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Fusing Rapid Manufacturing with 3D-Virtual Facility and Cyber Tutor System into Engineering Education

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Fusing Rapid Manufacturing with 3D-Virtual Facility and Cyber Tutor System into Engineering Education to Cultivate Technical Success

To date, 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. This paper discusses a new course preparation to support undergraduate and graduate Science, Technology, Engineering, and Mathematics (STEM) learning environments through Cyber Based Rapid Manufacturing (CBRM) and virtual manufacturing curricula – preparing students for the needs of industry and promoting advanced manufacturing technologies in higher education. As part of the effort, a set of CBRM related courses will be redesigned or newly developed covering the topics of quick response, additive and advanced manufacturing within the programs of Industrial, Manufacturing and Systems Engineering (IMSE) and Mechanical Engineering (ME) at the University of Texas at El Paso (UTEP). Specifically, this paper aims to support the development of the multidisciplinary educational activities.

Introduction and Background

Currently, colleges and universities in U.S. are challenged to contain and even reduce technology costs while at the same time respond to the expectations of the "New Millennial Generation" to upgrade educational systems that involve technologies which are neither simple nor inexpensive. One suggestion is to focus on new and innovative models for facilitating collaboration with other higher education institutions. The reason is evident. A majority of the more than 3,500 colleges and universities in the United States that have fewer than 2,000 students cannot afford to make costly, recurring investments. The benefits of on-line lab course offerings range from defined and anticipated to unexpected and extensive[1]. Moreover, 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 the 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. Therefore, the intensive, informative and **24 hour** access learning and training tools are demanded. This is a collaborative project between IMSE department and ME department to significantly enhance effectiveness in cyber based learning. This collaboration is to address the fundamental, yet challenging problem in manufacturing education: (*1*) *How to improve teaching and learning effectiveness in online course and facility oriented learning and training; (2) How to better educate students online facility oriented learning and training without interaction with instructors*[2-12].

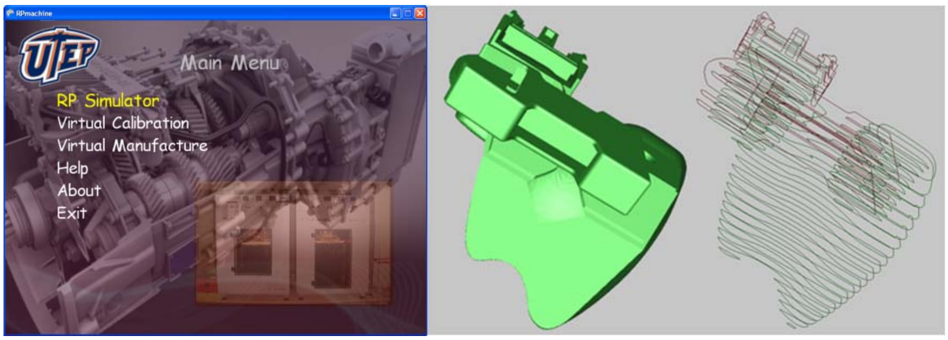
Rapid Manufacturing (RM) technologies are becoming popular due to their rapid development and improvement in capability. Several technologies collectively known as RM have been developed to shorten the design and production cycle, and have transformed many conventional manufacturing procedures. The distinction between RM and Agile Manufacturing (AM) is RM is more production process oriented while AM is focused on responding quickly to customer needs and market changes[13]. 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[14]. 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[15]. Layered manufacturing (LM) is actually better known as RP where the fabrication of part by depositing or bonding successive layers[16]. 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[17-21]. The opportunities for significant growth of RP technologies have increased recently since different industries are now beginning to use RP in direct production, and consequently the term direct digital manufacturing (DDM) emerged. DDM has a vast potential to become the next technological trend as it can develop novel products and processes in markets of strategic importance to the United States (i.e. medical, defense, and electronics). For example, component insertion into LM-produced parts as they are being built has resulted in miniaturized integrated electronic systems (see Figure 1)[22-24].

