DELIVERING CONTINUOUS MANUFACTURING EDUCATION AND TRAINING VIA AN INTERNET-BASED DISTRIBUTED VIRTUAL LABORATORY

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Abstract *This research considers the application of a distributed virtual laboratory (DVL) to deliver continuous education and training in manufacturing-related disciplines via the global Internet. This presentation begins by reviewing motivations for the research. A pilot implementation of the DVL that employs a networked client-server approach using readily available information technologies is then described. An assessment case-study application of the DVL within the training center of a Pittsburgh-area industrial engineering consulting firm is considered. Results from this study suggest that implementations of the distributed virtual laboratory may be feasible alternatives to face-to-face continuous manufacturing education and training.*

Index Terms *continuous education, distributed virtual laboratory, World-Wide Web browser, Java applet.*

INTRODUCTION

The importance of frequent continuing education and training for individuals working in manufacturing-related industries was underscored in a wide-ranging report issued by the National Research Council's Committee to Study Information Technology and Manufacturing [1]. The Committee suggested that multimedia and virtual reality technologies used in conjunction with intelligent tutoring systems, distance learning systems, and experiential learning tools offer significant potential to deliver flexible interfaces for educational and skill-building programs. Development of the distributed virtual laboratory (DVL) described here attempted to address a limitation of contemporary distance and asynchronous learning systems by providing an interactive learning environment that accommodated the experiential learning style of individuals working in manufacturing-related industries. Further motivations for this research are considered in [2].

The distributed virtual laboratory makes use of Internet, World-Wide Web, and distributed information technologies to realize a media-rich interactive environment of sufficient fidelity for conducting experiential activities associated commonly with a physical laboratory. The pilot DVL implementation described here was made up of client Java applets that ran within a VRML-capable Web browser (for content presentation and three-dimensional scene rendering), and a Unix-based server that ran open-source database and Web server processes. Resources needed to implement the DVL are diagrammed in Figure 1.

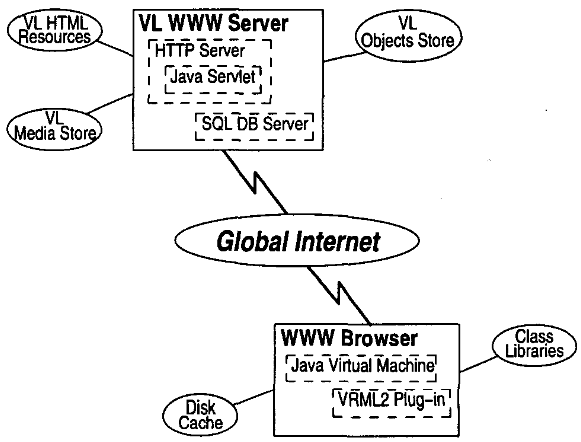

FIGURE 1
DISTRIBUTED VIRTUAL LABORATORY ARCHITECUTRE

The client-side of the distributed virtual laboratory consists of two separate, but integrated components. The first component implements a Web-Based Training (WBT) player as a Java applet. This WBT player is used to present text, image, and other media objects arranged on pages that are organized in a course, module, and lesson hierarchy. Content and organization for material presented by the WBT player is maintained in the remote server's SQL database. A collection of question objects (*e.g.*, short-answer and multiple choice) can be embedded in pages to establish varying levels of interactivity within lessons. Responses to

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question items are recorded at run-time in the remote database. The WBT player applet running within the Netscape Communicator browser on a Microsoft Windows personal computer is illustrated in Figure 2.

