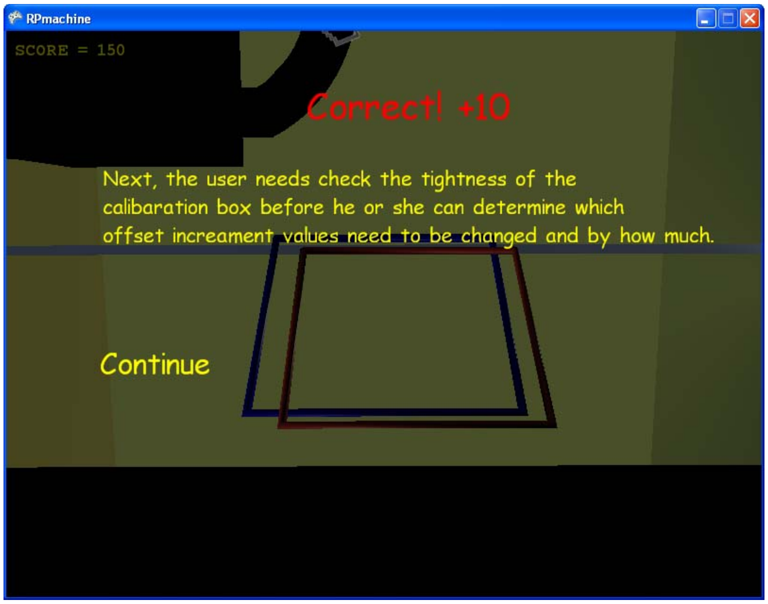

Figure 4: Building the calibration box (Blue: model material; Red: support material)

Here, the students need to calibrate the machine before manufacturing (see Figure 4). Before calibration sequence on the machine, the simulator will start the FDM Status for students, who will then need to send default settings to the machine. After this, the pause indicator on the control panel will be flashing. And then the students need to press the "PAUSE" button to turn off the flashing pause indicator. The simulator will then perform a brief calibration sequence that ends by placing the head at its default origin at the front left corner of the foam. When this process is complete, the pause indicator will begin flashing again. After the calibration sequence, the user needs to check the calibration box that has been built. If the support material roads don't lie directly on the center of the model material, the students need to check the tightness before he or she can determine which values need to be changed and by how much. And then the students need to input the offset increment values for x, y and z dimension in the FDM status window and send the new settings to the machine.

It is known that there is a need to improve the skills given to the future workforce, and that online courses are trying to be applied but the career that has the lowest implementation of online techniques in their given courses is engineering[1, 2]. Since online techniques are not being fully applied to engineering courses, there is not an actual educational plan to integrate virtual techniques into classroom teaching in order to improve the technical skills of the new upcoming workforce[15]. The main goals of the cyber RP simulator are: 1) Motivate students in studying more internet based rapid manufacturing systems, 2) Strengthen and build up the technical, problem solving and communication skills of students in order to practice in the classroom, and apply it in the real working world.

Problem Identification

Many manufacturing industries are trying to virtually connect all its operations; an example of this is using E-manufacturing[16]. By E-manufacturing it is meant that all the operations within the business will be integrated meaning suppliers, customer service, and manufacturing units; these will be integrated by the correct use of current technologies and web-enabled tools[16]. Since most education courses are still completely lecture-based, the students will have to learn the web-based technologies once in the work field; these skills need to be learned in the engineering curriculum in order to be ready for the actual job. Several industries such as automotive, and aerospace, have identified technical obsolesce and lack of communication skills as the main problems in the preparation of future engineers[4, 17]. There is an increasing demand for engineers due to the growth of advanced and sophisticated technologies[18, 19], with this growth the need to implement a different way of teaching in order to avoid the lack of required skills in future engineers is increasing. There are different gaps between manufacturing processes and the skills of the new engineering graduates; some of these gaps include design, quality and the way of interacting with manufacturing equipment and processes[20, 21]. In order to close the identified gap, a change in the engineering curriculum has to be made; implementing more hands-on manufacturing will be a good solution in order to improve the technical, communication, information search, and team-based skills.

