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Virtual Reality Case Study throughout the Curriculum to Address Competency Gaps*

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While most instruction aims to provide students with content knowledge accompanied by practical application, the classroom experience typically has difficulty providing students with non-trivial examples. Graduating students also express a lack of confidence in integrating knowledge gained in disparate courses regarding identifying problems and synthesizing solutions. Many programs include industry-based projects as a solution to these issues. This approach has various drawbacks, including the difficulty of implementing such a project in a sizable number of the courses, the need for a significant commitment of class time, establishing contacts and ensuring that students have sufficient access to them to develop a model. The Industrial and Manufacturing Engineering Department at Wichita State University is developing an integrated set of realistic virtual reality models of a manufacturing line at Boeing Wichita. This line and the virtual models will serve as a mega-case that will be used throughout the curriculum to vertically integrate the concepts across the curriculum and provide a situated learning experience for students. This large-scale virtual reality factory module, 'Innovation in Aircraft Manufacturing through System-Wide Virtual Reality Models and Curriculum Integration', is funded by the National Science Foundation through the Partnerships for Innovation program. The virtual reality models being developed include a Quest discrete-event simulation model of the 767 strut torque box manufacturing line and work cell level models in IGRIP and Jack software applications. Virtual Reality Markup Language (VRML) 2.0 files are generated from these models for use in case studies in various classes in the curriculum. Further details are available on the website (http://www.slvr.org). This paper recounts the gaps identified by the Society of Manufacturing Engineers and from surveys of our graduating seniors. A matrix that maps our plan to bridge some of these gaps in courses in the curriculum is presented. The use of virtual reality in general, and specifically in the classroom, is then discussed. The primary pedagogical approach used, situated learning, which places the learner at the center of the instructional process, is presented. Examples of course modules are then discussed to show practical applications of using the mega-case to bridge the gaps in manufacturing engineering education. A rubric developed for assessment of the critical elements required for an effective situated learning experience and the realization of these characteristics in the VR modules is presented. Lastly, the benefits and problems of this approach are discussed.

MOTIVATION

THE TYPICAL Industrial and Manufacturing Engineering curriculum aims to prepare graduates for a wide variety of tasks in a wide variety of industries. There is no natural artifact, such as an aircraft for Aerospace Engineering or the human body for Medicine, that students can use to consolidate and integrate disparate knowledge sets gained from different courses. While most of the instruction in Industrial and Manufacturing Engineering aims to provide students with content knowledge accompanied by practical applications, the classroom experience generally has difficulty providing students with non-trivial examples. The capstone senior project ends up as the primary experience where students are guided on to how to choose from and apply the knowledge gained throughout the rest of the curriculum.

The capstone senior project at WSU consists of two semester-long projects performed in teams of three. The large number of manufacturing firms in the Wichita area and the close association of the college with them have fostered this ability to integrate 'real-world' engineering with classroom learning. A key distinguishing characteristic of graduates of the Industrial and Manufacturing Engineering programs at Wichita State University has been their ability to be immediately productive in their first job assignments. This has been attributed, in part, to the emphasis on industry-based projects in the curriculum [1]. Table 1 shows a survey of five semesters of graduating Industrial and Manufacturing Engineering seniors, in which it was shown 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 indicates their perceived deficiencies upon graduation. In an additional study, senior project students were asked to identify the problems they encountered during the execution of their projects. Figure 1 presents the problems

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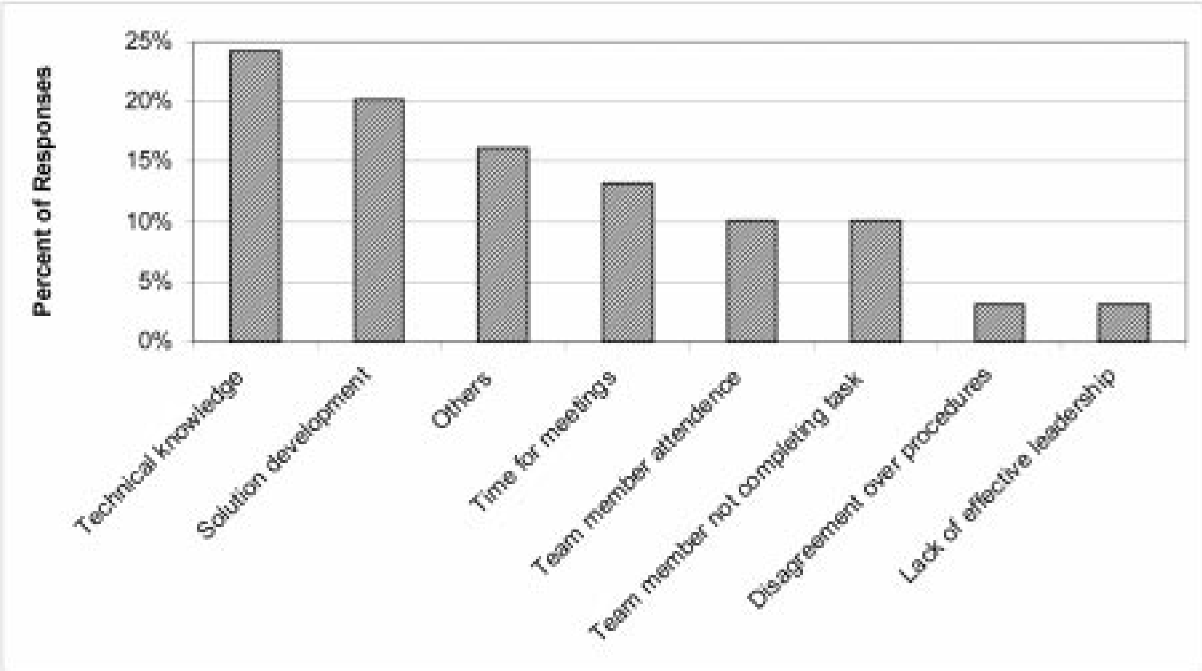