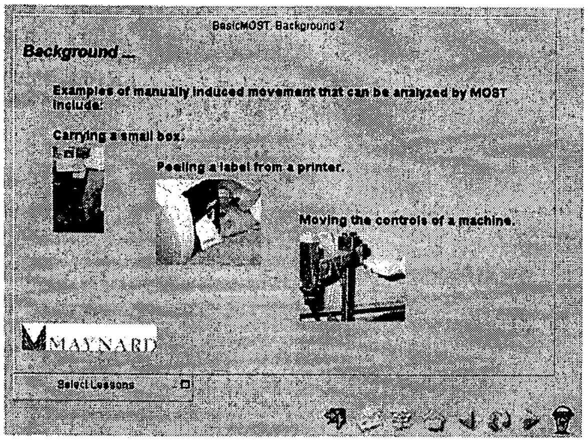

FIGURE 2
JAVA APPLET WBT PLAYER

Interactive Virtual Laboratory

The *interactive virtual laboratory* (IVL) component of the DVL is accessed from the WBT player applet by way of a hyperlink button control embedded in a lesson page, represented typically as a bit-mapped image (Figure 3).

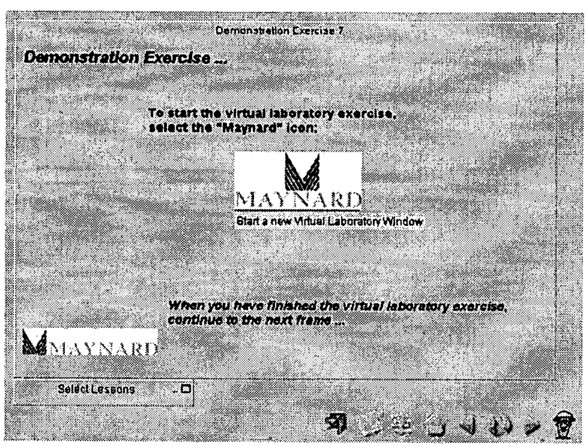

FIGURE 3
WBT PLAYER HYPERLINK BUTTON INTERFACE

Selecting this control object causes a new browser window to open, in which the IVL is realized. This new window, illustrated in Figure 4, contains an initially empty embedded Virtual Reality Modeling Language (VRML) scene, a Java applet that controls the activities within the scene (*e.g.*, scene creation, object behaviors, and task recording), and an HTML control for closing the window when the exercise is completed. The HTML and VRML directives for this page are generated dynamically by a Java servlet process running on the remote DVL server from information contained in the DVL's database.

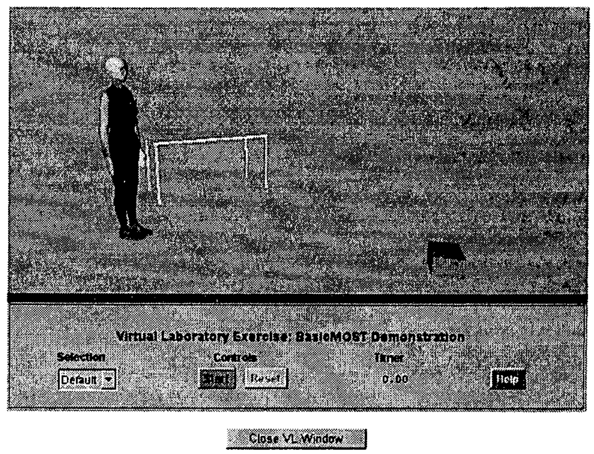

FIGURE 4
IVL CONTROLS AND INITIAL SCENE

The VRML scene illustrated in Figure 4 was built by the IVL's Java applet from objects described in the remote SQL database using the External Authoring Interface (EAI) [3]. Previous reports of VRML-based simulations for manufacturing, *e.g.*, [4], used static, hard-coded approaches to scene description.

An actor object consisting of segments and joints derived from the proposed H-Anim standard [5] is defined in the IVL; data for the actor object depicted in Figure 4 are based on Ballreich's *Nancy* [6]. A set of scripted behaviors based on the general move sequence of BasicMOST [7] is also defined within the actor object. These behaviors are summarized below.

