1. Introduction

This paper discusses curriculum innovation in an emerging area of engineering, which can be described as ‘Information Based Manufacturing Engineering’ (INBM). The key curriculum and research activities outlined in this paper are part of continuing efforts in the department of industrial engineering at New Mexico State University (NMSU) to develop a comprehensive undergraduate and graduate curriculum in INBM.

In today’s evolving global manufacturing environment, there is a need to educate engineering students in emerging Information Technology (IT) concepts and technologies, which are revolutionizing product development practices. The emergence of the Internet as a powerful communication vehicle has catalyzed the adoption of virtual engineering methods, which in turn have enabled organizations to become more agile. In this context, engineering students need to be knowledgeable in topics such as information modeling, distributed manufacturing and Internet based engineering. At New Mexico State University, several course modules dealing with these subjects have been introduced at the undergraduate senior and graduate levels (for mechanical, manufacturing and industrial engineering students).

The term ‘Information Based Manufacturing’ (or INBM) broadly refers to the Information Technology based principles, modeling approaches and computing frameworks, which are enabling the creation and deployment of global virtual manufacturing enterprises. INBM recognizes the substantial impact that information (and its seamless exchange) has on the accomplishment of manufacturing activities (especially in a Virtual Enterprise oriented context). Today, the role of information in a manufacturing enterprise has changed dramatically: information is recognized as a powerful entity, which drives the accomplishment of manufacturing activities and integrates various life-cycle activities. This information-centric perspective of manufacturing has its origins in the Integrated Computer Aided Manufacturing (ICAM) program of the US Air Force, D. Ross’s Structured Analysis and Design Technique.

Proceedings of the 2004 American Society for Engineering Education
Annual Conference & Exposition
Copyright © 2004, American Society for Engineering
(SADT) related work, and R. Mayer’s pioneering work at Texas A&M on the role of information modeling in the design of manufacturing systems, among others. With the phenomenal explosion of e-businesses and the continuing adoption of the Virtual Enterprise (VE) model in manufacturing, there is a substantial interest in American industry in the availability of engineering students who possess skills in this new work environment [3]. In a VE, the partner organizations are physically distributed, possess a diverse set of core skills (design, manufacturing, planning, testing, etc.) and heterogeneous computing resources, and communicate electronically to rapidly develop products and/or respond to customer requirements (see figure 1, Internet Encyclopedia paper). This VE model is being widely heralded as the collaborative model of the future as it holds distinct advantages and benefits for organizations worldwide [5, 6].

![Figure 1: A Virtual Enterprise](image)

In this decade and beyond, it is predicted that growing product complexity and resultant diverse skill requirements underscore the need for organizations to work together as a VE. More importantly, such a collaborative approach will enable the harnessing of remote and far-flung engineering/manufacturing facilities (and resources) and create new opportunities for these remotely located organizations who can become partners and pillars of the American and international industrial base. Small and medium sized operations with specialized capabilities can link with the industrial mega-giants or with other similar sized enterprises to produce a diverse mix of products that are beginning to typify the evolving global market. For this reason and several others, American and other international industrial organizations have shown keen interest in Virtual Enterprise related principles and practices [2]. The role of communication vehicles such as the Internet (and other E-Commerce technologies) in the creation of VEs has also been recognized by initiatives such as the National Industrial Information Infrastructure
Protocols project [NIIIP 02]. These technologies have served as catalysts for the continuing evolution seen across the international business landscape.