An improvement in education has to be seen as it has been shown in the industries' operations; as stated before companies are trying to implement the Internet and web-based technologies into their operations in order to have a full connection between different systems to have updated data at an instant[16, 22]. There are some steps toward involving current technologies used in manufacturing processes in the classroom, but nothing completely developed has been used[23, 24]. The main involvement of online technology in the classroom is that of general online courses in which most of the time they are limited to just on-line material, emails, and a communication board between the instructor and students[25, 26]. The idea of developing a cyber-based rapid manufacturing using a cyber-Rapid Prototyping simulator is derived from the fact that there is not an actual education model integrating current online technologies to improve the students' skills in the manufacturing and engineering sector. A way to explore and evaluate the use of online technologies applied in the classroom setting will be by using the cyber-RP simulator with an online testing system that will help evaluate the students' performance in different educational settings.

Aggregation between the Cyber Facility and the On-line Testing System

The cyber facility, integrated with a tutor system, aims to enhance the student learning by approaching it in a unique way. Unlike the traditional method, the cyber facility allows the students to pace their learning with its easy access to content requiring no physical material to be distributed. Also, unlike the traditional method, it allows the students to interact with the system in a simulated environment which has proven to result in high retention rates in many such similar cases. The key features of cyber facility are: a) Learning material can be accessed anytime and from anywhere from the globe; b) Constant access to latest material as content can be easily and constantly updated and c) Affordable expense for student to gain access to cyber facility.

The cyber facility and on-line testing system has certain benefits such as the faster share of lecture information and the fact that the student will be able to obtain it anywhere. These benefits have not proved any significant difference when it comes to a comparison with the FTF lectures. The most probable cause for the lack of significant difference, and assuring that the cyber facility teaching could be better is that students are not used to the lack of human contact when not having an instructor giving the lecture. Even if the students can email their instructors or post comments on message boards using the cyber facility method, the real time classroom interaction between the student and the instructor turned out to be superior. Figure 5 illustrates implementation of the two different teaching methods to compare learning effectiveness for the RM related courses. **The principle of Continuous Quality Improvement (CQI) is also applied in developing the evaluation methodology to eliminate potential bias and variation and enhance appraisal accuracy.** Note that due to technical issues related to operation facilities, the hands-on test isn't included in student performance measurement.

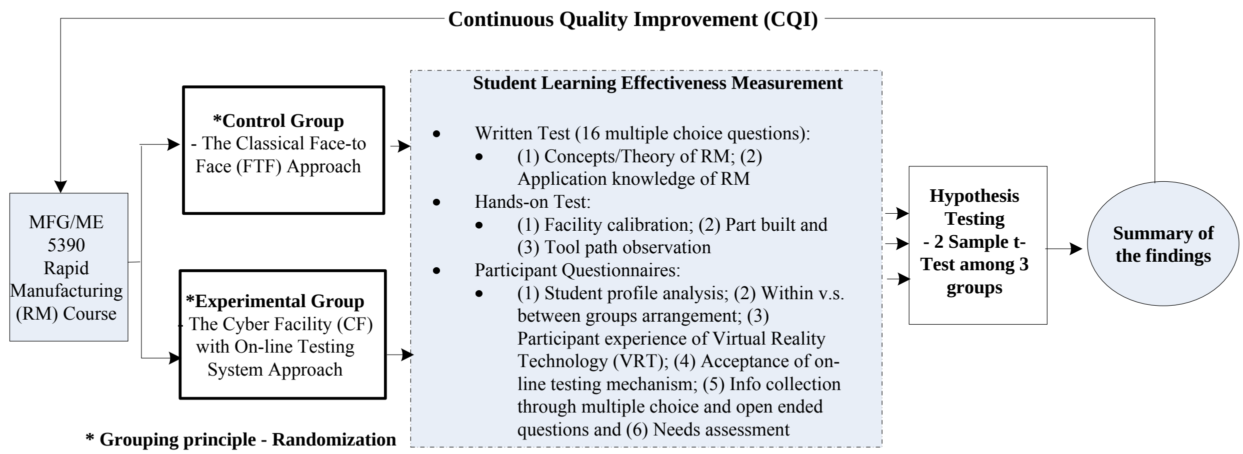

Figure 5: A methodology of learning effectiveness evaluation for the RM related courses

Illustrative Case Study: Comparison of Learning Effectiveness between the Traditional Teaching Approach and the Cyber Facility with Online Testing System Approach

UTEP has offered a course related to Rapid Manufacturing called Rapid Manufacturing Systems (RMS) in Fall, 2012. This course is an introduction to Rapid Manufacturing (RM); as stated before RM is part of additive manufacturing which in turn involves using layer by layer manufacturing of products and different possible additive manufacturing techniques. The RM technologies basically fabricate three-dimensional parts by using layer by layer manufacturing processes from the parts' Computer-Aided-Design (CAD) model.

