

VIRTUAL LEARNING ENVIRONMENTS FOR MANUFACTURING EDUCATION AND TRAINING

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Abstract

While some universities may be able to expose their students to the latest manufacturing systems and technologies, others may not be that fortunate due to the lack of financial resources. Because of this, alternative avenues for providing their students with equivalent education and training need to be developed. A potential response to this call is the adoption of advanced computer technology to facilitate the provision of flexible manufacturing-related education and training programs. To date, many studies have shown that the use of computers for teaching and training purposes is feasible and rapidly becoming an integral part of the general learning process. It has also been confirmed that recent advances in information and communications technologies have positively influenced and changed the economics of engineering education. These advances can be exploited as a powerful vehicle for educators to develop IT-enabled learning environments for manufacturing that utilize simulation, automated data acquisition, remote control of instruments, rapid data analysis, and video presentations. Computer applications related to simulating manufacturing processes have shaped a field which is currently known as Virtual Manufacturing (VM). In this paper, the authors present an introductory overview of Virtual Learning Environments (VLEs) for manufacturing related education and training. After an initial discussion of educational advantages of such VLEs, technological realization aspects, typical IT infrastructures and equipment configurations are explained. This is followed by an illustrative example of a specific VLE for manufacturing that has been developed

and implemented at the Eastern Mediterranean University in Turkey.

Introduction

Since the advent of globalization, the manufacturing industry has been subject to continuously increasing pressure of competition. Products have to be developed faster than before, with equivalent or higher quality, and at significantly lower cost.

While modern manufacturing systems provide the technological edge to meet these challenges, one needs to bear in mind that related education and training of both engineering students and the current workforce also has to be kept up-to-date. Only engineers that are familiar with the latest advancements in the manufacturing sector and are well trained in the use of state-of-the-art technology and tools will be able to effectively help their employers face the competition. Many engineering students receive fundamental manufacturing related education and training through their degree programs. For the current workforce, however, continuing the development of their professional skills and competencies throughout their entire professional life can become a challenge. While some universities and companies may be able to expose their students and employees to the latest manufacturing systems and technologies, others may not be that fortunate, due to lack of financial resources. For the latter, alternative avenues for providing equivalent education and training opportunities have to be explored.

One potential approach to education and training in the manufacturing sector is the utilization of Virtual Learning Environments (VLEs). While such VLEs are already widely used for fundamental engineering education in academia, they also bear a huge potential for successful deployment in distributed corporate settings[1]. Manufacturing-related VLEs provide an affordable and safe environment for education and training, ranging from the fundamentals of modern manufacturing to expert level training in manufacturing process planning and simulation, without any need for, or cost of, physical equipment, materials, tools or travel. The utilization of VLEs in manufacturing is considered to be one of the most promising ways of providing a safe, cost-effective, and flexible environment for training and education[3].

In this paper, the authors present an introductory overview of virtual learning environments for manufacturing related education and training. After discussing educational advantages of such VLEs, technological realization aspects, typical IT infrastructures and equipment configurations are explained. This is followed by an illustrated example of a specific VLE for manufacturing that has been developed and implemented at the Eastern Mediterranean University in Turkey.

Virtual Learning Environments

Over the past decade, rapid developments in the Information Technology (IT) sector have led to a significant increase of computer-based teaching and learning aids in the classroom. One particular category of such tools is that of so-called Virtual Learning Environments (VLEs). VLEs are generally defined as “*computer-based environments that are relatively open systems*”[5]. They are capable of supplementing traditional face-to-face teaching methods and normally work over the Internet. Most browser-based systems are password-protected to offer a secure, closed environment and to prevent unauthorized third-party access.

In general, VLEs can be categorized into two groups[2]; (1) Systems that support interactive and multimedia features including computer animations, audio and video, 3D graphics, on-line databases; and (2) e-learning systems with Internet-based features such as e-mail and chat room facilities which can be integrated to create a cyber-platform for learning.

VLE functions and activities

Functions and activities supported by VLEs typically include:

- A curriculum mapping section for import, creation, and delivery of course materials, assignments, quizzes, etc.
- A communication and cooperation section to support online interaction between students and instructors.
- An administration and assessment section to support online registration as well as tracking and assessment of students' progress.

Why VLEs?

