Using Virtual Reality to Address Competency Gaps

Larry Whitman, Ph.D., P.E., Vis Madhavan, Ph.D., Don Malzahn, Ph.D., Janet Twomey, Ph.D., Krishna Krishnan, Ph.D.

Wichita State University

Abstract

This paper presents how the use of a virtual reality model of a real world manufacturing line can be used to integrate a manufacturing engineering curriculum and address the competency gaps defined by the Society of Manufacturing Engineers. A Quest discrete-event simulation model was developed of an actual Boeing manufacturing line. A virtual reality markup language (VRML) 2.0 file was generated from the Quest model. Students use the virtual reality model for case studies in various classes in the curriculum.

Introduction

The Industrial and Manufacturing Engineering Department at Wichita State University is developing an integrated set of virtual reality models of a manufacturing line at Boeing Wichita. Researchers at WSU and Boeing will use these high fidelity models to identify and design improvements to the line. They will also be used in a mega-case from which various line studies are derived to vertically integrate the concepts across a manufacturing engineering curriculum, provide situated learning to our students and address many of the competency gaps identified by the Society of Manufacturing Engineers. The targeted competency gaps addressed include: project management, business skills, supply chain management, manufacturing process control, manufacturing systems, quality, problem solving, and product/process design. The best method for students to gain real world experience is to interact with industry. The virtual reality models are intended to supplement this by providing a realistic environment for initial learning and application. By utilizing a virtual model of the line, students are able to view the process and interrogate the process details, make changes and observe the effects, and gain a better understanding of the concepts and their interrelationships. The approach is based on each student experiencing multiple views of the real-world manufacturing line in a sequence of models that will mimic experience that could be gained by rotations through a series of jobs on the line. This paper describes competency gaps, project-based learning, case studies, and virtual reality. The paper then presents an approach to using virtual reality and to addressing the competency gaps.

Background

Competency Gaps

The success of a manufacturing curriculum depends on its effectiveness in ensuring that the graduates, in addition to understanding the principles and theory in manufacturing processes and systems, are also educated and trained to apply this knowledge in a real-life setting and be productive as soon as they graduate. In order to ensure their continued productivity, graduates must be able to perform life-long learning and adapt to new techniques, concepts and technologies. Another key issue that has to be addressed is the ability to work in multi-disciplinary teams and to effectively communicate and understand concepts from various perspectives. In addition to these competency gaps, the Society of Manufacturing Engineers[1], through extensive surveys of industrial representatives, has identified the following:

- Business knowledge/skills
- Project management
- Written communication
- Supply chain management
- Specific manufacturing processes
- Oral communication/listening
- International perspective
- Manufacturing process control
- Manufacturing systems
- Quality
- Problem solving
- Teamwork/working effectively with others
- Materials

The primary goal of this effort is to use virtual reality for project-base learning and case studies to supplement our department's attempts to address these competency gaps.

Project-Based Learning and Case Studies

The Industrial and Manufacturing Engineering curricula at Wichita State University have previously attempted to address these competency gaps through the use of industry-based projects in the curriculum[2]. The average graduate has had over five industry-based projects during their education. Two of these are semester long Senior Design projects performed in teams of three students. The large number of manufacturing firms in the Wichita area and the close association of the College with these manufacturers have fostered this ability to integrate "real world" engineering with classroom learning. Despite this success, the faculty finds that graduating seniors have relatively:

- Poor retention of basic concepts;
- Limited transfer of knowledge from previous courses; and,
- Little integration of process knowledge and analysis tools.

These findings are similar to those found for Civil Engineering seniors at Georgia Institute of Technology[3], and are probably characteristic of many engineering graduates. A recent survey of graduating Industrial and Manufacturing Engineering seniors of the WSU program in Table 1 shows that they have relatively low confidence in their knowledge of engineering design and science (the focus of much of their education) and their communication skills (a major component of their terminal projects). This data was collected after their capstone industry-based project experience and thus indicated their perceived deficiencies upon graduation.