Fig. 1. Problems perceived by students in executing industry-based projects.

that students claimed they experienced in applying their technical education to the development of alternative solutions to 'messy' industry-based problems. The figure shows the percentage of total responses. Interviews were conducted with these students to determine the specific nature of their perceived technical problems. They indicated that they had difficulty in translating the situations that are found in an industrial setting to the language and concepts that they had learned in the classroom. This is in contrast to the commonly held view that teamwork problems are a major deficiency in engineering programs. Students can successfully solve homework problems, but have difficulty in applying that knowledge to practical situations. This is the motivation behind our desire to integrate a single case into the whole curriculum.

In addition to these self-perceived problems, the faculty find 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, [2] and are probably characteristic of many engineering graduates.

There has traditionally been a separation between knowing and doing in engineering education. Currently, in most curricula, only the capstone senior design project provides students with the experience of integrating knowledge learned in previous courses in order to formulate alternatives and solutions to a problem. Recent notable increases in cooperative education programs, industrial internships, design laboratories, and industry-based design problems are attempts to

Table 1. Graduating seniors' relative confidence in knowledge and skills, ranked from low to high (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	Functioning in a global environment	3.14
Probability and Statistics	3.14	Building teams	3.29
Teamwork	3.43		

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 cooperative 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 thereby alleviate the problems listed above.

Graduating students often express a lack of confidence in integrating knowledge gained in disparate courses regarding identifying problems and synthesizing solutions. Many programs include industry-based class projects as a solution to these issues. This approach has various drawbacks, including the difficulty of implementing such a project in a sizable number of the courses, the need for a significant commitment of class time, establishing contacts and ensuring that students have sufficient access to them to develop a model. The logical artifact for an Industrial and Manufacturing Engineering curriculum would be a real-world factory. However, students would not be able to apply any of their concepts to a real-world factory and see the effect of the changes made. Also, the logistical problems in providing sufficient student access to a factory would be daunting.

To achieve the advantages of a real-world factory environment for the students without the logistical and other disadvantages of using an actual factory, a partnership of Wichita State University, The Boeing Company (Wichita), Cessna Aircraft Company, Raytheon Aircraft Company, Brittain Machine, Thayer Aerospace, Delmia Inc., and the Kansas Technology Enterprise Corporation has received funding from the National Science Foundation through the Partnerships for Innovation Program. The grant is aimed at fostering innovation in aircraft manufacturing through the use of integrated virtual reality models. The assembly line for the strut torque box of the 767 aircraft has been chosen as the test case. Virtual models are created to study details of operations at the individual cells as well as the system and supply chain levels. These models will be used by our industrial partners to validate current processes and identify potential improvements.

This paper describes the detailed virtual factory models, developed by the Industrial and Manufacturing Engineering Department at Wichita State University, which are used by students to consolidate and integrate knowledge gained throughout the curriculum. The virtual factory provides a natural method of vertically integrating the Industrial and Manufacturing Engineering curricula, by way of appropriate case studies in a sequence of courses from the freshman year to the senior year and throughout graduate studies. The virtual factory model provides the real-world context for the concepts learned and helps students understand how disparate concepts learned in different classes can be combined for analysis and improvement of real-world systems. As students are required to tackle non-trivial real-world problems, their skills in problem formulation will improve. Students should also be more motivated, because they understand the contexts within which coursework can be applied. The virtual models serve as a framework for embedding and simulating cases, they can be accessed over the Internet, and they allow students to interact with and study the cases in great detail. Students can make changes to models of the real world represented in the virtual factory and examine their consequences. Such student experimentation is generally impossible in the real world.

OBJECTIVES

The overall objectives of this grant are to:

- encourage the use of integrated virtual reality models of manufacturing systems by our partners to design, improve, and operate these systems; and
- teach the workforce (new graduates as well as industrial personnel), using the same integrated virtual reality models, to understand the systems they work with, both at global and local levels, and to serve as intelligent initiators and partners for change.

This paper will focus on progress in the second objective of using the models to train, in particular, industrial and manufacturing engineering students. Therefore, the objective is to use virtual reality for project-based learning and case studies to supplement our department's attempts to address these competency gaps.

APPROACH

The pedagogical approach used in this project is a strategy called 'situated learning'. Situated learning is described in this section, along with how it is used with virtual reality to address competency gaps and how it is integrated into the curriculum.