A significant body of literature suggests that VLEs can be an effective means of enhancing, motivating, and stimulating students' understanding; as well as for reducing educational cost[6,7]. VLEs overcome the limits of space and time in knowledge delivery and utilization, along with allowing students to determine their own learning path and pace. Studies have shown that VLEs offer a number of advantages over traditional teaching environments in terms of knowledge accessibility, convenience and flexibility[5]. The importance of VLEs in the global learning market is documented in a report by Ambient Insight (2007)[11]. According to this, in 2007 the approximate value of the global market for E-learning products and services (VLEs) was \$17 billion. This total is forecasted to rise to \$50 billion by 2010, which implies that the market will significantly expand in the near future[7]. Major advantages of VLEs are summarized in Table 1.

Advantages	Disadvantages
Delivering educational content at almost any time to almost any place.	Need for training in VLE administration and implementation for providers.
Online assessment and monitoring of students.	
Online student-to-student and student-to-instructor collaboration and interaction.	
Effective and efficient provision of teaching materials.	Special requirements to allow off campus access with regard to data access and network security.
Support of multi-media teaching aids, such as Video, Audio, Text, Animations, and 3-D Graphics.	
Integration of problem-based learning activities into VLEs.	

Table 1. VLEs Advantages vs. Disadvantages.

Combining Virtual Reality (VR) and VLEs

Virtual Reality (VR) can be defined as an integrated computer system which provides a synthetic three dimensional computer simulation environment that allows users to become part of an almost real scene. In Virtual Reality worlds, learners can be simultaneously provided with three-dimensional representations, multiple perspectives and frames-of-reference, as well as simultaneous visual and audio feedback. With careful design and implementation, combined with VLEs, these capabilities can be synthesized to allow users of such environments to develop a profound sense of motivation and concentration that is conducive to mastering complex materials[8,9]. Due to advances in information technology, extended network capabilities, and the internet, more and more web-based distributed Virtual Learning Environments that are available from any computer connected to the internet are developed and used in a wide variety of educational settings in both academia and industry.

The integration of VLEs and VR systems leads to immersive, interactive and flexible Virtual Learning Environments in which learners not only can share information and collaborate, but also actually customize and personalize their learning environment according to their individual needs[10]. It has been shown that such educational environments lead to a more active in-

volvement of students in their own learning processes, which in turn facilitates deep learning, helps to improve the quality of the learning experience, and last but not least, reduces educational costs.

VLEs in Manufacturing Education: Virtual Manufacturing

The term Virtual Manufacturing (or VM) is widely used in literature. From the early 1990s, in part through the U.S. Department of Defense Virtual Manufacturing Initiative[12], support has been delivered to develop virtual manufacturing terms and concepts. For the first half of the 1990s, only a small number of major enterprises and a few academic research groups were actively involved in the field of virtual manufacturing[13]. More recently, however, the use of virtual manufacturing has become increasingly prevalent and a considerable volume of research has been carried out with regard to both the conception and implementation of virtual manufacturing systems. So what is Virtual Manufacturing actually all about?

In simple terms, the word ‘virtual’ refers to a concept applied in many fields and is defined as “that which is not real but may display the full qualities of the real”. The term ‘manufacturing’ refers to all activities and processes involved in industrial product development. VM is often referred to as “a computer system which is

capable of using information technology to generate information about the state and behavior of a manufacturing process that can be observed in a real world manufacturing environment”[13-15].

According to the Institute for Systems Research, University of Maryland[17-19], virtual manufacturing is “an integrated, synthetic manufacturing environment exercised to enhance all levels of decision and control” (Figure 1).

A major outcome of the virtual manufacturing research has led to the development of Virtual Factories (VF). A Virtual Factory can be defined as “a complex computer based simulation system that provides the manufacturing system designer all the resources and tasks necessary to achieve the optimized operation of designing, producing and delivering a product”[13].

The Scope of a Virtual Manufacturing System

The concept of virtual manufacturing may encompass the entire enterprise hierarchy. According to a definition by Onosato and Iwata (1993)[16], each manufacturing system comprises two sub-systems: a real information system and a physical system. Whilst the real information system is associated with the entire system’s architecture, manufacturing information activities and decision making within cost, weight, investment, timing and quality constraint, the physical system comprises important units such as resources, machines, and parts. The scope of Virtual Manufacturing Systems (VMS) can be subdivided into three levels (Figure 2): the information system, product and process design, and factory/shop floor.