Table 1: WSU graduating seniors' relative confidence in knowledge and skills ranked from low to high. Scale (1=Low confidence to 5=High confidence)

Knowledge		Skill	
Engineering Design	2.43	Verbal Communication	2.71
Basic Science	2.57	Written Communication	2.86
Engineering Science	2.57	Engineering Synthesis	3.00
Mathematics	2.86	Graphical Communication	3.00
Engineering Professional Practice	3.00	Self Learning	3.14
The Context of Practice	3.00	Function in a Global Environ	3.14
Probability and Statistics	3.14	Build Teams	3.29
Teamwork	3.43		

Traditionally, there has been a separation between knowing and doing in engineering education. Currently in most curricula, only the capstone senior design project provides students the experience of integrating the knowledge learned in all their previous courses in order to formulate alternatives and solutions to a problem. Based on a survey of educators, Iwata and Onosato[4] investigated the fact that manufacturing does not invite the interest of students. They conclude, "in addition to imparting general concepts and knowledge, education must also provide students with the overall image of manufacturing systems actually operated in industries"[4]. Recent notable increases in co-operative education programs, industrial internships, design laboratories, and industry-based design problems are attempts to bridge this gap. Many of these may be viewed as a return to "apprenticeships." Over 60% of the Industrial and Manufacturing Engineering students at Wichita State University have had at least one semester of co-operative education or equivalent industrial experience. This exposure is valuable in many respects but our experience indicates that this does not directly lead to an integration of engineering knowledge and skills and thus alleviate the problems listed above.

A case study is typically defined as, "a problem statement suitable for use by students and set in narrative form. The narrative should provide information that will lead more to a discussion of a problem than to its solution"[5]. The use of cases studies in managerial and business science is pervasive and well documented[5]. The use of case studies in engineering education has just begun to become a useful tool for teaching subjects such as engineering ethics and economics. Recently Raju and Sankar[6] reported on their research investigating "Teaching real-world issues through case studies." The typical approach is to use a single case study that was utilized in a single course to impart "cross-disciplinary education (finance, marketing, communication) in the engineering classroom." Integration over the curricula is carried out by distributing concepts and topics among courses taken in any given semester and team teaching the courses[7]. Raju and Sankar developed their case study according to the traditional business definition highlighting the technical aspects of the problem[6]. Their approach to the development of the case study was well done and will be utilized in part by this research team.

In this project we propose a novel use of case studies, which is in contrast to what has been its typical function. A series of case studies derived from the real world ‘mega-case’ (integrated virtual models) will be employed in courses within the Industrial and Manufacturing Engineering curricula to integrate them and make interrelations between the knowledge and skills gained in different courses obvious to the students. This approach has the advantage of requiring minimal modification to the courses and can be easily adopted by other institutions and adapted to other engineering disciplines. Currently in most curricula, only the capstone senior design project provides students the experience of integrating the knowledge learned in all their courses to formulate alternatives and solutions to a problem. The ‘mega case’ will also be utilized as a mechanism to educate the current work force.

Virtual Reality

If a picture is worth a thousand words, then an interactive 3D model is worth a thousand pictures[8]. Virtual reality (VR) is beginning to be widely used in fields such as entertainment, medicine, military training, and industrial design. Virtual reality models of manufacturing systems range in complexity from the level of a single process on a single machine[9], to flexible manufacturing cells[10], to virtual models of entire factories[4].

Jones et al.[11] discuss the use of virtual reality to present the results of simulations as a “super” graphical animation that will lead to an expanded role of simulation in decision-making and communication. Lefort and Kesavadas[12] have developed a fully immersive virtual factory testbed for designers to test issues such as plant layout, clusters and part flow analysis. Many researchers[13-16] have discussed the use of large-scale simulations for studying the virtual behavior of factories. Virtual factories have also been used for simulation-based control of real factories[17], for studying the interaction between business decisions and quality[18], optimal design of large-scale automated facilities such as postal mail process facilities[19], and for optimizing the performance of flexible manufacturing systems by testing different system configurations and control policies[20].