Figure 1. Miniaturized 3D electronics fabricated using LM technologies: evolution of a 3D magnetic flux sensor illustrating increased levels of 3D component placement and conductor routing, leading to improved integration and packing.

Applications of RM can be found in different sectors. For instance, researchers at the University of Texas at Austin have reproduced human bone shapes using SLS to form titanium castings during the late 2000[25]. Casting dies for automobile deck parts were fabricated by LOM[26]. IBM used SL to produce operating display units of its ThinkPad tablet computer. A turbine part with a complex shape was built by 3D printing using a Pro Metal RTS-300 machine[27]. In general, RM allows three dimensional geometry parts to be fabricated by which the designers can shape parts optimally without any constraints imposed due to forming, machining, or joining. Moreover, it utilizes the computer description of the part shape directly, and allows integration of the Computer Aided Design (CAD) with the Computer Aided Manufacture (CAM) of the part [28-30]. Consequently, the manufacturing cycle with seamless transition through design, simulation, modeling and fabrication is performed. In this project, we perceive "**Rapid Manufacturing**" as integration of RP and AM to be covered broader spectrum in manufacturing profession.

Virtual Facility and Tutor System

Based on the development of 3D Virtual Facility, the authors have conducted an experiment to explore if the use of operating the RP simulator is performing as good as the use of implementing the real FDM 3000 machine. The experiment reveals that students who have used the RP simulator perform not as good as students who have an instructor in the laboratory, particularly in the comprehensive exam and the calibration operation[31]. Consequently, the authors would like to conduct further investigation to learn about (1) **If integration of VF and Tutor System (TS) can achieve similar performance as a real instructor in the classroom**; and (2) **What components should be incorporated in the TS to enhance learning effectiveness.**



(a) The main menu of the RP simulator; (b) The virtual manufacturing process

Figure 2. The Rapid Prototyping (RP) simulator developed by University of Taxes at El Paso

Virtual Facility Embedded with the Tutor System

In this section, the proposed Cyber Based Tutor Systems (TS) which is embedded in each Virtual Facility (VF) is introduced. The purpose of developing cyber based tutor systems is to facilitate users in a condition of lack of instruction on site (or using VF for learning and training) and acquiring knowledge to learning and operate the facility. In this project, we will use a Rapid Prototyping facility called FDM 3000 as an example. Basically, the Tutor System can be used for both real facility and VF learning and training. In the proposed Cyber-Based Tutor Systems, there are five categories which includes nine options. Category #1- *Intro*: (1) Introduction and (2) Learning about FDM; Category #2 – *Operation*: (3) Operation demonstrations, (4) Viewing videos based on scenario, (5) Performing online operations; Category #3 – *Interaction:* (6) Interactive machine learning; 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 proposed TS are as follows: **Introduction to cyber-based tutor system**-Introduction provides a brief description about the software, practical uses and keypad buttons that are used while operating the virtual machine. **Learning FDM-**Instructions related to the operation of the RP machine 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 operation**: This option is used to interact directly with the RP and VF 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. **Interactive machine learning**-Interactive machine learning is a ***new concept*** related to virtual fabrication in which the virtual machine responds interactively with the user by providing the help at intermediate positions of the learning as well as help the user when something has gone wrong in operating of the machine. Therefore, the interactive machining is very useful feature to help students understand the procedure correctly. Moreover, students could benefit from this option to learn functionality and maintainability. **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 will be 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 FDM 3000. *In general, the proposed TS is based on the features of the VF. In other words, both VF and TS can be enhanced and augment according to students' needs.*