In this context, there is a need for our educational institutions to develop innovative curriculum, which will enable our students to ‘hit the ground running’ when they begin working in their respective organizations upon graduation. Our manufacturing industry needs a new type of engineer, who must not only possess a strong background in manufacturing (and systems) but also be skilled at designing and building processes and systems in the context of virtual manufacturing enterprises [2]. Undergraduate manufacturing education must be re-vitalized with students exposed to real-world oriented information technology environments, and educated in emerging concepts and methods which are beginning to revolutionize enterprises such as Chrysler, NASA and Boeing [Cecil 01, Goldin 99]. Based on a preliminary study conducted as part of a curriculum planning effort [Cecil 02b], a preliminary summary of the knowledge required and set of skills desired in the next generation of manufacturing engineer have been identified. University professors as well as engineers from industry and government laboratories including Knowledge Based Systems, Inc., MicroSat Systems, National Institute of Standards and Technology (NIST) and the Air Force Research Laboratory (AFRL) participated in this planning effort. The skills identified for the next generation of manufacturing engineers include the following:

1. Ability to understand as well as design manufacturing processes and systems
2. Ability to develop information oriented models of processes, manufacturing systems and computer based systems (which are used to automate or help accomplish the manufacturing / engineering activities)
3. Ability to work as part of distributed cross-functional teams, which rely on network based communication. This includes knowledge of distributed collaborative / concurrent engineering approaches, enterprise modeling methods for communication and planning among distributed teams and technologies to support VE based product development (such as virtual reality)
4. Ability to design, develop and implement solutions (which use techniques such as Virtual Reality based product / process prototyping, the Internet / EDI based information exchange, etc.) that reduce product development / engineering costs, improves enterprise agility, and increases customer satisfaction. This also includes knowledge of computer programming (in languages such as C++ and Java) and robust distributed computing architectures (such as CORBA and DCOM) and mobile agent based technologies.
5. Have a broad understanding of the functioning of Virtual Enterprises and the role of information technology in the creation of VEs

The activities proposed in this document are in the context of these above-mentioned skill and knowledge requirements. These requirements were developed through discussions with industry partners, review of information from media sources (including business and manufacturing journals and articles, Internet, etc), and academic researchers.
In section 2, the use of virtual reality based environments to teach manufacturing engineering concepts is discussed. Students use VR based environments to learn new concepts and are also exposed to the creation of VR based environments for engineering applications. In section 3, the design of inter-university projects as part of senior/graduate level courses in information based manufacturing is discussed. Section 4 discusses educational activities related to the study of computer architectures based on the Internet. In section 5, outreach activities related to INBM are described. Section 6 concludes this paper.

2. Curriculum Initiatives related to virtual engineering

The first major focus area of the curriculum innovation deals implemented deals with an area termed as Virtual Prototyping. In a product development context, virtual prototyping can be used for both product and process design applications. Today, most leading manufacturing and engineering enterprises have adopted virtual prototyping approaches to help design and build better products at a lower cost. Graduating engineers need to have a fundamental understanding of the principles, approaches and software technologies of this cutting edge area. In a course on virtual manufacturing at NMSU, new course modules have been developed along with a substantial laboratory component, which introduces senior and graduate level students to virtual prototyping concepts and practices. In addition, students are introduced to advanced manufacturing and assembly engineering approaches using Virtual Reality based simulation environments. The manufacturing domains include metal cutting operations, and assembly of satellites and micro devices.

Virtual prototyping techniques (in general) involve the use of virtual prototypes and models to propose, evaluate, refine and compare potential solutions and identify problems. Virtual Prototyping can be described as a modeling philosophy, which seeks to simulate the functional realism of a target system using Virtual Prototypes [3]. A Virtual Prototype (VP) can be described as a physics based Virtual Reality (VR) based software model, which ‘mimics’ or simulates the intended physical system’s (or target) behavior, response, appearance and geometry with a degree of realism comparable to the actual physical system [3]. Research findings have reiterated the fact that Virtual Prototyping also facilitates Concurrent Engineering (CE) by supporting communication of ideas, and earlier identification of problems and solutions among cross-functional team members in an organization [1, 3, 7]. A Virtual Reality (VR) can be described as a computer-based environment for displaying 3D immersive images, providing real time user tracking system, facilitating human-computer interaction, and providing means for representing users in the environment. A virtual environment supports immersive applications such as walk-through (fly-through of proposed layouts, etc), visualization of projected results (assembly / disassembly, collision detection, motion planning, etc), object manipulation (load/unload, pick n place, etc), and some forms of feedback mechanism (haptic interface, audio cues, visual signals, etc.).