BEND	From full-standing position; no input parameters.
PLACE	Input parameters: *dwell time*, *waist bend angle*, *shoulder angle*, and *elbow angle*.
REACH	Input parameters: *side* (left, right, or both), *dwell*, *shoulder angle*, *elbow angle*, *waist angle*, *twist angle*, *wrist bend angle*, and *wrist twist angle*.
RISE	From full-bend to full-standing positions. Input parameters: *shoulder angle*, and *elbow angle*.
WALK	Input parameters: *lead side* (left or right), *direction*, *steps*.

Lookup tables of actor object root node translations and joint angles were used to implement the *walk,bend* , and *rise* actions. The actor object performing *ar each* following a *bend* during a running scene is illustrated in Figure 5; a *place* action is depicted in Figures 6 and 7.

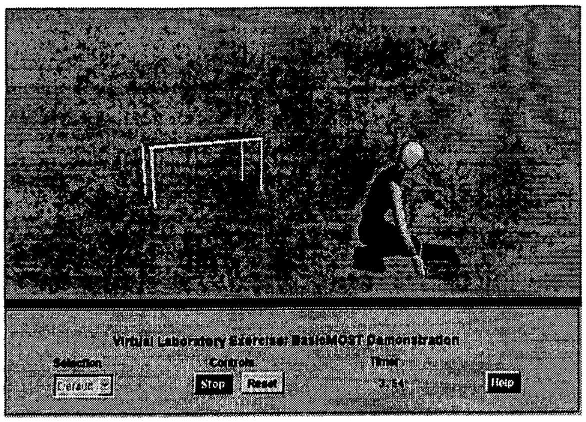

FIGURE 5
IVL RUNNING SCENE

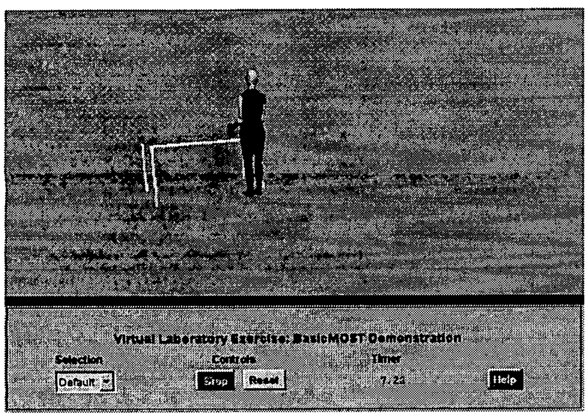

FIGURE 6
IVL FINAL SCENE

Movement of the IVL scene's viewpoint is available through additional controls found within the VRML plugin application. The initial scene calls for the plugin application's own control panel to be minimized. Appropriate manipulation of the scene navigation controls when the panel is made visible allows for alternate views of the running scene. Figure 7 illustrates an alternate view of the scene presented in Figure 6. Additional details regarding the DVL's implementation are described in [8].

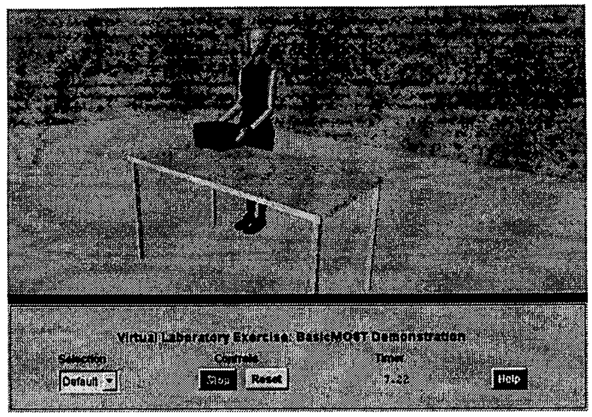

FIGURE 7
IVL FINAL SCENE ALTERNATE VIEW

ASSESSMENT STUDY

An assessment of this pilot distributed virtual laboratory was conducted in a case-study application at the training center of H. B. Maynard and Company, a Pittsburgh-area Industrial Engineering consulting firm. The DVL was used to present a twenty-minute segment within the week-long *Fundamentals of Work Measurement* course to a randomly selected group of subjects participating in the assessment study. The instructional content presented by the DVL was contained in three lessons, the first of which briefly described the use of the WBT player. The second lesson provided the bulk of the presentation using static text and bit-mapped images. Frequent "self-check" review questions were interspersed within this presentation. The last lesson presented a demonstration of the application of the BasicMOST General Move sequence using the DVL's interactive virtual laboratory component (Figures 4-6). The demonstration was followed by concluding material and a final self-check question by way of the WBT player.