To survive in the most competitive manufacturing environment in 21st century, RM capacity and sustainable workforce become the key to be successful in the competition. However, sustainable workforce should come from intensive learning and labor/operation skills. Consequently, the learning and training efforts have a significant impact on labor skills. Companies and institutions could encounter significant damage or loss due to workers' faulty operations. Therefore, we propose to establish a Cyber Based Manufacturing (CBM) laboratory which includes **hardware facilities, virtual facilities** with embedded **tutor systems** and to develop or improve a set of courses at UTEP. Using various graphic developing software, we will build several virtual facilities. Sensors will be strategically deployed at manufacturing lines. The sensing signals will be transferred through Internet to a central control unit to be processed and diagnosed, and remote control will be realized by changing the control parameters of the actuators on manufacturing lines. This operation setting will allow us to experiment and verify the Cyber Based Rapid Manufacturing (CBRM) concept, as well as to educate our students learning the next-generation manufacturing system. To date, there is **no** comprehensive education model fully integrating available Internet technologies and virtual reality into the classroom with an emphasis on the improvement of students' skills in problem solving and information seeking[32]. Therefore, the authors propose to use a hybrid instructional approach and on line web courses between IMSE and ME Departments at UTEP to explore the use of Internet for active learning and problem solving skills enhancement in engineering curriculum.

In the paper, virtual teams will be formulated through IMSE and ME Departments and the authors will develop and revise several courses to collaborate on the proposed courses. The W.M. Keck Center will be used to facilitate the proposed work. The authors will coordinate virtual teams to implement and test the proposed activities. Note that the Microsoft® Window 7 operating system will be used as the software platform. The connection with the internet-based communication and control software link to manage geographically dispersed manufacturing operations is based on Ethernet interface and TCP/IP networking. Several courses that can utilize the proposed lab as a test-bed for educating CBRM concepts, even at the stage of lab set-up is prepared. The curricula that will be significantly impacted by this proposal are, but not limited to, Digital Manufacturing Systems Simulation, Design for Manufacturability, Rapid Manufacturing Systems, which will be described in detail in Section "Courses."

Proposed Activities and Solutions

This main objective of this paper is to explore "**how to improve pedagogical effectiveness of online education for the rapid manufacturing related courses which include the use of virtual facility embedded with tutor system?**" These discoveries will open new avenues in how to radically improve engineering curriculum with information technology. Sharing lab resources with clearly defined educational methodologies and assessment formats will become feasible if the project is successfully completed. In this project, **the goals** of the proposed educational plan are as follows: (1) Cultivate and train undergraduate students participating in the proposed education/research activities; (2) Incorporate applied research themes in rapid manufacturing and technology goals into lecture and laboratory classes to engage students as active participants in web based courses; (3) Implement the most up-to-date technologies in virtual reality, 3D image and rapid manufacturing production systems to better educate engineering students; (4) Recruit high school students, especially minority and women, through web-accessible courses and laboratories, to increase their awareness and participation in science and engineering by stimulating their interest from early stages; (5) Secure our graduates with quality professional skills in manufacturing field. Based on the aforementioned goals, **the specific activities** to be executed in the two-year period are: (1) To establish a CBRM lab reflecting new technology trends in rapid manufacturing and with development of virtual facility embedded with tutor systems; (2) To develop several course modules addressing and incorporating cyber based automation, production and rapid manufacturing technologies in order to restructure the existing courses and develop a new course in the Department of IMSE and the Department of ME (see Figure 3); and (3) To implement a hybrid instructional approach (i.e., integration of synchronized and asynchronized lectures) and virtual facility with tutor systems to improve learning effectiveness.