Delmia Incorporared offers a suite of virtual manufacturing software, which allow the creation of virtual mockups of workcells and production lines. These virtual mockups can engender substantial time and resource savings as errors made in design can be discovered and rectified before practical operation. One of the virtual manufacturing packages is Quest, a discrete event simulation tool that can be used to model and analyze the layout of production lines in real time by modifying the various model variables. The workcells from which these lines are composed can either be created in Quest itself or imported from IGRIP, a software tool used to model and detect collisions between parts, tools, fixtures, and surroundings. Organizations such as GE, TRW, Boeing, and Lockheed have used IGRIP for the validation of assembly sequences, off-line robot programming, human factors studies, and maintainability evaluation. Examples of the use of Quest include optimization of the number of workcells and the layout.

The Virtual Reality center at WSU has been established in response to a need identified by the aviation industry in Kansas and to help WSU further the FAA’s mission in research, development, and training. An immersive digital stereoscopic virtual reality system is being installed for 1:1 scale visualization by groups of people (up to 25 people). A variety of input/output devices allow natural interaction with virtual objects as can with real objects. These will be complemented by a set of development workstations with stereoscopic visualization hardware (including Head Mounted Displays), a complete suite of software, and high quality support staff.

Approach

The curriculum integration will be explicitly geared to addressing the Critical Competency Gaps identified by the SME. Table 2 provides a plan for addressing the various competency gaps in courses. The competency gaps have been classified using Bloom's taxonomy[21] as a knowledge, skill, or attitude thus providing direction as to the methods to be used in formulating learning objectives and assessments. This plan identifies each class that will address each competency gap and the general approach for implementation and assessment. Details about the learning outcomes and the nature of the virtual models to be used are presented for all the targeted courses in Table 2.

Virtual Reality modules will be developed in three domains and then integrated. The domains are: 1) Operation; a specific machining or metal forming process, 2) Workstation; an individual performing a task or a sequence of operations, and 3) Line; a system of workstations. Because of the differing natures of these domains, different approaches to model development will be used but the sense of integration will be maintained.

Each of these domains can be applied toward learning objectives in two basic methods, static and dynamic. By static, we imply that the model generates information or data that is used by students for offline data analysis. Examples of this are collecting standard time data, quality control data, reach and posture information, or cycle times. A dynamic application implies that actions taken by students are presented in terms of effects on the model. Examples of dynamic applications are the effect of varying inventory policy on order fulfillment, the effect of varying tool feed rate on surface finish, or the effect of changing to cellular layout on flow times.

Assessment Plan

All courses to be addressed in this research have clearly defined learning objectives and formal means of assessing the achievement of these objectives. However, to specifically evaluate the students' use of the integrated mega-case, virtual reality models, and data from the real world in courses, a formal rubric for project scoring will be developed. A tentative rubric currently being developed is shown in Table 3.

Table 2. Courses and Critical Competency Gaps Targeted

	Course & Model Characteristics			Critical Competency Gaps													
				Professional Gaps					Technical Gaps					Other Gaps			
	Required (R), Elective (E)	Model Domain (O- Operation, W- Workstation, L- Line)	Static(S)/Dynamic(D) Application	Business knowledge/skills	Project management	Written communication	Oral communication/listening	International perspective	Supply chain management	Specific manufacturing processes	Manufacturing process control	Manufacturing systems	Quality	Problem solving	Teamwork	Materials	Product/process design
Learning Outcomes (Bloom)																	
Knowledge				K	K			K	K	K	K	K	K			K	K
Skill				S	S	S	S		S		S	S	S	S	S		S
Attitude							A	A							A		
Targeted Courses																	
IE 254 Engr Prob & Statistics I	R	O	S	X							X		X	X			
IE 524 Engr Prob & Statistics II	R	O	S	X							X		X	X			
IE 554 Stat Quality Control	R	O	S	X		X					X		X	X			
IE 664 Engr. Management	R			X	X	X	X	X					X	X	X		
MfgE 258 Mfg. Methods & Mat I	R	O	D							X	X				X	X	X
MfgE 558 Mfg. Methods & Mat II	R	O	D							X	X				X	X	X
MfgE 502 Mfg Measurement Analysis	R	O	S								X		X				
MfgE 554 Mfg Tools	R									X	X						X
MfgE 545 Mfg Systems	R	L	D	X		X			X			X		X	X		X
MfgE 622 Computer Aided Design & Mfg	R	O	D											X			X
IE 452 Work Systems	E	W	S	X		X						X		X	X		
IE 549 Industrial Ergonomics	E	W	S			X	X							X	X		
IE 563 Facility Design	E	L	D			X						X		X	X		X
IE 565 Systems Simulation	E	L	D			X	X					X	X		X		