Pre- and post-treatment surveys were used to collect various information on the first day of the course. The pre-test survey instrument, administered to all subjects prior to the start of the first morning session, contained two sections:

- An eleven-item multiple choice examination of subjects' knowledge of the case-study topic (in this instance, BasicMOST). An algorithm was applied to scores from this section to assign subjects randomly to DVL and non-DVL groups so that differences in mean and variance between the two groups were minimized (including all prior valid sessions).
- Reports of prior experience with related instructional delivery technologies (desktop personal computers running Microsoft Windows, graphical World-Wide Web browsers, self-paced computer-based training, and

on-line training systems) and the case-study topic (predetermined motion time systems and BasicMOST) using the categories *none* (never seen or used it before), *acquainted* (aware of, seen it in use, have not applied it), *occasional* (studied it, apply it occasionally), *user* (use it on a daily basis, apply it regularly), and *expert* (thorough understanding, recognized by peers).

The post-test survey was administered to both DVL and non-DVL groups immediately following the morning session. It consisted of four sections:

- A twenty-eight item experiential learning styles inventory [9].
- A re-examination of subjects' knowledge of the case-study topic.
- Eleven quality items related to both the DVL and instructor's presentations following Evans [10]; these items are presented in Figure 8. Responses to items in this section were rated according to the five-point Likert scale [11] *strongly disagree* (-2), *disagree* (-1) *neutral/undecided* (0), *agree* (1), and *strongly agree* (2). Note that item Q01 in Figure 8 was a reflected item. Two additional items in this section elicit open-ended written responses (comments and/or suggestions) to the two presentation methods.
- A record of subjects' demographic information (*e.g.*, highest degree completed and field of study, current industry and job title, and age range).

Q01	The virtual laboratory detracted from my understanding of the material.
Q02	I was satisfied with the instructor's presentation.
Q03	The virtual laboratory software was easy to use.
Q04	I found the virtual laboratory's self-check questions to be useful.
Q05	The virtual laboratory's interactive demonstration helped me better understand the material.
Q06	The instructor's responses to questions were useful to me.
Q07	The virtual laboratory is an appropriate delivery tool for this topic.
Q08	I was satisfied with the virtual laboratory's presentation.
Q09	The pacing of the instructor's presentation was appropriate for my needs.
Q10	I was satisfied with the virtual laboratory's interactive demonstration.
Q11	I found the instructor's demonstration of the General Move Sequence to be effective.

FIGURE 8
ASSESSMENT STUDY POST-TEST QUALITY ITEMS

The scope of the assessment study was limited by the total time made available to it by Maynard's Training Center, and a requirement that no subjects were permitted to be removed from any of the instructor's face-to-face presentations. To accommodate these conditions, the assessment study's research protocol made use of a quasi-experimental design [12], in which the DVL was presented during an extended mid-morning break, directly after which the instructor's presentation of the equivalent material was made to the entire group. The post-test measurement immediately followed the instructor's presentation.

RESULTS AND DISCUSSION

The assessment data presented here was collected during six *Fundamentals of Work Measurement* sessions conducted from mid-November 2000 through mid-February 2001. A total of 50 clients enrolled in the week-long course agreed to participate voluntarily in the study. Two subjects did not finish the study due to incomplete post-test surveys; data from these subjects are not included in these results. A summary of study subjects' demographics are reported in Table I. Reports of *other* in Table I include categories with two and fewer responses; *unknown* records categories that were not specified by subjects.