Situated learning

Atman and Turns use 'concept maps' as a mechanism for allowing students to develop their own ways of integrating engineering knowledge and skills. They have shown that these maps become more complex as students progress through their education [3, 4]. They propose that the maps produce an 'external artifact' that may provide a means for students to integrate and thus recall and apply knowledge and skills acquired during the learning process. Some engineering disciplines have natural 'artifacts' (chemical engineering, aeronautical engineering, computer engineering, etc.) that can be the focus for organizing knowledge and skills. Industrial and manufacturing engineering have less tangible 'products' to use as organizing agents.

The 'external artifact' proposed in this project is a virtual factory. We propose a novel use of case studies, which is in contrast to what has been their typical function. A series of case studies derived from a single real-world 'mega-case' embedded in a set of integrated virtual reality models will be employed in courses within the Industrial and Manufacturing Engineering programs to integrate the curricula and make interrelations between the knowledge and skills gained in different courses that are available to students. We intend to integrate a significant portion of our engineering curricula through situated learning.

> In the situated learning approach, knowledge and skills are learned in the contexts that reflect how knowledge is obtained and applied in everyday situations. Situated cognition theory conceives of learning as a socio-cultural phenomenon rather than the action of an individual acquiring general information from a decontextualized body of knowledge . . . It should be noted that situated learning theory has not yet produced precise models or prescriptions for learning in classroom settings [5].

Situated learning places the learner at the center of the instructional process. It differs from other processes by: 1) content, emphasizing higher-order thinking processes; 2) context, placing the learner in the social, technological and political environment of application; 3) community, providing the setting for social interaction and dialogue; and 4) participation, requiring the engagement of others to develop meaningful systems.

In an effort to summarize the research relevant to the design of a situated learning experience, Jan Herrington and Ron Oliver [6] have reviewed and organized much of the research to date. They used these characteristics to design and assess a situated learning environment with computer-based multimedia components for the domain of 'mathematics education'. The 'students' were math educators. The researchers concluded that 'situated learning is an effective instructional paradigm for advanced knowledge'.

The virtual factory models, along with the embedded real-world data for the case, can be readily disseminated to other educators and institutions for them to incorporate them into existing curricula as they see fit. The models will be made available in the form of Virtual Reality Modeling Language (VRML) files. A browser and a plug-in, which can both be obtained at no cost, are the only

Table 2. Situated learning characteristics to be implemented

		Situated Learning Characteristics to be Implemented								
		Authentic Contexts	Authentic Activities	Expert Modeling	Multiple Perspectives	Collaborative Knowledge	Reflection	Articulation	Coaching & Scaffolding	Authentic Assessment
MfgE 258	Manufacturing Methods & Mat I	X	X			X			X	
MfgE 554	Manufacturing Tools	X	X	X	X				X	X
MfgE 558	Manufacturing Methods & Mat II	X	X	X	X					
MfgE 622	Computer Aided Design & Manufacturing	X	X	X	X	X			X	
IE 554	Stat Quality Control	X	X	X					X	
IE 755	Design of Experiments	X	X	X	X	X	X		X	X
IE 775	Computer Integrated Manufacturing	X	X	X	X	X	X			X
MfgE 502	Manufacturing Measurement & Analysis	X	X	X					X	
IE 452	Work Systems	X	X	X	X	X	X	X	X	X
IE 549	Industrial Ergonomics	X	X	X	X	X	X	X	X	
IE 950	Occupational Biomechanics	X	X	X	X	X				
IE 563	Facility Design & Layout	X	X	X	X	X	X	X	X	X
IE 780N	Supply Chain Management	X		X					X	
IE 780S	Lean Manufacturing	X	X	X		X	X	X		X
IE 880R	Enterprise Engineering	X	X	X	X	X	X	X	X	X
MfgE 545	Manufacturing Systems/IE 553	X	X	X		X	X			
IE 845	Quality Engineering	X	X	X	X	X	X	X	X	

requirements for viewing and interacting with the models. Table 2 presents our approach to implementing situated learning characteristics in each course.

Matching gaps to the curriculum

The Society of Manufacturing Engineers [7], through extensive surveys of industrial representatives, has identified competency gaps in many manufacturing engineering graduates. The competency gaps targeted by WSU include: project management, team working skills, business skills, manufacturing process control, manufacturing systems, quality, problem-solving, and product/process design. Other gaps identified include: written communication, supply chain management, oral communication/listening, international perspective, and materials. The primary goal of

Table 3. Courses and the 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 Statistical 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		

this project is to use virtual reality case studies to supplement our department's attempts to address these competency gaps.

The curriculum integration is explicitly geared to addressing the critical competency gaps identified by SME. Table 3 provides a plan for addressing the various competency gaps in courses. The competency gaps have been classified using Bloom's taxonomy [8] 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 for the targeted courses are presented in Table 4.

Virtual reality

If a picture is worth a thousand words, then an interactive 3D model is worth a thousand pictures [9]. 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 [10] to virtual models of entire factories [11].

Jones *et al.* [12] 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 [13] have developed a fully immersive virtual factory test bed for designers to test issues such as plant layout, clusters and part flow analysis. Many researchers [14–18] have discussed the use of large-scale simulations for studying the virtual behavior of factories.