A brief note on the difference between virtual prototyping and CAD/CAM tools is necessary as these terms have been often been used incorrectly in literature [3]. In this

Proceedings of the 2004 American Society for Engineering Education
Annual Conference & Exposition
Copyright © 2004, American Society for Engineering
paper, the term ‘virtual prototyping’ is used in a formal context. ‘Virtual Prototyping’ does not merely refer to the use of computer models or software tools for engineering applications. A Virtual Prototyping tool has a major distinguishing characteristic: it uses Virtual Reality technology and allows ‘immersive’ or ‘semi immersive’ interaction. While there are numerous CAD/CAM software tools widely used in industry today for manufacturing process simulation, only a few of them can be described as belonging to the category of ‘Virtual Reality based prototyping’ (or Virtual Prototyping). For example, tools such as Master CAM® and CAM Works® can allow users to ‘visualize’ tool-cutting paths (in G-code and other formats). However, they do not allow an user to wear Virtual Reality sensors, motion trackers and stereovision eyewear to immerse themselves. A Virtual Reality based prototyping environment will allow users to ‘immerse’ themselves (they can essentially ‘enter’ an environment), walk around virtually, pick up a tool, turn a machine ‘on’, unclamp a fixture and perform other tasks. Software tools such as Virtual NC®, (whose use is described in the following sections) Envision®, Vislab ® fall under this category. With the help of adequate haptic interfaces, they can even provide force feedback to the user depending on the type of physical activity involved.

The virtual engineering course modules have three areas of emphasis: (1) Virtual Prototyping of metal cutting operations using commercial tools such as Virtual NC (2) Virtual Prototyping of Assembly and other operations related to space systems and satellite product development. Discussions of these 2 areas follow.

2.1 Virtual Prototyping of Metal cutting operations

As part of the new course modules, Virtual Reality based environments of metal cutting machines (such as Computer Numerical Control CNC milling and drilling machines) were created using a commercial tool called Virtual NC® (from Delmia Corporation). Through specially designed laboratory modules, undergraduate students were introduced to concepts such as CNC machines and flexible manufacturing. Students were grouped into teams and completed self-learning oriented tutorials. Using the virtual fly-through capabilities, they were able to ‘immerse’ themselves in the virtual environment and perform ‘what if’ analysis aimed at improving their understanding of target processes and CNC machines. Figure 2 provides an illustration of one such VR environment, which was used to facilitate learning of manufacturing engineering concepts. While some of the virtual reality models used were provided by the software manufacturer (Delmia), other models were created for student use. The advantages of using such VP tools for manufacturing process design, re-design of work cells and process planning was highlighted to the students using various part design and manufacturing examples. With the help of software tutorials, students built simple and complex virtual reality environments of machining environments.
The creation of a virtual prototype (or model in Virtual Reality) is a complex process. An information model of the virtual prototyping process was built and then used as a basis to enable student understanding of the various phases involved in building a virtual prototype for manufacturing applications. Subsequently, using this information model, the various phases involved in creating a virtual prototype was discussed and analyzed. Finally, using Virtual NC, two member student teams built virtual prototypes of milling machines and then virtually manufactured prismatic parts. As part of class projects, students’ first created CAD models of the various parts of a machine, then assembled them in the virtual environment, and then detailed the machine’s characteristics (including the degrees of freedom of the various components, their capabilities, etc). Subsequently, they developed the respective ‘G Codes’, which were used to virtually manufacture target parts. The virtual reality based environment allowed the students to understand the functionality of the G code and allowed them to modify the code if the target part was not manufactured in the desired manner or shape. Such a laboratory based learning process was useful in highlighting to the engineering students the power of virtual prototyping. Using a virtual prototype helps a process engineer compare machining alternatives as well as help identify problems before actual material is cut or before a costly investment is made. It also allowed teams of engineering students to understand each other’s perspectives better. In industry, such an approach facilitates the adoption of a ‘concurrent engineering’ approach where designers, manufacturing specialists and process specialists can work more effectively as a team through better communication.