This course of RMSs collected data to make a comparison in students' performance in the different teaching techniques. The data was collected in (1) FTF instruction, (2) RP Simulator without an online testing approach and (3) RP Simulator with an online testing approach. **The main objective of the comparison is to discover if a non-traditional instruction approach through the RP Simulator and the RP Simulator with an on-line testing system can challenge and substitute the common, traditional method of FTF instruction.** To perform the comparison of these three teaching approaches three groups were created. Figures 6-8 show the different division of the groups. Group #1 receives FTF instruction, Group #2 receives instruction using the RP Simulator without online testing approach, and Group #3 receives the new instruction using the RP Simulator and online testing. For the experiment purposes, Group #1 is considered the control group and Groups #2 and #3 are the experimental groups.

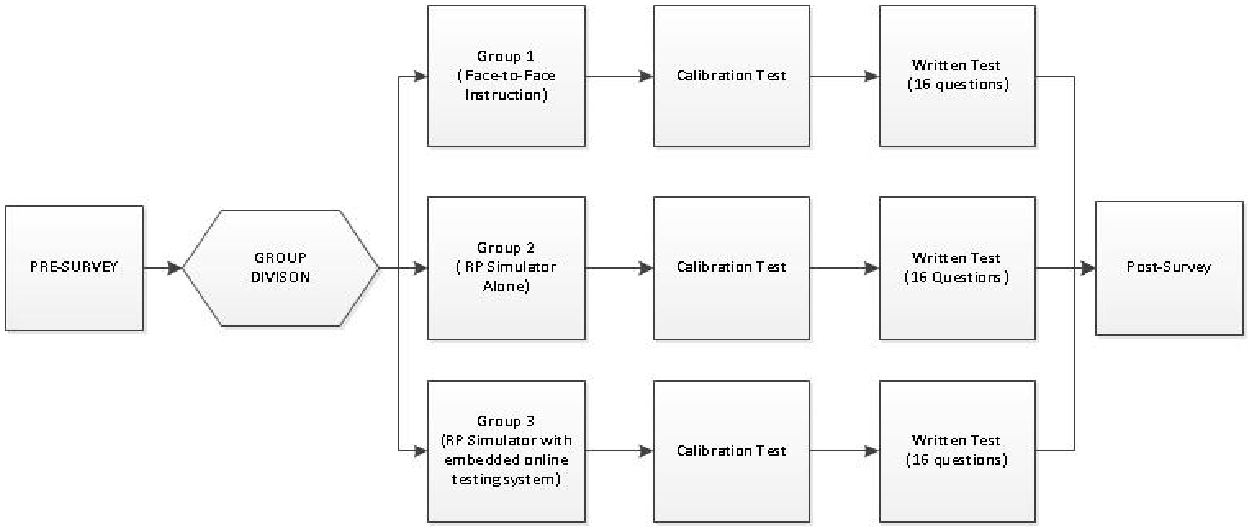

Figure 6: Three groups designated to the data collection plan (Group #1- the control group; Group #2 & 3 – the experimental groups)

Figure 7: (a) Group #1 – Live RP instruction with hands-on practice; (b) Group #3 – Implementation of the RP simulator with an on-line testing system

Figure 8: (a) and (b) - Group #2 – Implementation of old version of the RP simulator without an on-line testing system

Hypothesis Testing Related to the Three Teaching Approaches

Here, three different hypotheses tests among (1) the traditional FTF approach, (2) the old version RP simulator (i.e., without the on-line testing system), and (3) the new version RP simulator (i.e., with the on-line testing system) are listed below:

Hypothesis #1: (Group #1 v.s. Group #2)
Significance between (1) the traditional FTF approach and (2) the old version RP simulator implementation approach
Hypothesis #2: (Group #1 v.s. Group #3)
Significance between (1) the traditional FTF approach and (2) the new version RP simulator implementation approach
Hypothesis #3: (Group #2 v.s. Group #3)
Significance between (1) the old version RP simulator implementation approach and (2) the new version RP simulator implementation approach

For **Group #1**, also called as a control group, it consisted of 8 students derived from class MFG/ME 5390. They were given instructions through an instructor on how to operate an FDM 3000 machine. They were taught on the machine operation, calibration and its applications without the use of any simulated software.