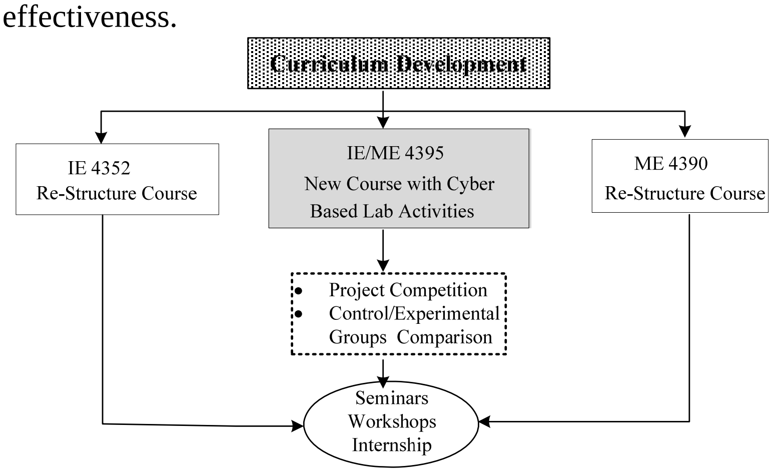


Figure 3. A framework of the proposed activities

Cyber Based Rapid Manufacturing (CBRM) through information and communication technologies are key elements to deploy real-time control of production processes in a global manufacturing enterprise. The role of communication vehicles such as Internet/Intranet in the creation of supply chain management has been recognized[33-34]. We intend to offer an IE degree with a manufacturing emphasis that will combine a rigorous and advanced curriculum with modern topics in CBRM. The implementation of Cyber Based Technologies in our IE and ME collaborative program will involve three major steps resulting in seven (7) courses modules associated with automation, production and layer manufacturing technologies. All three courses will be delivered through implementing the hybrid instructional approach and the use virtual facility with embedded tutor systems to improve learning effectiveness. The **first** step requires restructuring the current courses IE 4352 Digital System Simulation. The **second** step will involve the development of one new Internet based manufacturing technology course: IE/ME 4395 Design for Manufacturability. The **third** step will involve developing one restructured course ME 4390 Rapid Manufacturing Systems. These courses, of interdisciplinary nature and their associated hands-on laboratory experience will become capstone courses, which will include CBRM practice, operating on hardware, virtual facility embedded tutor systems and term projects. Moreover, the proposed activities also include project competition in IE/ME 4395. *Two students who perform excellent in the semester project from each department will be given participant awards.* The authors also plan to collect information related to the hypothesis – if (1) the use of VF and Tutor System and (2) the use of API (i.e. a remote access tool) is equally effective to an instructor demonstrate/operate the facility in the lab. The written test, hands-on test and pre/post survey will be provided to accept/reject this hypothesis.

Generation of Course Modules and Courses

Two restructured courses and one new course constituted by seven different course modules are introduced in this project. In general, a restructured course contains less course modules, hardware, software and virtual facility than a new developed course. The conceptual framework of module-based course development through the hybrid instructional approach is illustrated in Figure 4. **First,** it is started from contemporary issues related to cyber based rapid manufacturing suggested by the Department of Industrial, Manufacturing and Systems Engineering (IMSE) and the Research Institute for Manufacturing & Engineering Systems (RIMES) advisory board committee. **Second**, the authors and a support group from staff members of Texas Manufacturing Assistance Center (TMAC) have determined what course contents (e.g., course modules) should be included in each course. **Third**, the authors have discussed with faculty from IMSE/ME Departments who are interested in joining this curriculum reform to identify a course module pool. However, the course contents could be revised based on suggestions from an annual advisory board meeting. **Fourth**, the instructors will determine the percentage of synchronized classroom lectures and asynchronized web-based lectures. **Fifth,** Comparison of the control group and the experimental group will be conducted to validate effectiveness of the new/innovative learning materials like VF and TS. **Sixth**, semester seminars and summer workshops are scheduled to be held for project dissemination purposes.