2.2 Virtual Prototyping of Assembly Activities for Nanosatellites and Space Systems

The second area of emphasis in the new modules relates to the development of space systems and satellites. As part of a combined research and curriculum development...
(CRCD) initiative, a virtual satellite assembly environment was created to help study the assembly of nanosatellites. This environment was used to create a learning test bed for engineering students and is currently being used to teach them concepts related to satellite assembly and development. Nanosatellites are small satellites, which typically weigh less than 10 kilograms and are less than 20 inches in height. They have a complex product development cycle, which necessitates cross-functional design and interaction among product and process designers including manufacturing planners, testing, and launch engineers. Figure 3 provides an illustration of a nanosatellite. Using the virtual reality (VR) based environment, industrial and manufacturing engineering students were introduced to issues in satellite assembly as well as the role of virtual prototyping environments. The VR environment allows students to immerse themselves and learn concepts and principles underlying satellite assembly. They compare satellite design alternatives and then identify process design problems using the virtual environment. With the help of motion trackers, sensors and devices referred to as ‘Wands’, students were able to pick up satellite parts and manually attempt to assemble them. They could also use an automatic mode to input specific satellite assembly sequences and compare alternatives. A view of this virtual assembly environment (which has been implemented on a Unix environment on a Silicon Graphics workstation) is shown in figure 4.

![Figure 3: Typical components in a nanosatellite](image-url)
3. Learning through Participation in Inter University Distributed Manufacturing Projects

In [12], several distinct phases were identified to enable the successful creation and implementation of VEs. These phases include (a) the development of an understanding of a given VE’s product(s) and customers, (b) identification of the potential VE partners and formation of the product development team, (c) development of an Information Oriented Enterprise Model (IOEM) of the VE’s collaborative activities and tasks, (d) design and Implementation of an Internet-based distributed software system, (e) identification of metrics to evaluate functioning of VE, initiation of a pilot initiative, and (f) identification and adoption of necessary changes.

Various reports including [INT EN 03, NIIIP] have highlighted the importance of educating students in topics related to virtual enterprises. As part of a new course titled ‘Distributed Manufacturing’, engineering students form virtual enterprises and plan, design and manufacture identified part designs using the Internet as the vehicle of communication. Inter university student teams form design, planning and manufacturing teams for this innovative learning experience. They create IOEMs, which is then used as the formal basis for collaboration and product development activities. Lectures and laboratory modules were used to introduce students to information modeling methods and distributed manufacturing concepts.

Figure 3: A view of the virtual environment created to support the study of nanosatellites
Figure 5 provides a synoptic view of the major activities in this project. Students from Monterrey Tech, New Mexico State University and Penn State University formed teams and (using the Internet as a communication vehicle) designed, planned and manufactured various part designs. Information models of the various collaborative activities were initially created as a basis for understanding available resources as well as to help formulate a cohesive plan for the distributed activities.

The goals of the project were first described along with the learning outcomes, the project deliverables and grading policies. It was made clear that the participants would not exchange email messages (other than through the specially designed project page) or telephone their ‘virtual’ partners.