TABLE I
DEMOGRAPHIC FREQUENCIES, ALL GROUPS

Highest Education		**Field**		**Industry**		**Job Title**	
High Sch.	6	*Industrial*	9	*Mfg*	33	*Engineer*	21
Associate	3	*Mfg*	8	*Retail*	6	*Analyst*	6
Bachelor	29	*Business*	7	*Logistics*	3	*Supervisor*	4
Master	6	*Mechanical*	4	*other*	2	*other*	13
unknown	4	*other*	9	*unknown*	4	*unknown*	4
		unknown	11				

As suggested by Table I, subjects in this sample represented well the primary audience for instructional delivery systems that facilitate experiential learning, typical of the virtual laboratory described here (*i.e.*, professionals with four-year engineering degrees working in manufacturing-related industries). Reports of subjects' prior experiences, summarized in Table II, suggest that they have had little experience with asynchronous and distance learning environments, but were comfortable with standard desktop personal computer applications (*e.g.*, graphical World-Wide Web browser programs).

TABLE II
PRIOR EXPERIENCES WITH DELIVERY TECHNOLOGIES, ALL GROUPS

	Windows PCs	**WWW Browsers**	**Self-Paced CBT**	**WBT**
None	—	1	7	16
Acquainted	3	1	14	15
Occasional	2	8	16	10
User	30	29	8	5
Expert	11	7	1	—

The experiential learning styles inventory considered in the post-test measured subjects' emphasis on each of the four dimensions of Kolb's Experiential Learning Model [13]. The ranked scale dimension scores for all groups are summarized in Table III.

TABLE III
EXPERIENTIAL LEARNING MODEL DIMENSION SCORES, ALL GROUPS

Dimension	α	$\bar{x}$	s	98.8% C.I.
Active Experimentation	.91	4.22	.68	3.96,4.47
Abstract Conceptualization	.86	4.07	.58	3.86,4.29
Reflective Observation	.83	3.63	.73	3.36,3.90
Concrete Experiencing	.83	2.95	.79	2.65,3.24

Dimension scale scores summarized in Table II were determined by calculating the average of all items related to the respective dimension. The dimension scale scores reported here may be considered internally reliable for this sample since Cronbach's split-half reliability coefficient (α) for each of the four dimensions was greater than 0.80 [14]. Previous characterizations of individuals working in manufacturing-related industries suggest that learning style emphases of *active experimentation* over *reflective observation* and *abstract conceptualization* over *concrete experiencing* are to be expected in such groups [15]. The scale scores observed in this sample agree with these previous characterizations.

Gain scores across pre- and post-tests of content knowledge are summarized in Table IV. In two of the six sessions, the research protocol was not achieved when the instructor of the course did not allow for the presentation of the appropriate material to the entire group directly following the DVL's presentation to the that group. This material was presented to the entire group at some point following the post-test in these two cases. These sessions are denoted as *non-protocol* sessions in subsequent references.

TABLE IV
PRE-, POST-, AND GAIN SCORES

Protocol Sessions		Pre-Test		Post-Test		Gain	
Group	n	$\bar{x}$	s	$\bar{x}$	s	$\bar{x}$	s
Non-DVL	14	7.29	1.82	9.50	1.09	2.21	1.97
DVL	15	7.13	2.00	9.87	1.46	2.73	1.75
Non-Protocol Sessions							
Non-DVL	8	6.88	2.70	6.88	2.03	0	1.31
DVL	9	6.89	2.26	10.22	1.09	3.33	1.80

The nonparametric Wilcoxon Rank Sum Test was applied to the *protocol* session data to test for a significant effect of the DVL session on test gain scores. The test failed to reject the null hypothesis (*i.e.*, no significant effect observed) at $\alpha = 0.10$ with a one-sided probability of 0.2505. The analysis of covariance (ANCOVA) procedure was considered here, but was found to be unsuitable with the present sample due to a violation of the procedure's requirement for normality of residuals in the underlying linear models.