Table 3. Virtual Reality Project Scoring Rubric

Score Levels	Virtual Reality *The integration of VR objects, animation, data, and other tools to represent and convey information.*	Collaboration *Working together jointly to accomplish a common purpose as opposed to what might have been accomplished working alone.*	Content *How well does the project address the content, knowledge to be gained, and concepts of the course?*
5	Students have used VR in creative and effective ways that exploit the particular strengths of VR. All elements make a contribution. There are few technical problems, and none of a serious nature.	Students were a very effective team. Division of responsibilities capitalized on the strengths of each team member. The final product was shaped by all members and represents something that would not have been possible to accomplish working alone.	Meets all criteria of the previous level and one or more of the following: reflects broad research and application of critical thinking skills; shows notable insight or understanding of the topic; compels the audience's attention.
4	The VR model is complete, but does not have any innovative use of the tool	Students worked together as a team on all aspects of the project. There was an effort to assign roles based on the skills/talents of individual members. All members strove to fulfill their responsibilities.	The project has a clear goal related to a significant topic or issue. Information included has been compiled from several relevant sources. The project is useful to an audience beyond the students who created it.
3	There are imperfections in the VR model or data generated as compared to the real life system under study	Students worked together on the project as a team with defined roles to play. Most members fulfilled their responsibilities. Disagreements were resolved or managed productively.	The project presents information in an accurate and organized manner that can be understood by the intended audience. There is a focus that is maintained throughout the piece.
2	VR models or data used do not represent the manufacturing system being modeled	Presentation is the result of a group effort, but only some members of the group contributed. There is evidence of poor communication, unresolved conflict, or failure to collaborate on important aspects of the work.	The project has a focus but may stray from it at times. There is an organizational structure, though it may not be carried through consistently. There may be factual errors or inconsistencies, but they are relatively minor.
1	No VR Models used in presenting the project	Presentation was created by one student working more or less alone (though may have received guidance or help from others).	Project seems haphazard, hurried or unfinished. There are significant factual errors, misconceptions, or misunderstandings.
	Multimedia score =	Collaboration score =	Content score =

In addition to the above rubric, the student learning outcomes will be assessed using procedures recommended by the "Field-tested Learning Assessment Guide"[22], which classifies assessment methodologies by student learning outcomes; knowledge, skills, or attitudes. These outcomes are then matched with "Classroom Assessment Techniques" (CATs) that are most appropriate for assessing a particular learning outcome.

A significant motivation for this project is to improve the retention and integration of the knowledge and skills demonstrated by the programs' graduates. A standardized 60 question "Core Competency Examination" is administered to each graduating senior. We have also monitored the integration of knowledge and skills through the two industry-based Senior Design projects. We have used the same nine-factor rubric for five semesters for evaluating project final presentations. A team of faculty and industrial sponsors assesses presentations.

Performance on these assessments initiated discussions ultimately resulting in this proposal for curriculum development. Currently, only the instructor of the course and the projects' industrial sponsors, evaluate written proposals, progress reports, and final reports. We will be instituting a consistent rubric and external evaluations for the written documents.