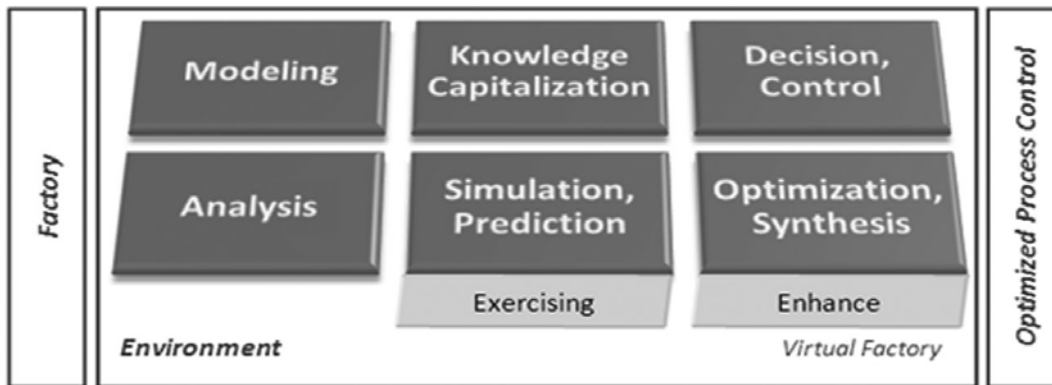


Figure 1: Virtual Manufacturing (adapted from Virtual Manufacturing User Workshop, 1994).

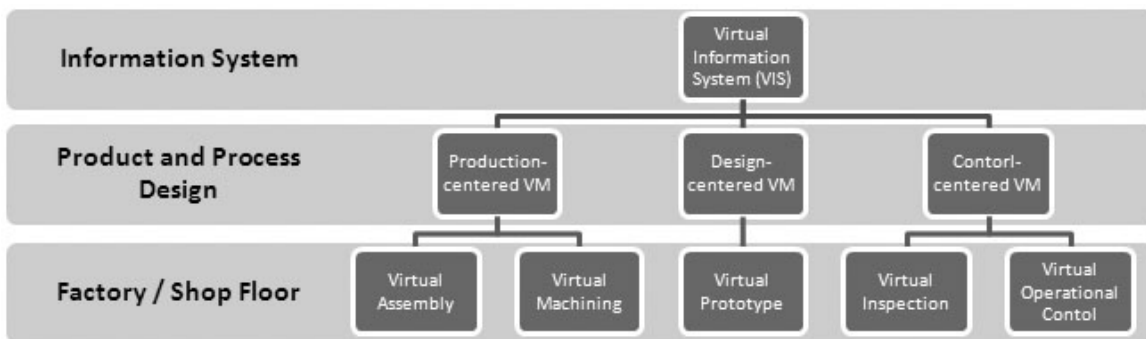


Figure 2: General Scope of Virtual Manufacturing.

Virtual Manufacturing System Infrastructures

As mentioned before, a Virtual Manufacturing System can be defined as a “computer-based simulation of the entire manufacturing activities and processes”. According to this definition, two core characteristics of VMSs are (1) modeling, which encompasses specifying what to model and at what level of abstraction, and (2) simulation, which is the procedure of the model exploitation and provides manufacturing process attributes with certain degrees of accuracy and precision. According to Depince and Chablat (2004) [19], typical infrastructures of comprehensive virtual manufacturing systems can be classified based on their:

- Manufacturing characterization.
- Modeling and representation technologies.
- Visualization, environment construction technologies.
- Verification, validation and measurement capabilities.
- Multi-discipline optimization.

Virtual Manufacturing Environment Applications

As discussed before, in virtual manufacturing the simulation environment created by computers is an artificial environment reflecting real physical objects and dynamic behavior. Advances in virtual reality technology have made it feasible to directly utilize VR for the modeling and realization of Virtual Manufacturing Environments. The use of virtual environments in simulating manufacturing environments gives engineers and/or engineering educators the opportunity to play a pro-active role in identifying flaws and optimizing any aspect of manufacturing-related processes and activities. The features of virtual environments provide an important foundation of virtual manufacturing. Virtual Manufacturing Environment systems can be used in a wide variety of manufacturing systems contexts and have often been classified into the following categories:

- Product Design – 3D product design.
- Product Design - Virtual Prototyping.
- Process and Production Planning.
- Factory layout operation.
- Virtual Assembly.
- Virtual Inspection.
- Virtual Operational Control.
- Virtual Agile Manufacturing.
- Virtual Material Handling Systems.