For **Group #2**, also called as an experimental group #1, it consisted of 8 students and they were given instructions on how to operate the RP simulator software and they were directed to learn the operation of the FDM operations and other applications. The version of the software used doesn't have an embedded online testing system.

For **Group #3**, also called as an experimental group #2, it consisted of 6 students and they were given instructions on how to operate a different version of RP simulator software which has an embedded online testing system.

At the end of each activity corresponding to each group, a written test comprised of 16 multiple choice questions (see Appendix) 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 1 and Figure 9):

Table 1: The test performance among the designated three groups

Group #1 (Control Group-Live Instruction)		**Group #2 (RP Simulator-Old Version)**		**Group #3 (RP Simulator-New Version)**	
S. No	For 16	S. No	For 16	S. No	For 16
1	14	1	10	1	9
2	8	2	9	2	9
3	11	3	9	3	7
4	13	4	8	4	9
5	11	5	8	5	9
6	10	6	11	6	9
7	11	7	9		
8	13	8	4		
Average	11.37		8.5		8.6

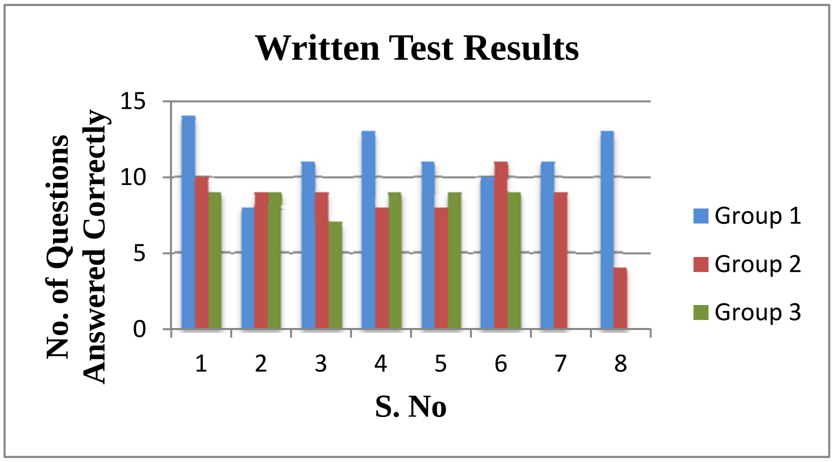

Figure 9: The test score among the designated three groups

For Group #1, students were trained through an instructor alone but were not allowed to use the simulated version (RP Simulator) on how to operate the FDM machine. At the end of class, they were given tests based on what they have learned. The test consisted of 16 multiple choice questions. Simultaneously instructions were also given to Group #2 and Group #3 separately who are using the RP simulator without and with embedded online testing system respectively and were tested at the end of class. All the test scores were taken and the following analysis was made with the help of Minitab 16 software to see if there exists any significant difference between the three groups. **Here we assume the null hypothesis is "the difference between the means of two samples is not significant." Therefore, the alternative hypothesis will be that the difference in means between two samples is significant.** We assume $\alpha = 0.05$

Comparing the results between Group #1 and Group #2 by conducting a two sample paired t-test, we obtain a p-value of 0.012. Since p – value is less than α, we can reject the null hypothesis and conclude that the difference is significant. **Hence this implies that the samples obtained from the group #1 when compared with the group #2 are significantly different.**

Table 2: Two sample paired t-test (Group #1 vs. Group #2)

Group	Mean	StDev	t-value	p-value
			2.88	**0.012**
1	11.38	1.92		
2	8.50	2.07		

Comparing the results between Group #1 and Group #3 by conducting a two sample t-test due to different sample sizes, we obtain a p-value of 0.007. Since p – value is less than α, we can reject the null hypothesis and conclude that the difference is significant. **Hence this implies that the samples obtained from Group #1 when compared with Group #3 are significantly different.**

Table 3: Two sample t-test (Group #1 vs. Group #3)

Group	Mean	StDev	T-Value	P-Value
			3.21	**0.007**
1	11.38	1.92		
3	8.66	0.816		

Hence we can conclude from Table 2 and Table 3 that significant differences between the three groups indeed exist, one group who were taught using an instructor but without a simulated software while the other without an instructor but with a simulated software without an embedded testing system, and the other group with one.