Delmia Incorporated offers a suite of virtual manufacturing software, which allows the creation of virtual mock-ups of work cells and production

Table 4. Courses selected for integration with mega-case study

	Program	Enrollment	Model Scope	Static/Dynamic	Spring 2002	Fall 2002	Spring 2003	Fall 2003	Spring 2004	Fall 2004	Spring 2005
MfgE 258 Mfg Methods & Mat I	IE/Mfg E	20	O	D	VM	VM	VM	VM	VM	VM	VM
MfgE 545 / IE 553 Mfg Systems	IE/Mfg E	40	L	D	LW	HC	LW	HC	LW	HC	LW
IE 554 Statistical Quality Control	IE/Mfg E	35	O	S	GW		GW		GW		GW
IE 452 Work Systems	IE	20	W	S	DM		DM		DM		DM
IE 563 Facility Design & Layout	IE	25	L	D		KK		KK		KK	
IE 549 Industrial Ergonomics	IE	35	W	S			MJ	MJ			
MfgE 502 Mfg Measurement & Analysis	MfgE	15	O	S			HC		HC		
MfgE 558 Mfg Methods & Mat II	MfgE	15	O	D		VM		VM		VM	
MfgE 622 Computer Aided Des & Mfg	E/Gr	15	O	D		KK			KK		
IE 755 Design of Experiments	E/Gr	25	O	S			GW			GW	
IE 775 Computer Integrated Mfg.	E/Gr	15	L	D			KK			KK	
IE 780N Supply Chain Management	E/Gr	35	L	D					LW		
IE 780S Lean Manufacturing	E/Gr	30	L	D		LW			LW		
IE 845 Quality Engineering	Gr	30	L	S				GW			
IE 880R Enterprise Engineering	Gr	30	L	D	LW				LW		
IE 950 Occupational Biomechanics	Gr	15	W	D		MJ			MJ		

lines. These virtual mock-ups can engender substantial time and resource savings, as errors made in design can be discovered and rectified before practical operation begins. 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 work cells 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.

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. The center houses an immersive digital stereoscopic virtual reality system for 1:1 scale visualization by groups of people (up to 25 people). A variety of input/output devices allows natural interaction with virtual objects, as 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.

Integration into curricula

Specific case objectives for each course will be defined and required data will be collected for their implementation. Instructors will emphasize how the case material for their particular class relates to the production of the product and the Industrial and Manufacturing curricula. The real-world manufacturing case materials will be integrated into 16 courses in the Industrial Engineering and the Manufacturing Engineering curricula. Eight of these courses are required by one or both of these programs and eight are undergraduate electives or graduate-level courses.

The Virtual Reality modules are 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, it is implied that the model generates information or data that are used by students for off-line 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.

The remainder of this section describes details of implementation in a sample of courses. Some of the descriptions are plans for the courses, where VR modules have not yet been implemented, and the remaining descriptions outline the VR applications and the learning objectives. The assessment of the VR applications is presented in the assessment section.

Manufacturing Systems, MfgE 545 (3 credit-hour class). This course presents quantitative techniques used in the analysis and control of production systems. This includes forecasting, inventory models, operation planning and scheduling. In the spring of 2003, two different virtual reality modules were used. One module required the students to work in groups to determine how many parts to order. There were three different parts for which they were to determine the economic order quantity (EOQ). As shown in Fig. 2, the students observed the processing of a part to analyze the steps to separate them into setup steps and part cycle steps. The students then further separated the setups into external and internal setup. The students performed fairly well, and, when the instructor presented the 'solution', a very profitable discussion occurred and a much clearer understanding of what constituted a setup was understood by the entire class. The other module deals with how variability affects the design of a line as students note the process and arrival variability, utilization, and process times of the line and propose what to change and how to change it.

The order quantity assignment, for example, had two learning objectives: 1) determining the quantities required and explaining why the EOQ model is appropriate for each type of part (Bloom's taxonomy, level six), and 2) classifying the types of setups in an assembly environment (Bloom's taxonomy, level four).

Work Systems, IEN 452 (3 credit-hour class). Work Systems introduces students to graphical and quantitative tools for the documentation, measurement, and design of work systems. This includes work measurement systems, methods engineering, work sampling, predetermined time systems, and economic justification. Experiences with industry-based senior design projects indicate that students have difficulty in translating activities in a work setting into an abstraction or model that is accessible to analysis. In order to increase student skill and confidence in modeling a messy production process, an assignment was developed using a VRML model of approximately the first half of the strut torque box manufacturing line. This model, implemented in spring 2003, presented the development and integration of four subassemblies that used 11 workstations with a total of 46 operations and inspections. Students teams were asked to develop an 'as-is' operation process chart to document the process in a standardized