Virtual Manufacturing Environments in Education and Training

The efficient use of human skills, knowledge and experience is the major power of modern enabling technologies of agile manufacturing. A manufacturing enterprise needs skilled, cooperative and motivated people in order to achieve its goals. The participation of people throughout the enterprise in planning, designing and implementing new technologies and systems is the essential success factor. Hence, in the development of an agile manufacturing system, technical systems need to be designed not just to meet economic and technical goals, but also to satisfy organizational and human skills, judgment, creativity, knowledge, and ingenuity, and to make full use of modern computer-based technologies.

Flexible Manufacturing Systems (FMS), automation equipment, robotic manufacturing lines, programmable systems such as Computer Numerical Control (CNC) machines and Automated Guided Vehicles (AGVs) are examples of systems that fit into the category of modern and computer-based technologies which improve manufacturing agility. However, the technologies that make these systems agile consist of highly expensive and complex systems, which involve potentially dangerous machinery and robots. Companies incur high costs in order to train their work force to use such systems and equipment.

In manufacturing education it is often desirable for engineers, technicians and even line managers to gain more practical experience in handling modern equipment and productions

systems. However, it is time-consuming to learn how to use the fine controls of the equipment, as well as how to implement new manufacturing systems. Trainees have to be supervised while operating manufacturing equipment to avoid potentially expensive damage and large amounts of money have to be invested to experience different production and manufacturing activities. To date many studies have shown that the use of computers in teaching and laboratory work is feasible, and has changed the economy of manufacturing education[20]. It also has a positive impact on student motivation and appears to have similar educational effectiveness to 'hands-on' training.

The utilization of Virtual Environments in manufacturing education (Virtual Manufacturing Learning Environments) has been emphasized by many researchers, e.g.,[21-22]. It has been shown that people can indeed learn to perform certain tasks such as console operation from virtual environments and that knowledge and skills acquired through a VR simulation can be effectively applied in the real world[20].

Virtual Reality in instruction utilizes computer models in order to simulate the behavior of a manufacturing system or process [23]. In this way it is possible to repeat an operation many times, comparing the findings with model-based values. In general, one can expect that the use of VE and other types of educational software in manufacturing training will provide a sufficient degree of interaction with the trainees. Their use also improves the overall quality of manufacturing-related education and offers a number of important advantages in terms of pedagogical value:

- Trainees devote their time to useful discussion and observations, have the opportunity to analyze results, repeat experiments, compare results with theory, etc.
- Trainees concentrate on understanding fundamental concepts and not performing tedious writing.
- Drilling can be enabled at any time without supplementary effort by the instructors.

- Minimization of failures due to incorrect parameters.
- Trainees can gain experience in manufacturing activities that usually require hours or days to complete within a few hours or even minutes.
- Pace and complexity of education can be adjusted to suit individual experience.
- Any number of trainees can practice and be trained at any time.
- Trainees can be provided with a virtual tour, guidance, and assistance during the training.
- New possibilities for continuous education, distance learning, and collaboration with other industries in training[23-25].

The various applications of Virtual Environments in manufacturing which were outlined in the previous section can be effectively utilized in manufacturing education. One of its most important applications is for training in operating manufacturing equipment such as machining equipment and robots. It is generally accepted that training on real machines includes disadvantages such as:

- High costs because of system down times.
- Fixed site for the training.
- Hazards for trainees and instructors.

For instance, CNC machines are one of the most widely used pieces of machining equipment in the manufacturing industry. Due to their high cost and complexity it is often difficult for companies to keep up with the rapid developments in equipment. The same applies to training of the workforce. Traditionally, the user needs to work through operation manuals and then follow the instructions to practice and learn how to use the equipment. The user may also ask an experienced worker for help, however lengthy explanations are time consuming and ineffective. A new user may make many mistakes while operating the real machine in the initial stage of familiarization. In addition, limited availability of facilities and personnel can make it difficult to train large numbers of trainees for any given machine.

In summary, virtual environments provide excellent training opportunities for manufacturing by allowing each trainee full access to the entire facility in order to practice new and existing tasks in a safe, controlled environment.