Comparing the results between Group #2 and Group #3 by conducting a two sample t-test, we obtain a p-value of 0.856. Since p – value is greater than α, we can do not reject the null hypothesis. Hence this implies there isn't significant difference between Group #2 and Group #3. **Hence there isn't significant difference between the groups, one who were taught using an RP simulator without the embedded testing system and other group who were taught using a version of RP simulator which has an embedded testing system.**

Table 4: Two sample t-test (Group 2 v.s. Group 3)

Group	Mean	StDev	T-Value	P-Value
			-0.19	**0.856**
2	8.5	2.07		
3	8.66	0.816		

According to Tables 2 - 4, we can conclude that only comparison between 1 v.s. 2 and 1 v.s. 3 are significant. In other words, only **the group with live instruction** has the best performance in this test.

Survey Results from MFG/ME 5390-Rapid Manufacturing Systems Course

As can be seen from Figure 6, two surveys are conducted, one before the start of class and the other after the end of class and tests were conducted.

1. Pre-course and Post-course Survey: Two different questionnaires were developed for the MFG/ME 5390 course. These questionnaires were to be given before taking the course and after being done with the course. The objective of these surveys was to obtain the students' opinions in a different method of teaching and whether or not they found this new method satisfying. The three groups divided for the experiment were given the same questions in the teaching methods. The results were formulated to included graduate students only.

Pre-Course Analysis:

The pre-course survey focused in the students' background in the topic of the course and its possible content. The questionnaire was taken by 22 students who attended class on that day; the results are shown in the histogram below in Figure 10. The histogram has the question number in the x-axis and the percentage of responses in the y-axis. The questions' answers are very specific when it comes to the students' point of view of the instruction method.

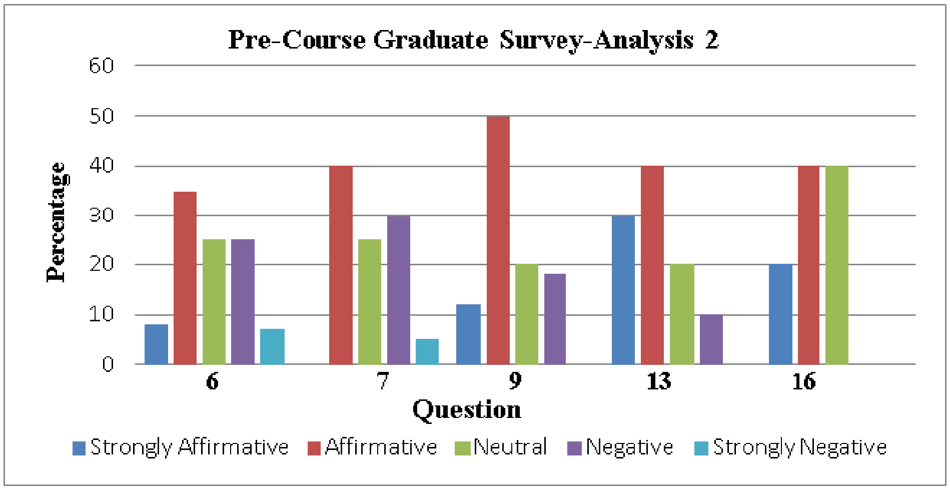

Figure 10: Pre-course survey for graduate students

Post-Course Analysis

For the post-course survey the same process was followed. The results were taken for graduate students only, but this time the questions were focused in the students' thoughts of the Rapid Manufacturing Systems course. The final results were shown in the same way the pre-course results were given, histograms represented the percentage of responses in the y-axis and the x-axis had the question number.