As discussed by Bell and Fogler[23], the appropriate infrastructure must be in place for students to use the basic capabilities of virtual reality. Their ten steps are presented in Table 4. Of their ten steps to developing virtual reality applications for engineering education, we have taken a phased approach. For steps zero and three, "plan for the future" and "identify the intended audience and the end user's probable equipment," we have taken a two-pronged approach. One is to develop applications that can be viewed on a typical computer system either owned by the student or in the lab, which involved ensuring that add-in applications were installed or available. The other prong is to use the virtual reality lab at WSU for more detailed models. This is also how we addressed step five, "consider the tradeoffs of simulation realism versus performance." For step six, "start with a simple framework and then gradually add details," we used a phased approach in the level of detail added to each model beginning with the basic line layout and cycle times and then added more details. We are in the initial stages of student feedback for the first courses, which is in line with step seven, "provide for student evaluation early and often." Our approach is to use this phased implementation and consider the pertinent aspects of Bloom's taxonomy.

Table 4. The Ten Steps to Developing VR Applications for Engineering Education[23]

Step	Stage
0	Plan for the future: Never underestimate how fast technology will change during your development process
1	Understand the strengths and weaknesses of educational VR
2	Identify an application that is suitable for VR
3	Identify the intended audience and the end users' probable equipment
4	Choose an appropriate development platform (hardware and software)
5	Consider the trade-offs of simulation realism versus performance, and plan out the simulation very carefully
6	Start with a simple framework, and then gradually add details
7	Provide for student evaluation early and often; Develop the simulation based upon user feedback
8	Prepare written instructions suitable for students, faculty, and system administrators
9	Incorporate the simulation into the curriculum
10	Share your results far and wide

Results

A Quest discrete-event simulation model has been developed of an actual Boeing manufacturing line. The actual model was developed using the Quest simulation tool. A virtual reality markup language (VRML) 2.0 file was generated from the Quest model. Additional annotations are available through web queries of the model. A screen shot of a virtual reality model of the line is shown in figure 1. The students are able to examine the details of the line by “walking through” the line using the VRML file.

Future plans are for students to query individual machines and labor to view detailed reports about each. For example, when a student clicks on a machine in the VR model, the quality data is displayed and the student can develop the X-bar charts for a statistical process control class. A student can select a laborer, and the anthropometric data will be displayed. The students can investigate the model and determine details about each individual process. The students can document the steps and determine the times and resources required for each step in the process and develop a simulation model.