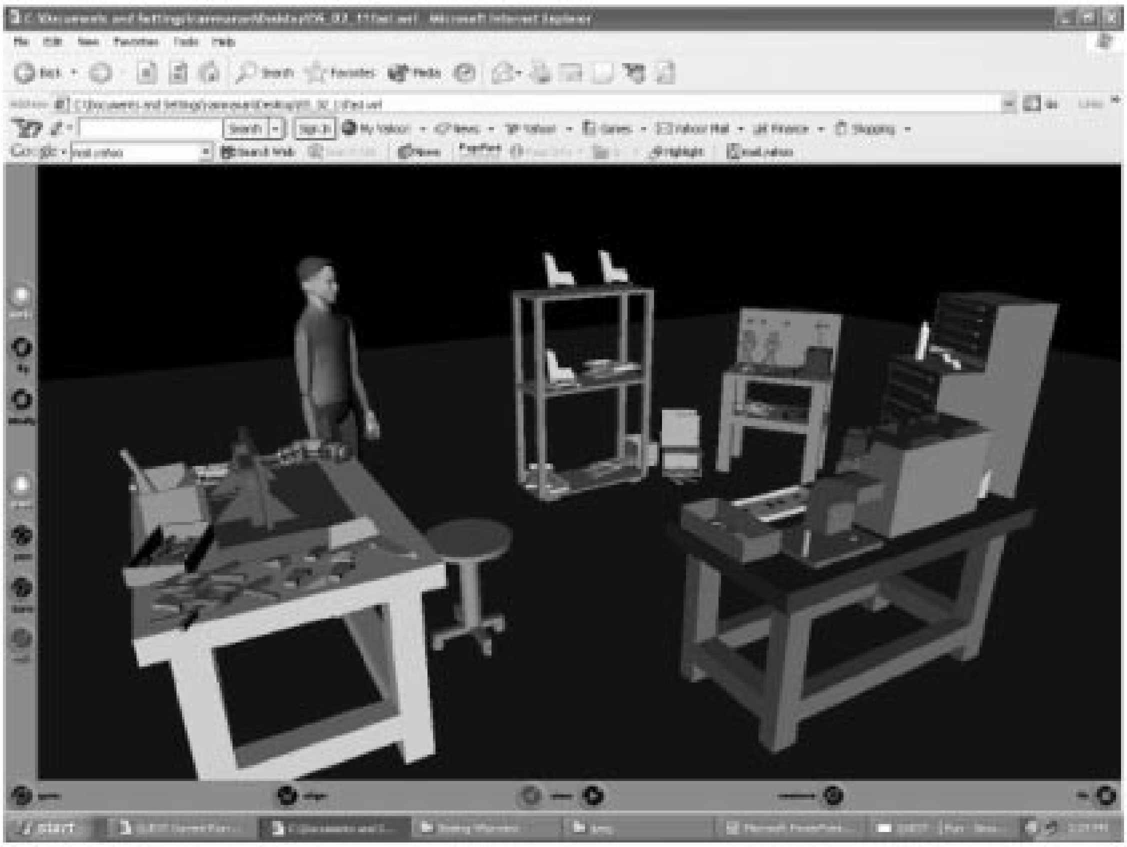

Fig. 2. Work cell in the VRML browser.

format. Each of the groups developed reasonable models of the process. The in-class discussion indicated that the students experienced problems in maintaining consistency in process and part identification and missing transportations and inspections. These are the same issues faced in an industrial setting, but the common experience of the assignment provided an opportunity for students to discuss strategies for improving the accuracy and usefulness of their operation process charts. A particularly useful discussion formed around the question of when it is better to start documenting a work system: at the entry or exit operations. Without the experience with the 'messy' production process presented in the VRML model, this discussion would not have had the same relevance.

Statistical Methods for Engineers, IEN 724 (3 credit-hour class). In this class, students study and model real-life engineering problems and draw reliable conclusions through application of probability theory and statistical techniques. The topics covered include both descriptive and inferential statistics, regression analysis and empirical modeling, as well as non-paramedic methods. Term projects are designed to integrate the concepts learned during the progress of the semester. This requires the use of case studies, which include a narrative description of the engineering problem and a set of relevant data. Students are asked to make recommendations and draw conclusions utilizing adequate models at specified confidence levels.

The skin drill model of the strut torque box was used as a midterm project during fall 2002. The model represents a workstation where two machinists perform drilling operations, as shown in Fig. 3. The data on drilling times are generated from two normal distributions with different means but essentially the same variance (unknown to the student). During the simulation, information regarding the drilling time and operating conditions appear in the VRML browser console window. Students were given a 15-minute in-class demonstration on how to download the model, run the simulation and use the text window. The model was posted on the class website, together with a problem statement. Students were asked to assess the statistical significance of the difference between the two averages. Instead of specifying the sample size, students were required to achieve a given level of accuracy.

The assignment had two learning objectives: 1) analyzing operational data using appropriate statistical techniques and identifying appropriate distribution models (Bloom's taxonomy, level four), and 2) assessing the impact of training on operator performance using inferential statistics at a specified level of confidence (Bloom's taxonomy, level six).