Illustrative Example: The Virtual CIM Laboratory - VCIMLAB

The Virtual Computer Integrated Manufacturing Laboratory - VCIMLAB is an educational software system for use as a visual demonstration and laboratory support tool for teaching multi-disciplinary topics related to integrated manufacturing systems; such as programmable industrial robots, Computer Numerical Control (CNC) machines, quality control and automated assembly equipment, scheduling, process planning, production planning, and control of flexible manufacturing systems. The VCIMLAB has been completely designed and developed at the Eastern Mediterranean University (EMU) – Mechanical Engineering Department – since 2004. For the development of the simulation models, a real model of a CIM laboratory located at the Eastern Mediterranean University (EMU) Industrial Engineering Department was taken as a reference model. The reference laboratory consists of two flexible manufacturing cells, including programmable robot arms, a CNC milling machine and additional CIM equipment provided by Intelitek®. Based on real time operat-

ing principles and software interfaces used in the reference laboratory equipment, the virtual model of each piece of equipment has been generated such that the virtual simulation environment very closely replicates the real laboratory (Fig. 3). The students can operate the virtual simulation models of the real CIM equipment and the corresponding system software in the VR environment in real time. The runtime platform of the VCIMLAB has been developed as separate virtual module, in which the users interact either with the virtual laboratory equipment or the virtual software interfaces for simulation and control of virtual CIM system that are provided. The hardware and software operation in the virtual CIM laboratory is categorized according to the level of complexity of CIM equipments. The VCIMLAB provides several distinguished combinations of laboratory models for a step-by-step approach towards learning how to operate CIM systems. These distinguished simulation environments are called ‘rooms’. Each room contains a basic CIM training unit, such that the students focus on a specific part of the CIM hardware. The VCIMLAB provides a total of four rooms. The difficulty level increases from 1 to 4 with 1 being ‘simple’ and 4 being ‘very difficult’. As an initial step of operation of VCIMLAB, the level of difficulty is defined by the selection of VCIMLAB room (Fig. 4).

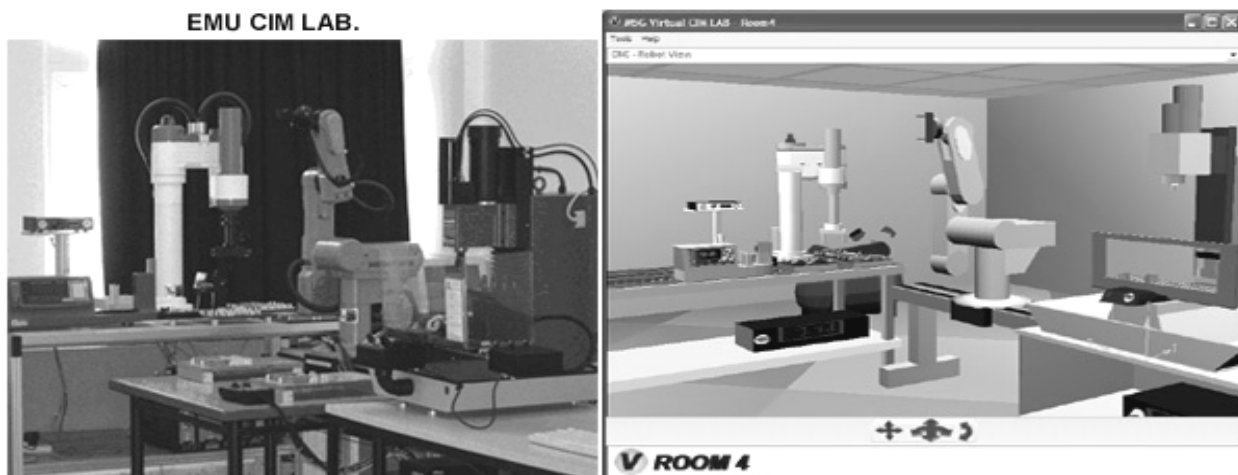


Figure 3: Real vs. Virtual CIM Laboratory.