The students were initially taught the information modeling methods and related software tools through lecture and laboratory sessions. Two modeling languages were used by two different groups of students: one was the called Enterprise Modeling Language (EML) [4, 10] and the other is a widely used functional modeling language called IDEF-0 [8, 9]. While IDEF-0 is an industry leading methodology, EML is a newly emerging language (proposed in 2001 [10] ) which was created to support the creation of virtual enterprises as well as to support software design and other collaborative planning / analysis activities. EML is capable of explicitly capturing temporal precedencies as well as functional relationships among activities and tasks for a given scope or modeling context.
The project findings highlighted the power of EML over the IDEF-0 methodology. Such information models (or information oriented enterprise models) can provide formal foundations for communication, planning and analysis in a real world industrial setting as well. The usefulness of these models were demonstrated through the specially designed inter university project involving manufacturing and industrial engineering students at New Mexico State University and Monterrey Tech (ITESM, Mexico). Lecture sessions highlighted the rules and process for creating the EML models. Prior to the start of the inter university project, students were exposed to several sample EML models ranging from a simple process (e.g. Process of making coffee using a coffee machine as a resource) to more complex examples involving manufacturing process planning and distributed manufacturing. They were given the option of either using a tool such as Microsoft Visio® or Powerpoint® to create the information based models to turn in example EML models. Figures 6 and 7 provide a top-level diagram of an EML model and its decomposition respectively. A segment of the modeled attributes have been omitted from figure 3 for brevity. Additional information on the creation of EML models can be found in [10].

The collaborative project web page provided more information on the project as well as provided a forum for the students to ask questions, exchange Computer Aided Design (CAD) models, process plans, a code called G-code (which is required by computer numerical control machines to perform various machining operations) as well as keep track of the project progress.

Based on the information models, the physically distributed student teams then began to implement the various engineering activities: product design, process planning, G-code generation and finally manufacturing the part. The part designs went through several iterations before a mutually agreed-upon design was completed. The teaching assistants and course instructors monitored the progress of the project and provided suggestions when problems arose. Using the project web page, the relevant intermediate part designs were posted and feedback was solicited from the various team members. The students evaluated the designs from manufacturing feasibility perspectives as well as availability of resources at each university laboratory. The manufacturing task was divided based on available machines and tools. For example, in one scenario, a portion of the door knob was machined by NMSU students. This was mailed subsequently to students at Penn State University, who then completed the machining of the door knob.

The major metrics for evaluating students performance was based on the quality of the information model developed, the time taken to complete their assigned tasks and overall project and complexity of the overall part manufactured. Feedback was also obtained on the effectiveness of the teaming strategies and problems encountered among student team members. It was noted that when the information models were not well developed or were developed without the involvement of all the distributed team members, the project implementation encountered problems. In these cases, the students did not have a clear picture of what their tasks were or what constraints they would be facing. The usefulness of the information models was reiterated through these inter-university projects.
Such project oriented learning experiences promote understanding of virtual enterprise related concepts. While American manufacturing organizations have started to adopt VE based product development approaches, there has been a lack of progress towards a structured process for such collaborations. Through this IOEM based approach, students were not only exposed to new models of collaboration but also able to experience the difficulties associated with virtual teaming and distributed collaboration. While the Internet is a powerful vehicle and promotes virtual partnerships, there has to be adequate planning and clarity in understanding the nature of the collaborative activities. Without the needed emphasis on the creation and use of a formal model such as an information model (discussed in this paper), completion of a collaborative project will become difficult and time consuming. When students become future engineers at companies such as Boeing, Ford or Intel (who have geographically distributed partners in various countries), such an approach can prove useful in implementing complex product development activities.

![E-0 level of EML diagram for “design, plan, and manufacture parts in a collaborative distributed environment”](image)

**Figure 6: An EML representation of the collaborative activities**
4. Study of Internet based architectures and frameworks

Another topic of emphasis in the information based manufacturing course taught to senior and graduate level students is the study of computer architectures which can support distributed manufacturing and facilitate the creation of virtual enterprises. The primary goal was to introduce manufacturing and industrial engineering students to computer architectures that could support seamless information exchange across heterogeneous computer platforms as well as educate them on the design and implementation of distributed manufacturing systems.