Lean Manufacturing, IEN 780S (3 credit-hour class). In this class, students learn lean concepts as

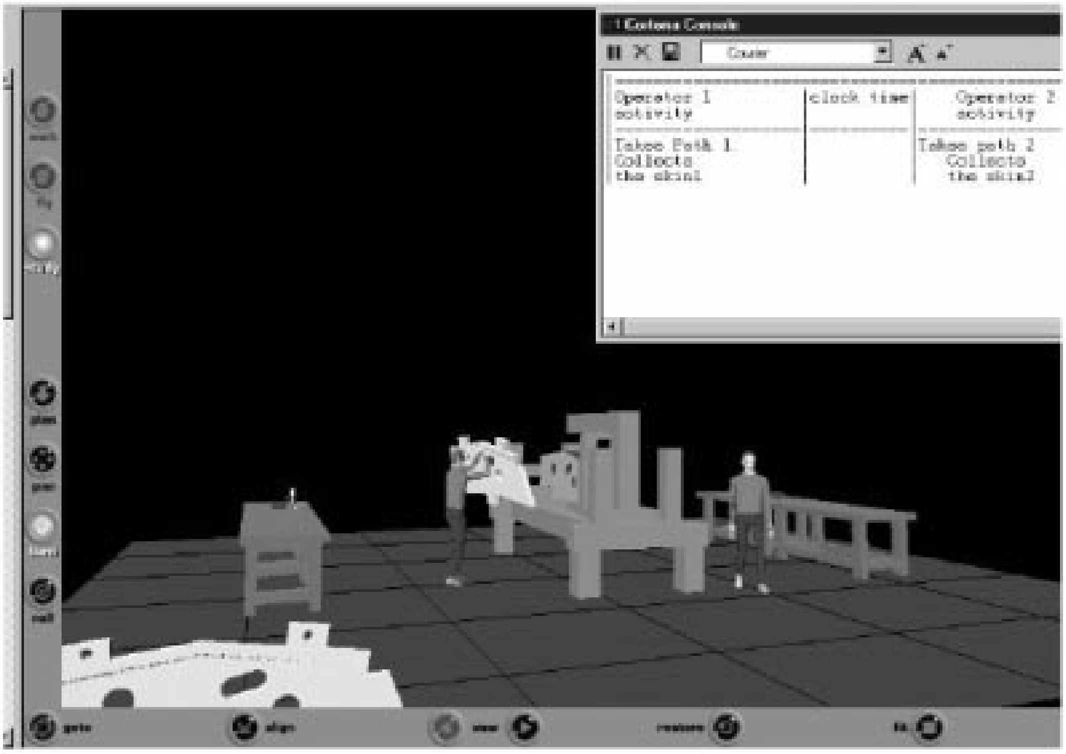

Fig. 3. Assembly activity with text console.

applied to the manufacturing environment. The course deals with the concepts of value, value stream, flow, pull, and perfection and includes waste identification, value stream mapping, visual controls, and lean metrics. In the spring of 2003, two different virtual reality modules were used. One module required the students to work in groups to apply the 5S method to a work cell (this work cell was the same one used for the Manufacturing Systems class). The worker operated in a 'messy' cell, with parts and tools placed randomly around the cell. The worker found some parts in drawers, some in cabinets, and some on the table. The other VR module used in this class was of the entire line. The line had many of the actual features of the Boeing line (flow and parts). However, the number of workstations was reduced and the process times were changed to allow inventory to build up in certain areas, as Boeing runs a 'timed move' line which minimizes inventory build-up. The line model is shown in Fig. 4. The students worked in teams to develop an as-is value stream map and then 'improved' the line and presented a 'to-be' value stream map.

The 5S assignment, for example, had two learning objectives: 1) classifying the activities in terms of the first three Ss (Bloom's taxonomy, level four), and 2) designing an improved work cell according to the 5Ss (Bloom's taxonomy, level five).

Enterprise Engineering, IEN 880I (3 credit-hour class). In this class, students learn how to design and improve all elements associated with the total enterprise through the use of engineering and analysis methods and tools to more effectively achieve its goals and objectives. The course deals with the analysis, design, implementation and operation of all elements associated with an enterprise and includes business process re-engineering, graphical enterprise modeling tools and architectures, and enterprise transformation. In the spring of 2002, the initial virtual reality module was used. The line was a very simple line that had no relation to the Boeing line but was rather intended as a first experience with VR. As a result of the small line, the model itself was rather small (approximately 4 Mb). The students were required to develop a process map of this line and performed well.

The learning objective of the process mapping assignment was to design an improved line, focusing on the functional interfaces (Bloom's taxonomy, level five).

Future course implementations

Facilities Planning and Design, IEN 563 (3 credit-hour class). This course presents quantitative and qualitative approaches to problems in facilities planning and design, emphasizing activity relationships, space requirements, materials handling and storage, and plant layout. Facilities planning is traditionally taught using two-dimensional planning boards, although facilities designed are three-dimensional in nature. The algorithms and methods utilized in teaching facilities planning design and material handling equipment selection are usually fairly verbose. Also, the steps involved in the calculation are usually time-consuming. Hence, the course is typically reduced to teaching algorithms rather than the analysis of the impact