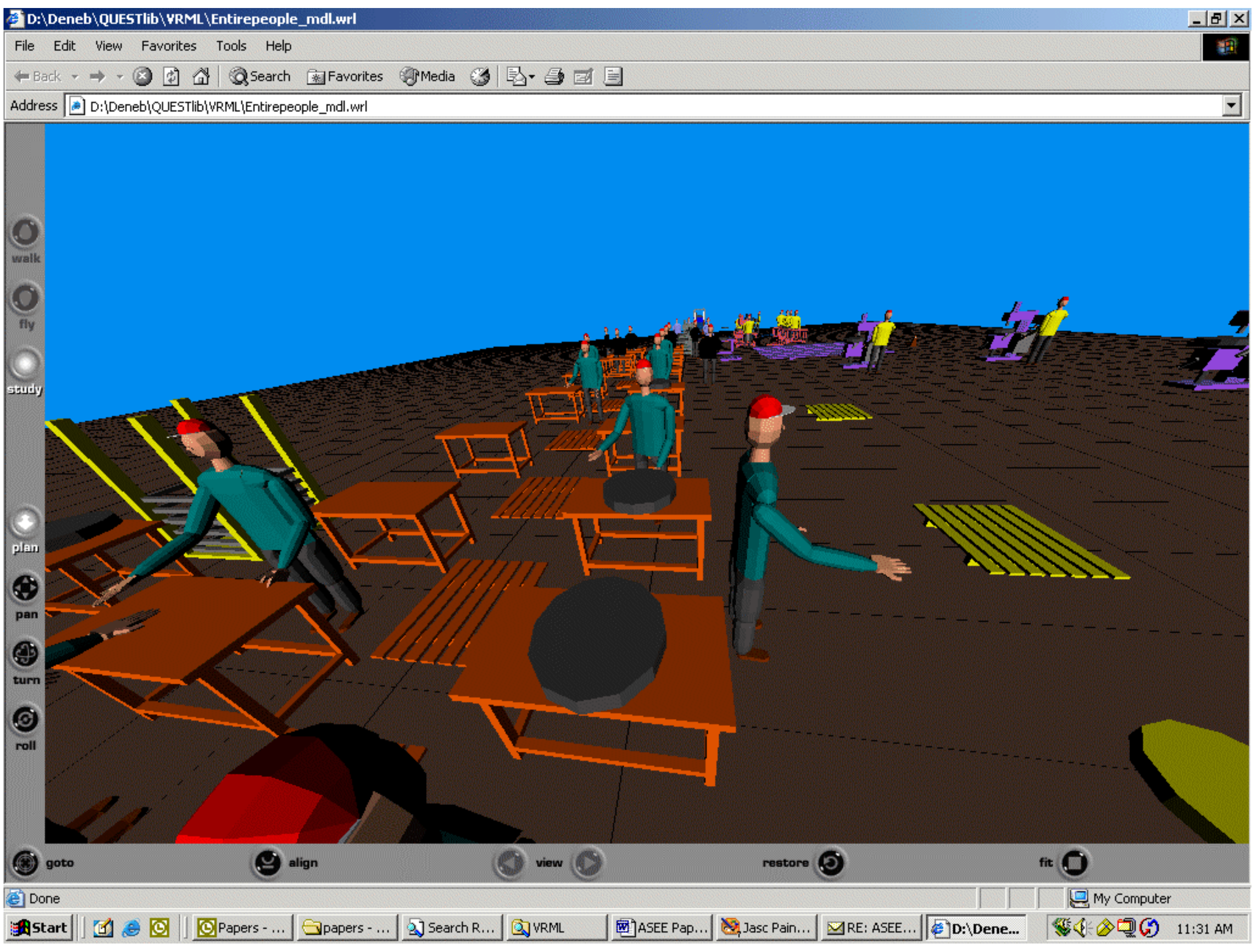

Figure 1: Model viewed in browser

Conclusion

This paper has discussed how virtual reality case studies can address competency gaps in manufacturing. Virtual reality can be used to bridge the gap between classroom lecture and industrial experience. Employing a series of case studies derived from the real world 'mega-case' (integrated virtual models) in our curriculum will enable students to synthesize the knowledge and skills gained in different courses. This approach has the advantage of requiring minimal modification to the courses and can be easily adopted by other institutions and adapted to other engineering disciplines.

References

[1] Society of Manufacturing Engineers. (1999). Manufacturing Education Plan: 1999 Critical Gaps. Dearborn, MI.

[2] Elliott, M. (2001). Who's afraid of the job market? IIE Solutions, 33, 30.

[3] Sulbaran, T., & Baker, N.C. (2000). Enhancing Engineering Education Through Distributed Virtual Reality. Proceedings of the 30th ASEE/IEEE Frontiers in Education.

[4] Iwata, K., & Onosato, M. (1996). Virtual Manufacturing systems for manufacturing education. Proceedings of the International Conference on Education in Manufacturing

[5] Ward, R.B. (1991). The case for case studies - and against. International Mechanical Engineering Congress.

[6] Raju, P., & Sankar, C. (1999). Teaching real-world issues through case studies. Journal of Engineering Education, 88, 501-507.

[7] Texas A & M. (2002). The Foundation Coalition. http://coalition.tamu.edu/Zope/fchome.

[8] Morgan, J. (1997). CAD exploits the internet. AUTOFACT - SME Technical Paper MS98-106

[9] Imperio, E., Boer, C., & Sacco, M. (1996). A virtual reality system for machining: A virtual lathe prototype. Proceedings of the International Conference on Education in Manufacturing.