Initiatives such as NIIIP have stressed the importance of open architectures such as CORBA and the role of information models [11]. Organizations such as NASA and Lockheed Martin have adopted the use of CORBA based architectures to link distributed software tools and product development modules [2, 6]. Two Internet based test beds were created to facilitate learning of distributed computing architectures in a manufacturing context. These test beds accomplished manufacturing process planning using geographically distributed software resources. One of the test beds was implemented based on the Common Object Request Broker Architecture (CORBA) while the other was built to demonstrate the concept of mobile agents in manufacturing. The CORBA based test bed was used to teach students the usefulness of creating manufacturing applications using the Internet and CORBA. CORBA is becoming widely used in industry as it enables seamless information exchange across heterogeneous computing platforms and software systems. The CORBA test bed mimics a real world manufacturing scenario and links software modules implemented in C, C++ and Java on
Unix, PC and Linux platforms. These software modules reside in computers in Las Cruces (New Mexico), Monterrey (Mexico) and State College (Pennsylvania). Through tutorials and software demonstrations, students are provided a detailed understanding of the usefulness of using an architecture such as CORBA for a virtual enterprise oriented manufacturing context. When the part design specifications change and the availability of a specific machining resource changes, a CORBA based system can quickly generate an alternate manufacturing process plan by facilitating communication and control across heterogeneous computing platforms [2].

Many industrial organizations with remote locations and distributed resources have adopted a VE model. These industries include aerospace engineering, airline and travel industry, shipbuilding, computer manufacturing, healthcare, IT systems consulting, banking, electronic commerce, and telecommunications. While functioning as VEs, organizations such as Ford, Boeing, the Sabre Group, Lufthansa, Schlumberger, Pratt and Whitney, Cisco Systems, Raytheon, and NASA Goddard Space Flight Center have adopted CORBA-based architectures to become more agile and customer responsive [13,14]. Boeing, the world’s largest producer of commercial airliners, uses a CORBA-based framework to integrate its design, manufacturing, and resource management activities [13]. At Boeing, the manufacturing activities involve as many as 3,000,000 individual parts for each aircraft produced. Information integration, inventory management, collaborative sharing of data (related to design, manufacturing, and work-in-process) are extremely complex and require a robust distributed IT infrastructure. Boeing’s Internet-based VE computer architecture (which is based on the OMA/CORBA model) can support more than 45,000 users and 9,000 concurrent users in various regions across the USA [13]. Manufacturing engineers who have an understanding of computer architectures such as CORBA will be able to become more involved in the design, implementation and management of distributed manufacturing systems. IT specialists (who are typically computer science majors) lack an understanding of complex interactions within manufacturing domains; consequently, the design of software systems to support distributed and virtual manufacturing is hampered by this lack of knowledge. Companies such as Boeing, Lockheed Martin and Honda will benefit from this next generation of manufacturing engineers who have a strong background in manufacturing systems but also in the design / implementation of software systems which serve as the information backbone for distributed product development activities.

Students are also exposed to the importance of designing software based systems for distributed manufacturing and virtual prototyping. Apart from EML, they are also taught the basics of information modeling using the Unified Modeling Language (UML). UML is becoming the international standard for software modeling activities. In the information based manufacturing courses, students are taught the basics of UML based modeling. Software applications for manufacturing process planning and virtual prototyping are designed and implemented using the UML models. As part of specially designed laboratory modules, students create (UML) collaboration, sequence and class diagrams for various manufacturing applications.
5. Outreach efforts aimed at school students

As part of outreach efforts related to information based manufacturing, some of the developed laboratory and lecture modules were modified and adapted for use in two newly created programs: Soaring Eagle and MIME. The Soaring Eagle initiative was created in 2002 with the objective of providing Native Americans an early introduction to engineering. MIME (Minorities in Manufacturing Engineering) focuses on Hispanic students at universities and schools in the Dona Ana county and surrounding areas including Anthony in Texas. The first phase of this outreach approach involved (a) introducing students in grades 4 – 12 to virtual reality technology through mini workshops (duration: four to eight hours) and use it as a vehicle to kindle their interest in engineering careers, (b) introducing teachers in middle and high schools to cutting edge software technologies and train / educate them in virtual engineering so that they can in turn train/educate their colleagues and students.