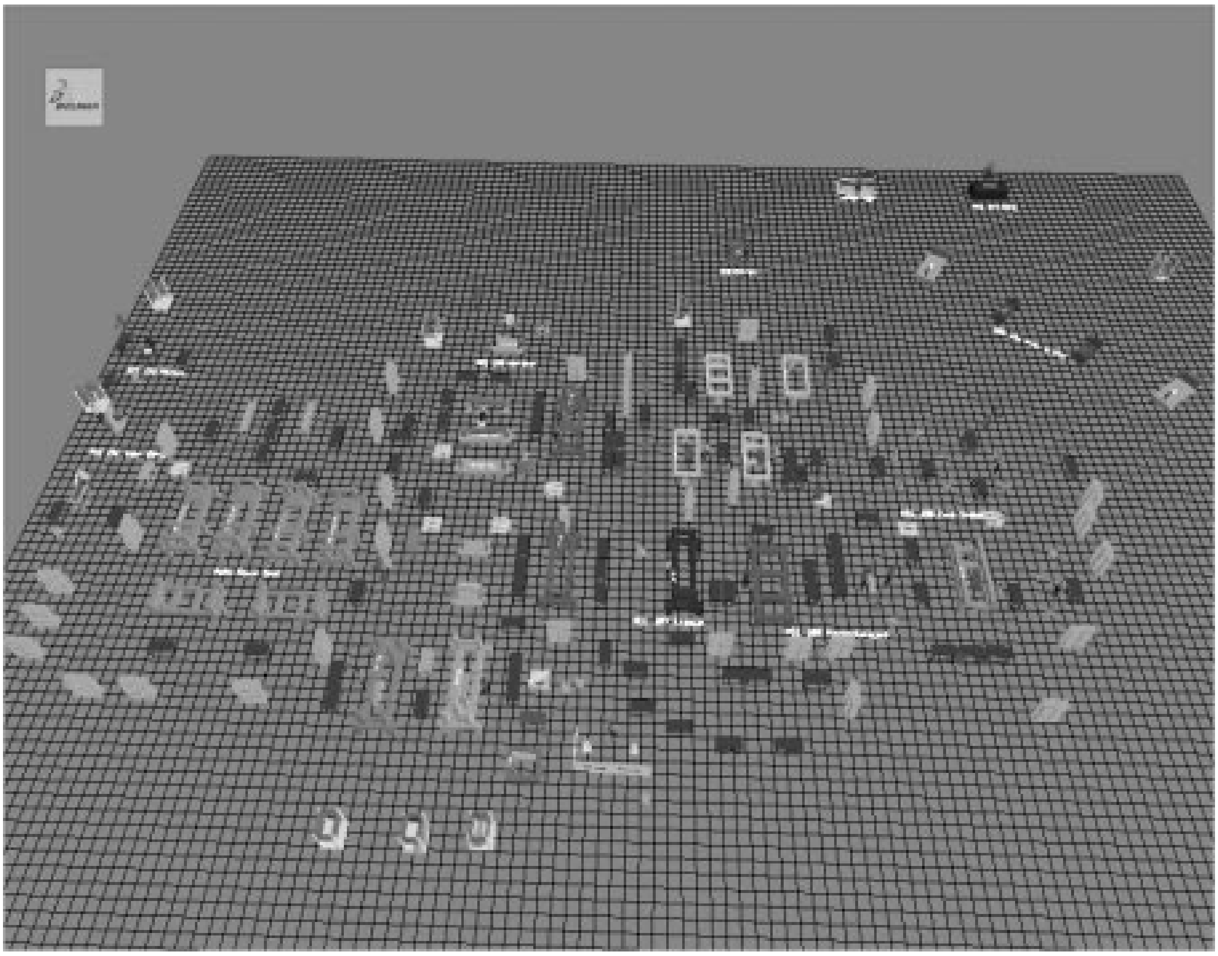

Fig. 4. Assembly line in VRML browser.

of the design and material handling equipment selected. The best teaching tools for facilities planning are three-dimensional software, as well as software implementations of algorithms, so that the course can spend more time on analysis than calculations. Although there is some software that provides three-dimensional modeling for purposes of teaching facilities planning, virtual reality may yet have the biggest impact.

In the integration of the 'mega-case' into the curriculum, the facilities planning modules are focused on the following: a) development of assembly charts, b) development of operations flow charts, c) development of operations process charts, and d) demonstration of yield factors and yield calculations in serial lines. This is being implemented in fall 2003.

Manufacturing Methods and Materials I, MfgE 258 (3 credit-hour class). In this introductory manufacturing methods and materials course, students gain a basic understanding of materials and processes that are used to manufacture products. Some of the major manufacturing processes covered in this course include: metal machining, metal forming, extrusion, casting, joining, and plastics forming. The course emphasizes the use of materials, sciences and mathematics to understand the behavior of materials undergoing the manufacturing process. This course includes an introduction to process planning. Students gain an

Table 5. Student questionnaire

1. Please rate the following statements on a scale of 1 to 5: (5 = strongly agree, 1 = strongly disagree)	1	2	3	4	5
I had no problem downloading and viewing the model.	○	○	○	○	○
The model created an interest in me to view it again.	○	○	○	○	○
The model was useful in defining the class assignment.	○	○	○	○	○
I would recommend the use of such models in future classes.	○	○	○	○	○
I was comfortable viewing the data on the Cortona console window.	○	○	○	○	○
I should have been given more training on viewing the model.	○	○	○	○	○

Table 6. Results from one class

Statement	Score				
	1	2	3	4	5
1	4	2	8	9	13
2	1	1	3	10	20
3	1	1	2	15	17
4	1	-	3	5	27
5	1	7	5	10	12
6	9	1	4	7	15

extensive hands-on experience in different manufacturing processes and in teamwork.