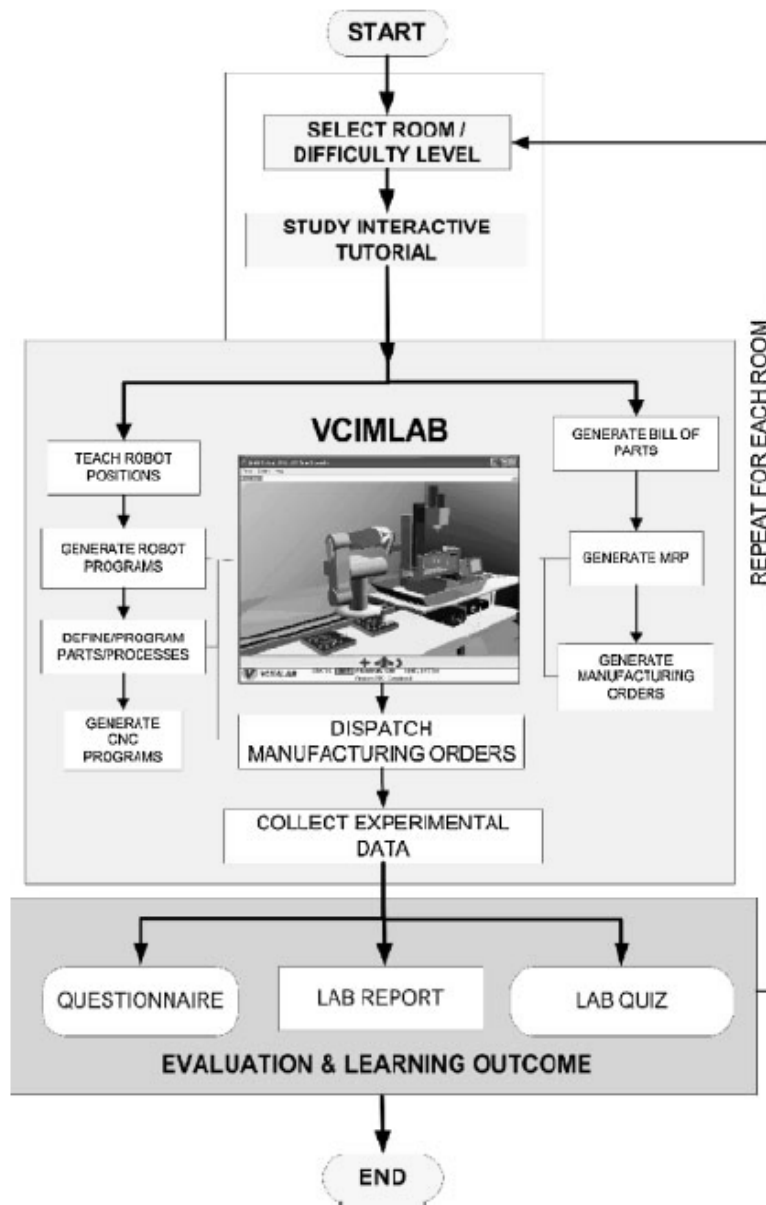


Figure 4: Overall Methodology of Operation.

VCIMLAB Room 1: Basic Training on Industrial Robotics

As a starting point of the CIM systems training, the principles of industrial robot control and programming are studied. The objective of this training is to familiarize the students with how to control and program an industrial robot arm safely for various pick & place operations and to prepare them for more advanced levels of CIM operations (See Fig. 5).

Advanced FMS Operations

The VCIMLAB contains conventional robot cells in which typical robot - CNC interactions, several assembly and quality control operations are studied. As a further step of the basic robot training, in Room 2 the students are expected to program the given robot to load the CNC machine with an un-machined part, and to program the sequence of the operations between robot and machine. This way, the students learn how

to operate a complete manufacturing cell to produce a part with the given specifications and how to program a robot for CNC operations without causing any collisions in a correct sequence. In the virtual laboratory Room 3, an assembly and quality control cell with a SCARA robot which is widely used in the industry for assembly operations, a laser scan micrometer as a quality control device is added.

Similarly, in Room 3 the students are expected to perform several assembly and quality control operations by programming a given robot and peripheral CIM equipment such as a Laser Scan Micrometer, Glue Dispenser, Screwdriver tool etc. (See Fig. 6).

The VCIMLAB Room 4 is a further step of training in cellular manufacturing operations. It consists of the combination of the equipment presented in Rooms 2 and 3. The knowledge and experience gathered in the previous levels of the training is applied in Room 4 to establish a parallelism in manufacturing system components.

In addition to the operations performed in Rooms 2 and 3, Room 4 provides the capability of combining two robotic cells to perform a variety of full manufacturing processes. One example is that the block parts can be machined in the CNC cell and be transferred to the assembly cell for further dispensing and assembly operations.

CIM System Control and Production Management

The Virtual CIM Manager is a VCIMLAB module shown in Figure 7, which provides the centralized control of the production activities in the VR based laboratory for performing the manufacturing orders defined by the user.

The module basically manages the CIM operations by managing the message flow between individual virtual station devices in each virtual room and receives responses, which enable it to

track the flow of parts during production. Besides the operational functions, this module represents the interaction of the students to the real centralized CIM control systems.