As part of Soaring Eagle, a collaborative partnership is being undertaken between the Virtual Enterprise Engineering Laboratory at NMSU and the Mescalero Apache Schools in the Mescalero Apache Reservation. While Native American students from other reservations have also participated in the workshops, the Mescalero Apache Schools have been most active in the outreach program. During these workshops, students from 5th grade to 12th grade are introduced to Virtual Reality and engineering concepts using software and computer systems. They work in teams of 3 to 5 students, complete tutorials involving creation of 3 D models using Virtual NC software as well as research oriented Virtual Reality environments. Typically, virtual prototypes of CNC machines, work cells as well as other objects of interest (which range from space vehicles to toy car assemblies) are created. The school students also are introduced to the virtual reality sensors and tracking equipment and learn to navigate inside a virtual environment using 3 D eye-wear. They are also introduced them to formal virtual prototyping theory including definitions, classifications and descriptions of the technology involved. The workshops are beginning to have a direct effect on the students beginning to express the interest in engineering careers. While a more detailed project evaluation is currently underway to study the overall impact of this continuing program, feedback from the students and teachers at Mescalero indicate that this early introduction to cutting edge engineering technologies and principles has sparked their enthusiasm in learning more about engineering and their interest in science and math classes in school.

The positive impact of the Soaring Eagle program activities on the students and teachers at Mescalero has resulted in the creation of a virtual reality laboratory on their campus; VR software tools (such as Virtual NC) used at VEEL have been purchased and installed; they are being used by middle and high school students to build virtual reality models as part of efforts aimed at continuing the introduction to engineering activities.
6. Conclusion

This paper outlined curriculum and outreach initiatives in an emerging area called Information Based Manufacturing (INBM). Three major areas of emphasis include information modeling, virtual prototyping and distributed computing for manufacturing applications. Information modeling deals with the creation of information oriented models for both process collaboration as well as design of software systems for manufacturing applications. Virtual Prototyping is concerned with the visualization and simulation of product and process design information in a product development context. Distributed computing focuses on the exchange of product and process design information using robust computing architectures and methods, which enable distributed manufacturing planning and manufacturing using the Internet. These topics are taught as part of new courses offered to manufacturing and industrial engineering students at New Mexico State University. This paper also delineated innovative inter university oriented student class projects, which emphasized information modeling and distributed collaboration using the Internet. Students at partner universities in Mexico and Pennsylvania also participated in this unique inter university project experience. The overall objective of this innovative curriculum development (based on cutting edge research activities) is to introduce the next generation of manufacturing and industrial engineers to emerging Information Technology based manufacturing practices that are being adopted worldwide. By providing these learning experiences and emphasizing the learning of both theoretical principles and software technologies (including virtual reality and Internet based approaches), this initiative seeks to prepare engineers to ‘hit the ground running’ upon graduation.

ACKNOWLEDGEMENT

Funding for the educational and research activities discussed in this paper were obtained from the National Science Foundation through a Combined Research and Curriculum Development (CRCD) grant (No. 0196303), an INBM research and curriculum planning grant (No. 0230709) and a grant from the Air Force Research Laboratory (Space Vehicles Directorate, Albuquerque). Software tool donations were provided by Knowledge Based Systems and Rational Corporation. Case studies and examples were obtained through the support of industry partners including MicroSat Systems and National Institute of Standards and Technology (NIST). The assistance of other industry partners including Sandia National Laboratories, NIST, Delmia Corporation, VRCO, Inc. and Fakespace Corporation is also gratefully acknowledged.

BIBLIOGRAPHY


**BIOGRAPHICAL INFORMATION**

J. CECIL

Dr. J. Cecil is an Assistant Professor in the Industrial Engineering department at New Mexico State University and directs the Virtual Enterprise Engineering Laboratory and the virtual Center for Information Based Manufacturing. His areas of interest are
primarily are in INBM with an emphasis on discrete parts manufacturing, assembly of micro devices, nanoscale processes, electronics manufacturing and satellite development.