In this course, students view a video of the tasks at the fan cowl support beam assembly station and discuss the observed sequence of tasks. A case study that discusses the history of process improvements by changes in fasteners, which directly relates to the Boeing line, is presented in this class. The incorporation of case studies enhances the realism and provides open-ended problems for the students to tackle.

Manufacturing Tools, MfgE 554 (3 credit-hour class). This class introduces the principles behind the design and fabrication of machine tools and production tooling. The class discusses: tool materials; machine tool kinematics, accuracy, instrumentation, and control; and designing fixtures and jigs. It includes an introduction to design of inspection tools, machining and press working tools, and modular fixturing. VR will be used in this class, with a focus on the fan cowl support beam area concerning the tooling, assembly techniques, and developing possible improvements, using some examples of tooling changes from the data collected during the project to stimulate idea generation. The students will be required to use software such as IGRIP to analyze current operations and tooling and the proposed improvement. Another module will discuss the redesign of the floor assembly jig used for the mid-spar assembly to also serve as the tool for assembling the forward spar and the aft upper spar onto the mid spar. Issues to be considered include the need to load and unload parts, access for the drilling tasks and the effect of deflections and thermal variations on the accuracy of large structures. Competency gaps that will be addressed include specific manufacturing processes (assembly), and product/process (tool) design. Assessment will be through labs in which students analyze relevant elements of the cases.

ASSESSMENT

Assessment of this project is ongoing. In the first attempt to use VR in the enterprise engineering class, student ability to use and be comfortable with the virtual environment was assessed. Students were asked how comfortable they felt viewing a virtual environment and all 32 students rated the usability of the VR model as either 'no problem' or 'little difficulty'.

A subsequent assessment was performed on the second use of VR in a class using a different survey. The survey included six statements, as shown in Table 5, along with an open question for general comments. Students were asked to score each statement on a five-point Likert scale. A score of 5 indicates that the student strongly agrees, while a score of 1 indicates strong disagreement. Three of the statements target an assessment of the model and difficulties in downloading and running the simulation. The other three statements assess the effectiveness of the integration.

Table 6 summarizes results from 36 participating students. As shown, survey results have indicated a good response to the VR model and its ability to define the problem and reflect real-life scenarios. Most of the surveyed students recommended future use of such models for class assignments and projects. However, there were indications of concern regarding the file size (56 Mb) and the simulation speed. There were also difficulties in running the model from other computer laboratories than the department's laboratory.

Additional informal assessments demonstrate the value of a 'real-world' environment in which student weaknesses in content understanding are identified and can be addressed early in the course. In many areas, such as distinguishing between types of setups as mentioned earlier, it is perceived that students understand and can apply the concept when, in fact, they do not fully grasp it.

PROBLEMS

The two key problems with using VR in courses are presented in this section. The are: 1) student familiarity with VR, and 2) the model size. Regarding familiarity, students frequently find it difficult to 'browse' and move around in VR. The mouse is not an intuitive device for moving in three dimensions. Students frequently lose their orientation and have no idea where they are in the factory. This does not make VR a good substitute for real factory tours. To mitigate this problem, a combination of approaches is used. Some classes spend some time in class demonstrating how to use the VR browser and how to 'tour' to find the information needed for the assignment. In addition to this, web-based lectures on how to use a specific VRML browser (Cortona) have been developed and are available to the students.

The model size of the VRML files can be quite large (approaching 50 Mb). Although there are utilities to compress the file size for speed of downloading, the compression does not help the actual loading of the file. Our experience shows that a computer with a slower processor but with increased RAM is more efficient than a computer with a faster processor with less RAM. To this end, AVI files are also created for the students. The AVI files are typically not smaller (and are frequently even larger—some reach 100 Mb), but seem to load on to computers with a smaller memory. The AVI files also have the advantage of using software that is typically already loaded on to the computer.

CONCLUSIONS

Much student learning is related to motivation. The virtual factory is a unique experience which motivates students to use the technology. The purpose of the virtual factory is for students to reinforce content knowledge and to synthesize knowledge from multiple courses. Also, the use of the same case, the Boeing strut line, motivates students to view the curriculum as an integrated whole rather than as a separate set of courses.

In contrast to the traditional case study format, the VR model offers the benefits of:

- increased realization of the value of data and the resources utilized in the collection and analysis of data (Students had to visit the virtual shop floor to obtain the data.)
- recognizing the relationship between the amount of data available and the statistical accuracy of the estimates (In the traditional case study scenario, students are confined to the data given. The VR model allowed students to iterate a number of times to obtain a reliable estimate. This is typifies the nature of real-life engineering studies.)

The integrated virtual models and special modules developed for use in courses will be made available in the form of Virtual Reality Modeling Language (VRML) files. An internet browser and a plug-in such as Cortona by ParallelGraphics, both of which can be obtained at no cost, will be required for displaying the models and interacting with them. CD-ROMs containing virtual models of the case, along with embedded real-world data and examples of the use of the cases in courses, will be made available to interested educators and institutions.

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 lectures 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.

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