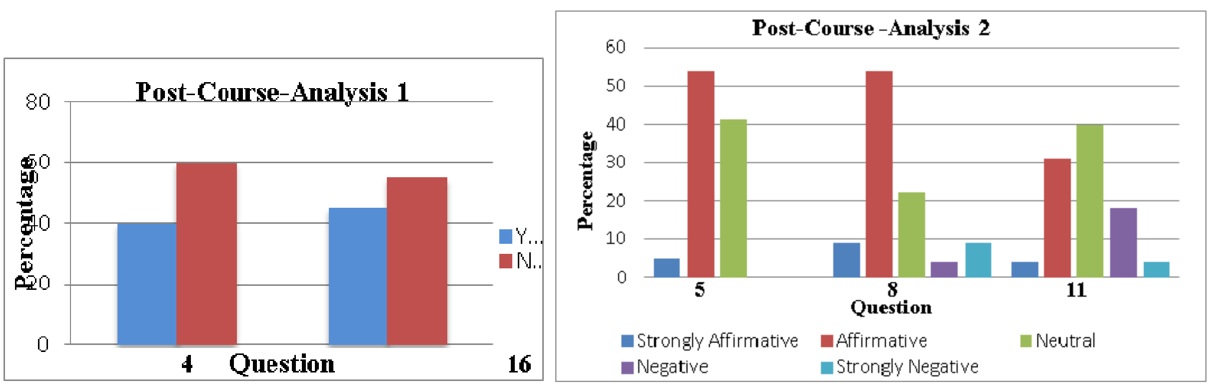

Figure 11: Post-course survey for graduate students

Lessons Learned and Conclusions

The approval or disapproval of the new teaching method has been evaluated through the surveys given to the students. As seen in the **Pre-course questionnaire**, most of the students are willing to learn the latest developments and techniques of RP technologies, but just as they are willing to learn they are lacking experience in handling most types of manufacturing machines including the RP machine. Most students do not have any experience in using remote techniques to handle a machine, but from their results they seem willing to learn. The survey demonstrates that students are willing to try new teaching methods, such as having more online involvement instead of a FTF course; they want the instructor around to answer possible questions but they do not rely completely in the instructors' presence. Some students have experience with regular online courses and are willing to add to that experience with having a hands-on laboratory experience through the online RP simulator.

In the **Post-course survey** results it can be seen that the students agreed with the usefulness of having the lecture materials available online at any moment. If a student missed class they could easily obtain the material given in that lecture, and the FDM 3000 machine manuals and terms of operation could be easily obtained at any moment. One of the most important changes in the **Post-course survey** was that the students believed that the FTF teaching method was much better than only online testing approach. The students' belief that FTF teaching could be influenced by the fact that this teaching method is new and most of them are more accustomed to the classical teaching method, and have a hard time accommodating. **Since the use of the proposed methodology is not as good as the traditional FTF approach, future investigation could be focused on (1) identifying the root causes related to low test performance in the experimental groups, (2) modifying/enhancing features and modules of the RP simulator based on analysis of such root causes, (3) acquiring multi-dimension evaluation mechanism to re-validate the proposed approach and (4) launching the hybrid approach through integrating the FTF approach and the proposed approach.**