While a statistically significant increase in gain scores due to the DVL's presentation was not observed in the study, evidence that the DVL was received favorably was noted in the quality assessments made in the post-test survey. Summaries of quality items from both DVL and non-DVL groups are reported in Table V. Bonferroni adjustments were made to the mean confidence intervals reported in Table V to account for simultaneous comparisons within families of items (Q01, Q04, and Q08; Q02, Q06, Q09, and Q11; Q03 and Q07; Q05 and Q10). A family level of significance of 0.10 was used to compute the adjusted mean confidence intervals in this assessment.

TABLE V
QUALITY- ITEM SUMMARY

	DVL				Non-DVL			
Item	n	$\bar{x}$	s	μ C.I.	n	$\bar{x}$	s	μ C.I.
Q01	26	1.19	.80	.84,1.55				
Q02	26	1.15	.65	.93,1.54	14	1.21	.58	.82,1.61
Q03	26	.92	.74	.62,1.22				
Q04	26	1.54	.58	***1.28,1.80***				
Q05	25	.80	1.00	.39,1.21				
Q06	26	1.23	.65	.93,1.54	14	1.29	.73	.79,1.78
Q07	26	.62	.98	.22,1.01				
Q08	26	.96	.53	.73,1.19				
Q09	26	1.08	.63	.78,1.37	13	1.15	.80	.59,1.72
Q10	25	.76	.83	.42,1.10				
Q11	26	1.31	.68	.99,1.63	14	1.07	.92	.45,1.69

Confidence intervals falling completely above zero (0) in Table V offered support to the claim that the sample agrees, on average, with each item's statement. Inferences on the strength of the average agreement to an item may be made from inspections of the item's mean confidence interval. In the case of item Q04 (helpfulness of the DVL's self-check questions), Table V, where the mean confidence interval fell entirely above one (1), strong agreement by the sample was observed. Support for this finding was offered by written comments submitted by subjects from the DVL group; these written remarks are considered next.

Twenty-one subjects from the DVL group offered written comments and suggestions regarding the DVL's presentation. Comment categories occuring two or more times are summarized in Table VI; these counts include multiple observations from subjects.

TABLE VI
WRITEN- COMMENT CATEGORIES, DVL GROUPS

Comment Category	*n*
IVL simulation speed	10
General positive experience	7
WBT navigation controls	4
More IVL examples	2
DVL self-check questions useful	2
Simplify WBT page navigation	2

While these written comments were mostly supportive of the DVL, remarks from ten subjects identified the need for a more realistic interactive virtual laboratory demonstration. These subjects noted that the IVL simulation ran too slowly for it to be useful. Examination of the usage metrics recorded by the IVL, which included *trials per task* and *time per trial*, offered support for these observations. All but one subject participating in the DVL group used (and completed) the IVL demonstration task at least one time. Several subjects started a second trial, but did not complete it. A mean time of 88.7 seconds (with standard deviation of 23.2 seconds) was observed for the first trial of a task that, in "real-time", can be completed in less than 8 seconds. Available VRML methods of implementing dynamic object motion within the IVL component, in particular, the human actor, were inadequate for portraying realistic (*i.e.*, operating in normal time) simulati ons.

CONCLUSION

This paper considered an assessment case-study of a pilot Internet-based distributed virtual laboratory to facilitate experiential learning in continuous manufacturing training and education settings. Results from the study presented here suggest that subjects using the distributed virtual laboratory (1) were satisfied with its presentation and level of interactivity, and (2) consider it an appropriate delivery tool for the case-study topic. The marginal performance of the personal computer client in rendering motion, particularly of the human actor, during the DVL's interactive demonstration suggests that significant improvements in perceived quality may be achieved as the next generation of World-Wide Web clients become available on ever higher performance personal computers.

Future work directly related to this research include the development of lighter client-side applets that take advantage of maturing multimedia extensions to the Java language (*e.g.*, Java 3D), and the development of authoring tools for scene generation and task specification, and object and behavior creation. As the level of available scene and task complexity increases, the addition of multiuser and collaborative task specification can be considered.

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