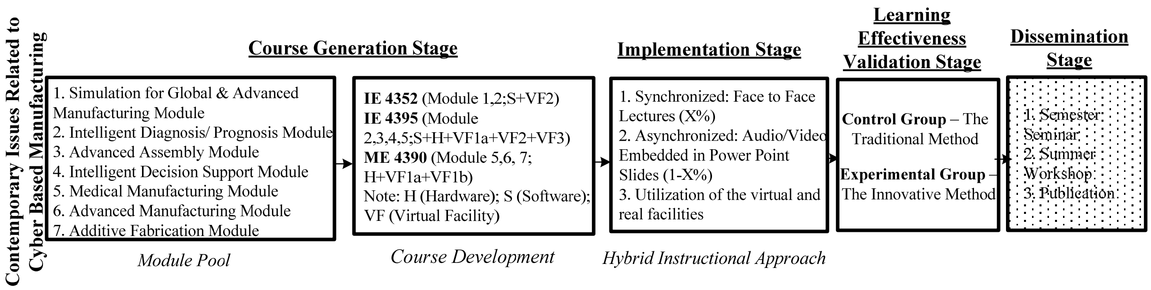


Figure 4. The conceptual framework of module-based course development through hybrid instruction and learning effectiveness validation

Course Modules

1. Simulation for Global & Advanced Manufacturing Module
   - Identify simulation and engineering tool integration requirements from hands-on experience with software tools, interactions with users and vendors, and industry road-mapping activities.
   - Capture relevant definitions, theory, algorithms, and data models as part of the science of manufacturing system integration.
2. Intelligent Diagnosis & Prognosis Module
   - Develop technologies to streamline and automate fault diagnosis and prognosis in intelligent maintenance systems.
   - Determine the safe life of equipment and drive the intelligent maintenance system by concentrating in data processing and data fusion/mining, intelligent diagnosis, and residual/service life prediction.
3. Advanced Assembly Module
   - Introduction to Microfabrication technologies and processes.
   - Brief introduction to assembly at the macro-scale.
   - Robotic assembly at the micro- and nano-scales.
4. Intelligent Decision Support Module
   - Improve decision making ability of managers by allowing more or better decisions within constraints of cognitive, time and economic limits.
   - Facilitate one or more of the decision-making phases (intelligence, design, and choice).
   - Facilitate problem solving flows.
5. Medical Manufacturing Module
   - Dynamic scanning technology can help manufacturing engineers solve certain high-volume metrology problems.
   - Measuring Systems.
   - Basic research into the micro cutting process and practical products.
6. Advanced Manufacturing Module
   - Identify appropriate applications for additive manufacturing.
   - Prepare a 3D solid model in software and fabricate a part using an additive manufacturing technology.
   - Discuss the wide variety of new and emerging applications like micro-scale additive manufacturing, medical applications, direct printing of electronics and Direct Digital Manufacturing (DDM) of end-use components.

7. Additive Fabrication Module

- Explain the capabilities, limitations, and basic principles of alternative Additive Manufacturing (AM) technologies.
- Evaluate and select appropriate AM technologies for specific applications.
- Identify, explain, and prioritize some of the important research challenges in AM.

Courses

IE 4352 - Digital Manufacturing Systems Simulation (restructured course, required core course)

This course is an introduction to manufacturing systems simulation with special emphasis on logic and methodologies of discrete event simulation, generation of random numbers a random deviates, survey of simulation languages. At the end of the course the student should be able to develop simulation models of industrial systems and to understand the issues involved in simulation studies. Learning outcomes should include students being able to identify and solve rapid manufacturing related issues through digital simulation approaches. The class contains 50% synchronized classroom lectures and 50% asynchronized web-based lectures. (Note: Virtual facility -2 is used in this course). **Prerequisite:** Senior standing or instructor approval.

IE/ME 4395 Design for Manufacturability (new course, elective course)

This course focuses on manufacturing and incorporates many of the processes developed by the integrated manufacturing industry, as well as novel techniques developed by scientists from all technical research areas including engineering, and mathematics. Principles of design for manufacturability and micro machining, assembly, measurement and medical manufacturing are covered in this class. Learning outcomes should reflect (1) students being able to apply knowledge of mathematics and engineering to identify and solve manufacturing problems and (2) knowledge of manufacturing systems and design for manufacturability. The class contains 80% synchronized classroom lectures and 20% asynchronized web-based lectures in a 16-week semester because more hand-on activities are anticipated in this class (Note: Virtual facility-1a and Virtual facility -2 are used in this course). **Prerequisite:** Senior standing or instructor approval.