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Appendix

- Other examples performed in the on-line testing system

Turn ON/Off

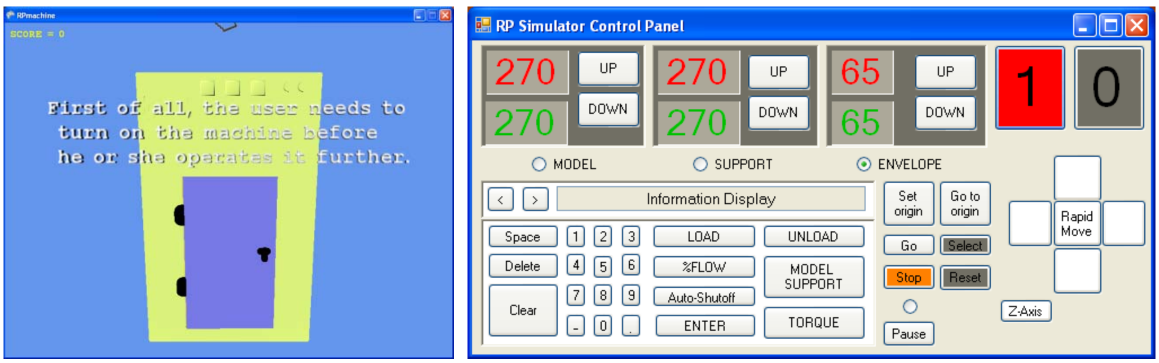

Figure A1: (a) Turn on/off and (b) Push the “1” button to turn on the machine

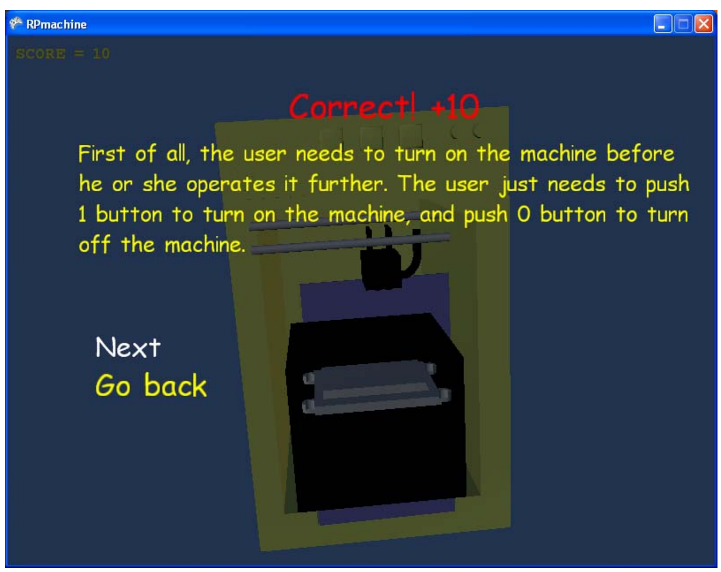

Figure A2: Students will earn points when performing the right operation

MFG/ME 5390: Rapid Manufacturing Systems
Fall 2012
Sample Questions for FDM 3000 Training

Name:

Group:

1. What is the right procedure to load the model material?
   A. Press the "MODEL/SUPPORT" button, the display will read "MODEL % 100". Then press the "LOAD" button and allow it to continue for about twenty seconds.
   B. Press the "MODEL/SUPPORT" button, the display will read "Support % 100". Then press the "LOAD" button and allow it to continue for about twenty seconds.
   C. Press the "LOAD" button. Then Press the "MODEL/SUPPORT" button, the display will read "MODEL % 100" and allow it to continue for about twenty seconds.
   D. Press the "LOAD" button. Then Press the "MODEL/SUPPORT" button, the display will read "SUPPORT % 100" and allow it to continue for about twenty seconds.

2. What is the FDM 3000 support tip temperature for Water Works (with ABS as the model material)?
   A. 210◦C
   B. 270◦C
   C. 235◦C
   D. 70◦C

3. What is the machine envelope temperature when using ABS (as model material) and WaterWorks (as support material)?
   A. 210◦C
   B. 270◦C
   C. 235◦C
   D. 70◦C

4. When loading material, what to do if you get a "LOAD TIME FAULT" message on the display?
   A. Press the "LOAD" button again.
   B. Press the "MODEL/SUPPORT" button again.
   C. Press the "ENTER" button.
   D. Press the "UNLOAD" button.

5. What is the support tip idle temperature for WaterWorks (with ABS as the model material)?
   A. 210◦C
   B. 270◦C
   C. 235◦C
   D. 70◦C

(Turn Over)

6. What is the difference between the support and modeler tip?
   A. Size and angle of tip
   B. Tips are made of different materials
   C. Tips use different thread sizes
   D. No difference

7. When loading material, what to do if if the support material does not flow within ten seconds?
   A. Press the "LOAD" button again.
   B. Press the "MODEL/SUPPORT" button again.
   C. Press the "ENTER" button.
   D. Press the "UNLOAD" button.

8. What is NOT one of the main components in the machine?
   A. Table
   B. FDM Head
   C. Z stage
   D. Control Box Display

9. What tip size is NOT available for the FDM 3000?
   A. 0.010"
   B. 0.012"
   C. 0.016"
   D. 0.020"

10. How to prevent the machine idling at high temperatures beyond a part completion?
    A. Press the "LOAD" button again.
    B. Press the "TORQUE" button again.
    C. Press the "ENTER" button.
    D. Press the "Auto-Shutoff" button.

11. What software in the FDM 3000 do you use to send the calibration file?
    A. Magics RP
    B. FDM Status
    C. Insight
    D. SolidWorks

12. What software in the FDM 3000 do you use to slice and prepare the file?
   A. Magics RP
   B. FDM Status
   C. Insight
   D. SolidWorks

13. How to turn off the flashing pause indicator when calibrating the FDM?
   A. Press the “Pause” button again.
   B. Press the “Stop” button.
   C. Press the “Reset” button.
   D. Press the “Select” button again.

14. When using the 0.016” tip what slice/build thickness is being used?
   A. 0.012”
   B. 0.010”
   C. 0.005”
   D. 0.001”

15. What is the egg time for the real FDM machine?
   A. 1 minute
   B. 60 minutes
   C. 20 minutes
   D. 120 minutes

16. When doing calibration, what does the user needs to do?
   A. Check the tightness of calibration box that has been built.
   B. Input the offset increment values for x, y and z dimension in the FDM status window.
   C. Send new offset increment values to the machine.
   D. All of above.

(Over)