The VCIMLAB - Virtual CIM Manager enables students to use and study components and subsystems individually as well as the entire integrated CIM system by performing the following basic functions:

- ***Evaluation of the Production Plans:*** Fills in details in the production plan on how to produce the parts submitted in an order.
- ***Execution of Production Plans:*** Controls and monitors the CIM equipment in the virtual environment to produce the parts as specified in the production plan.

The students prepare the production plans and issue commands to manage the production in the virtual laboratory using the Virtual CIM Manager. The VCIMLAB - Virtual CIM Manager provides a set of definition modules, which are used for preparing the overall system for production. These modules allow the users to view and edit the production processes carried out in the 'virtual factory' (Fig. 7). The supporting modules of the VCIMLAB CIM Manager are as follows;

- ***Part Definition Module:*** Definitions of the parts and processes in the system. It includes definitions of processes, routes, schedules, definitions of individual machines or equipment used in the production of the parts.
- ***Storage Definition Module:*** Storage Definitions, which inform the system about the current or initial status of the inventory of the virtual CIM environment. The module allows assigning the robot task programs, which are generated by the users, to the storage at each room.
- ***MRP Module:*** Materials Resource Planning and manufacturing orders to run the production.

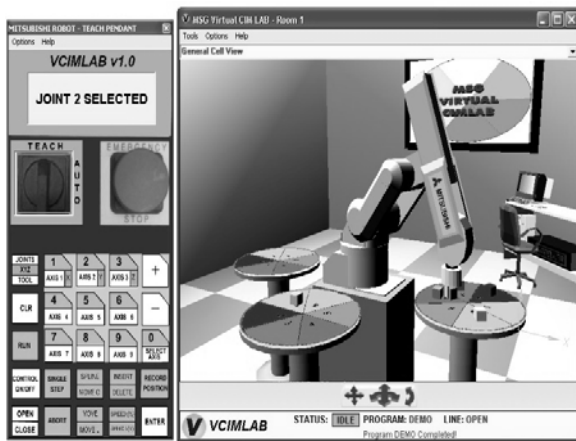


Figure 5: Room 1 – Basic Robot Training.

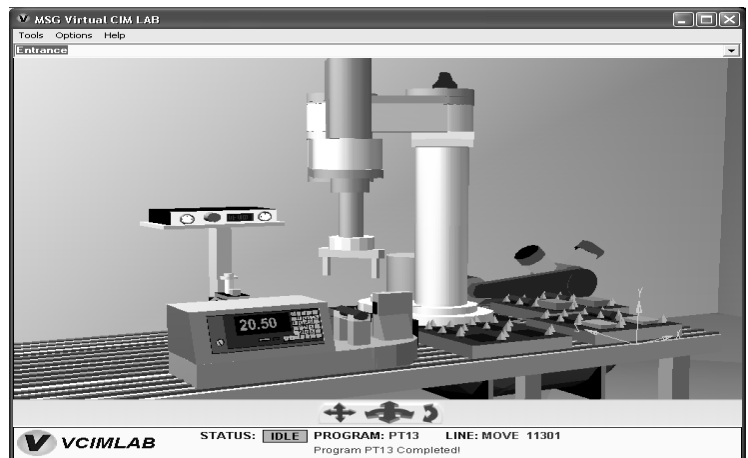


Figure 6: Assembly and Inspection Cell with SCARA Robot.

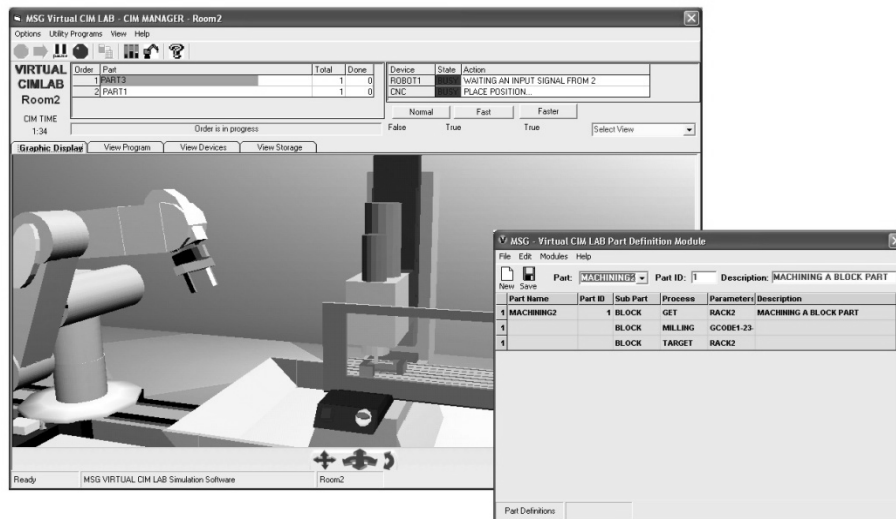


Figure 7: VCIMLAB – CIM Manager MRP Module.