ME 4390 Rapid Manufacturing Systems (restructured course, elective course)

The course, Rapid Manufacturing Systems, deals with various aspects of additive, subtractive, and joining processes to form three-dimensional parts with applications ranging from prototyping to production. Additive manufacturing (AM) technologies fabricate three-dimensional (3D) parts using layer-based manufacturing processes directly from computer-aided-design (CAD) models. Direct digital manufacturing (DDM) or rapid manufacturing (RM) is the use of AM technologies in direct manufacturing of end-use parts. In this course, you will learn about a variety of AM and other manufacturing technologies, their advantages and disadvantages for producing both prototypes and functional production quality parts, and some of the important research challenges associated with using these technologies. Learning outcomes should include that students being familiarized with applications in rapid prototyping manufacturing to production and solve issues related to it. The class contains 65% synchronized classroom lectures and 35% asynchronized web-based lectures in a 16-week semester (Note: Virtual facility 1b is used in this course). **Prerequisite:** Junior standing or instructor approval.

Future Work

In this paper, the future work could focus on replacement of FDM 3000 facility (i.e., uPrinter, see Figure 5) and expansion of the use of advanced mobile devices like Microsoft "Surface" or smart phones (see Figure 6). Consequently, students could access and learn course materials from different sources.

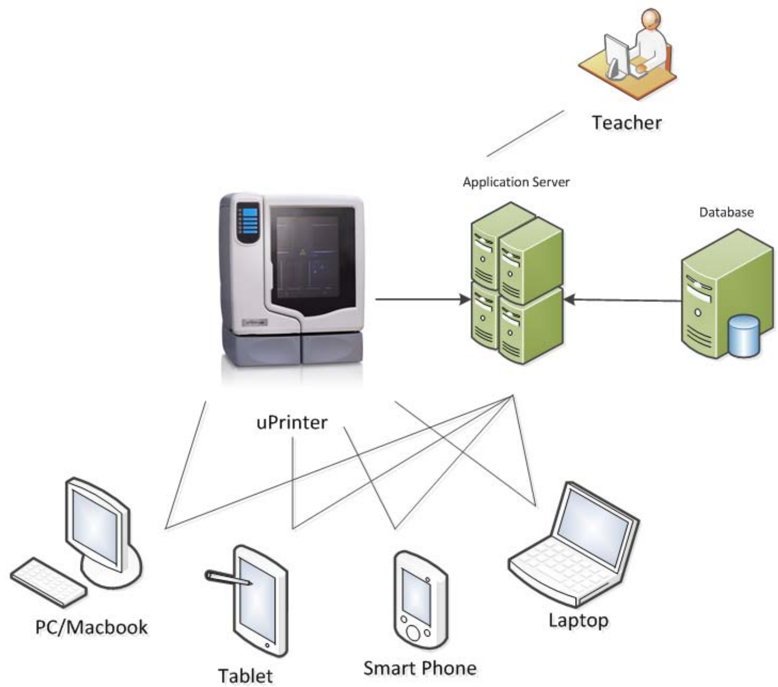


Figure 5. The conceptual framework of the advanced virtual RP facility with mobile devices

Figure 6. Access of the advanced virtual RP facility through tablet (i.e., MS Surface) and smart phone (Samsung)

Conclusions

This paper presents a framework for integration of rapid manufacturing with 3D-virtual facility and cyber tutor system to develop additive manufacturing relevant curriculum. The proposed activities for such curriculum development and how to cultivate technical success for engineering students through seminars, workshops and internship have been described. Moreover, generation of course modules and courses are also depicted in detail. This paper forms a good model to develop advanced manufacturing instruction materials.

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