[10] Bodner, D.A. & Reveliotis, D. A. (1997). Virtual factories: An object oriented simulation based framework for real-time FMS control. IEEE Symposium on Emerging Technologies & Factory Automation.

[11] Jones, K.C., Cygnus, M.W., Storch, R.L. and Farnsworth, K.D. (1993). Virtual reality for manufacturing simulation. Proceedings of the Winter Simulation Conference.

[12] Lefort, L., & Kesavadas, T. (1998). Interactive virtual factory for design of a shopfloor using single cluster analysis. Proceedings of the IEEE conference on Robotics and Automation.

[13] Henning, K. (1995). Simulation: The virtual factory. Proceeding of the APICS Annual International Conference.

[14] Geller, T., Lammers, S., & Mackulak, G. (1995). Methodology for simulation application to virtual manufacturing environments. Proceedings of the Winter Simulation Conference.

[15] Rembold, U., Reithofer, W., & Janusz, B. (1998). Role of models in future enterprises. Annual Reviews in Control, 22, 73-83.

[16] Rasmus, D. (1990). Working in a virtual factory. Manufacturing Systems, 8, 18-22.
[17] Lin, M., Fu, C., & Shih, T. (1999). Virtual factory- a novel testbed for an advanced flexible manufacturing system. Proceedings of the IEEE conference on Robotics and Automation
[18] Keane, J.A. (1998). Virtual factory approach to quality education. Quality Progress, 31, 10, 62-64.
[19] Lu, J., Tsai, K., Yang, C., & Wang, Y. (1998). Virtual testbed for the life-cycle design of automated manufacturing facilities. International Journal of Advanced Manufacturing Technology, 14, 8, 608-615.
[20] Bodner, D., & Reveliotis, S. (1997). Virtual factories: an object-oriented simulation-based framework for real-time FMS control. Proceedings of the Emerging Technologies and Factory Automation.
[21] Bloom, B. S. (1964). Taxonomy of educational objectives: The classification of educational goals. New York: Longman.
[22] University of Wisconsin. (2002). Field-tested Learning Assessment Guide. http://www.wcer.wisc.edu/nise/cl1/flag/default.asp.
[23] Bell, J.T., & Fogler, S.T. (1997). Ten Steps to Developing Virtual Reality Applications for Engineering Education. Proceedings of the American Society for Engineering Education Annual Conference.

LARRY WHITMAN
Larry Whitman is an Assistant Professor of Industrial & Manufacturing Engineering at Wichita State University. He received B.S. and M.S. degrees from Oklahoma State University. His Ph.D. is from The University of Texas at Arlington is in Industrial Engineering. He also has over 10 years experience in the aerospace industry. His research interests are in enterprise engineering, supply chain management, and lean manufacturing.

VIS MADHAVAN
Vis Madhavan has been working as Assistant Professor of Industrial & Manufacturing Engineering at Wichita State University since 1996 when he earned his Ph.D. from Purdue University. He is currently working on projects in virtual reality, machining and sheet metal forming, funded by Boeing, Bombardier, Cessna, NSF and Raytheon.

DON MALZAHN
Don Malzahn is Professor of Industrial and Manufacturing Engineering at Wichita State University. He has over 28 years teaching experience with research interests in engineering education, decision analysis, and project management.

JANET M. TWOMEY
Jan Twomey is an Associate Professor in the Industrial & Manufacturing Engineering Department at the Wichita State University. Her research and teaching interests are in the areas of simulation, probability and statistics, and artificial neural networks. She is currently on a temporary assignment as a Program Officer at the National Science Foundation.

KRISHNA KRISHNAN
Krishna Krishnan is an Assistant Professor of Industrial & Manufacturing Engineering at the Wichita State University. He received his M.S. and Ph.D. degrees in Industrial Engineering from Virginia Tech. He also has over 3 years experience in the aerospace industry. His research interests are in Computer-Integrated Manufacturing, real-time decision making systems and CAD/CAM.