Evaluation Method

The evaluation of learning for each experiment through VCIMLAB module takes place through: (1) A laboratory report, in which the students are asked to report the performed experiment by the procedures followed, results obtained, analysis and conclusions. (2) A questionnaire, which involves the questions regarding the VCIMLAB module in order to collect feedback and opinion about the bugs, usability and effectiveness of the software in students’

learning on the studied topic. (3) A lab quiz, given to all the students in order to measure the overall understanding of the subject studied through the laboratory experiment.

Figure 8 presents a summary of the VCIMLAB software usability evaluation based on the questionnaires. These descriptive statistics were given on each of the five usability subscales. The questionnaire results were calculated and scored based on the SUMI method.

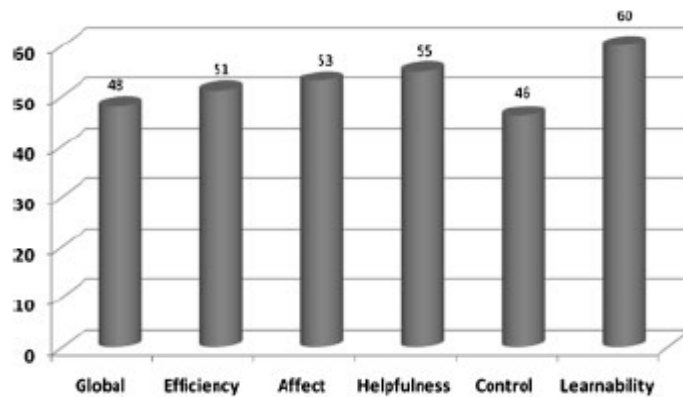


Figure 8: Software usability evaluation results of the VCIMLAB.

Closing

In conclusion, we have argued that the use of Virtual Learning Environments is an important and strategic means to facilitate manufacturing education initiatives. VLEs are one of the most promising methods of delivering safe, cost-effective, convenient and flexible learning environments to supplement traditional teaching and offer an effective means of enhancing the student learning experience. A point to note is that we are not proposing to do away with training using actual equipment or getting rid of laboratories and classrooms. In fact, the authors believe that VEs carry all advantages of self-directed activity, motivation, natural semantics and safe space in training, which result to help augment the learning process in training.

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Biographical Information

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Dr. Dirk Schaefer is an Assistant Professor in the Woodruff School of Mechanical Engineering at the Georgia Institute of Technology. Over the past ten years, Dr. Schaefer has been conducting research in the interface domain between Engineering, Computer Science, and Information Technology principles in Germany, the United Kingdom, and the United States. Long standing work has addressed product modeling, variant design, product life-cycle management, interdisciplinary EDAC-to-MCAD integration, design-with-manufacture integration, standardized product data exchange, knowledge management as well as virtual engineering, digital enterprise technology and systems integration. Dr. Schaefer's current research is focused on the Scholarship of Integration and the Scholarship of Education. His contributions to the Scholarship of Integration concern the highly topical area of Designing Mechatronic Systems. In his research, Dr. Schaefer addresses questions related to the integration of design domains, domain-specific CAD and CAE systems, interfaces for standardized data exchange between domain-specific PDM systems, and automated variant design generation of mechatronic systems and system families. Dr. Schaefer's contributions to the Scholarship of Education concern one of the 14 Grand Challenges for Engineering as stated by the National Academy of Engineering – "Advance personalized learning." In his research, Dr. Schaefer addresses the strategic design of engineering education for the next generation of engineers the integration of game-changing paradigms such as mass customization, person-

alization and collaborative learning into the engineering curriculum, as well as virtual learning environments and remotely/robotically controlled physical laboratory exercises for distance learning settings including associated pedagogies. Dr. Schaefer has published approximately 80 papers in journals, books and conference proceedings on Computer-Aided Engineering and Design as well as Engineering Education. In addition, he has substantially experience in curriculum development, ABET preparation and assessment.