Assessment of the Pedagogical Value of an Innovative E-Learning Environment That Uses Virtual Reality

Eugenia Fernandez, IUPU-Indianapolis
Jamie Workman-Germann, IUPU-Indianapolis
Hazim A. El-Mounaryi, IUPU-Indianapolis
Chirag Padalia, IUPU-Indianapolis

Abstract

The pedagogical value of an innovative e-learning tool, the Advanced Virtual Manufacturing Laboratory (AVML), is assessed by determining its effectiveness in student learning. The AVML is a collaborative web-based e-learning environment for integrated lecture and lab delivery which focuses on advanced machining using Computer Numerically Controlled (CNC) machine tools. Student learning using the AVML, which provides educational content for theory (lecture) and specific machine tool applications (laboratory) related to CNC machining, is evaluated using a quasi-experimental randomized study.

Students in two engineering-related courses at a large Midwestern university – one a graduate course in CAD/CAM Theory and Applications, the other an undergraduate course in Manufacturing Processes – served as subjects for the study. Both lecture and lab course content was taught using three teaching methods: traditional classroom, virtual using the AVML, and both. Various tasks encompassing lecture material (such as NC Programming and CNC Machining) and laboratory material (such as CNC operational procedures) were devised for students to be trained and evaluated on. Student learning was evaluated after each segment in both classroom and laboratory environments.

Analysis of variance was used to compare performance on both the lecture and lab tasks across teaching methods. A repeated-measures factorial ANOVA was conducted comparing student scores based on course component (lecture vs. lab) and teaching method (classroom, virtual or both). Significant main effects were found for course component and teaching method. Students performed better on the lecture component than the lab component and when both the AVML and classroom teaching were used) than either classroom or the AVML alone.

The results show that the AVML is an adequate alternative to classroom learning, but that hybrid learning (traditional classroom training combined with AVML based e-learning) provides the best learning outcomes. As such, it was concluded that the AVML does enhance student learning.

Key Words

Education Methods, Engineering Curricula, Engineering Technology Curricula, Innovative Teaching Methods, Outcomes Assessment, Technology in the Classroom

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Eugenia Fernandez
Associate Professor of Computer & Information Technology, Indiana University
Purdue University Indianapolis, Indiana, 46202, efernand@iupui.edu

Jamie Workman- Germann
Associate Professor of Mechanical Engineering Technology, Indiana University
Purdue University Indianapolis, Indiana, 46202, jkworkma@iupui.edu

Hazim A. El-Mounayri
Associate Professor of Mechanical Engineering, Indiana University Purdue
University Indianapolis, Indiana, 46202, helmouna@iupui.edu

and

Chirag Padalia
Mechanical Engineering Student, Indiana University Purdue University
Indianapolis, Indiana, 46202, chpadali@iupui.edu

I. Introduction

E-learning can be defined as course content or learning experiences delivered electronically over the Internet[1]. Such tools offer significant advantages by allowing 24x7 access to educational materials as well as enabling self-paced learning. The majority of electronic learning applications consist of html pages with embedded pictures, movies, and/or Macromedia Flash™ content.

Many e-learning systems currently exist. One example is the Advanced Learning Environment (ALE)[2], a virtual learning portal for online education developed at the Florida Space Research Institute. ALE offers self-paced, web classes in a variety of general science and aerospace education topics. It supports synchronous web classes, collaboration tools, and community discussions, and includes a speech capability using pre-recorded speech. Another system, ANDES, is used by the University of Southern California (USC) for management and delivery of web courses and has a special authoring language, called ATML, to generate Web-based courseware[3].

Most web-based course delivery systems are based on the student reading the course material and looking at static or animated illustrations. Some course delivery systems, like the ALE system, present the material using pre-recorded speech with Flash animations and movies. Newer systems, like the Advanced Virtual Manufacturing Laboratory (AVML)[4], are beginning to incorporate virtual reality elements into e-learning. The AVML is a collaborative web-based e-learning environment for integrated lecture and lab delivery which focuses on advanced machining using Computer Numerically Controlled (CNC) machine tools. The AMVL seamlessly and synergistically integrates multimedia lecture, interactive 3D simulation, and realistic experimentation in a virtual reality environment. The learning experience is further enhanced by the use of intelligent virtual tutors and lab instructors, who teach, guide, supervise, and test the students, answer their questions, monitor their performance, and provide them with feedback.

Since the first development of alternatives to classroom-based teaching, beginning with correspondence courses, student learning using the alternatives has been questioned. According to a report by Russell[5], numerous studies have shown there to be no significant difference in learning between face-to-face and distance delivery, of any type. Other studies[6,7,8] have found similar results, even when student learning styles were considered. These studies, however, do not negate the need to validate the content of any e-learning system. This paper details the results of a quasi-experiment conducted to evaluate the content validity of the AVML by studying student learning via the Advanced Virtual Manufacturing Laboratory.

II. The AVML

The AVML is built around two engines, LEA™ and IVRESS™. LEA (Learning Environment Agent) provides a platform for lecture delivery. The lecture is presented by a speaking virtual instructor and involves high end multimedia using Flash and movies for real-life illustrations, 2D/3D interactive simulation, and different types of practice questions. The lecture material is delivered in different formats to address the needs of different types of learners (visual, auditory, and kinesthetic). IVRESS (Integrated Virtual Reality Environment for Synthesis and Simulation) allows for the creation of a virtual lab with near-realistic, fully functional, and interactive CNC machine tools.

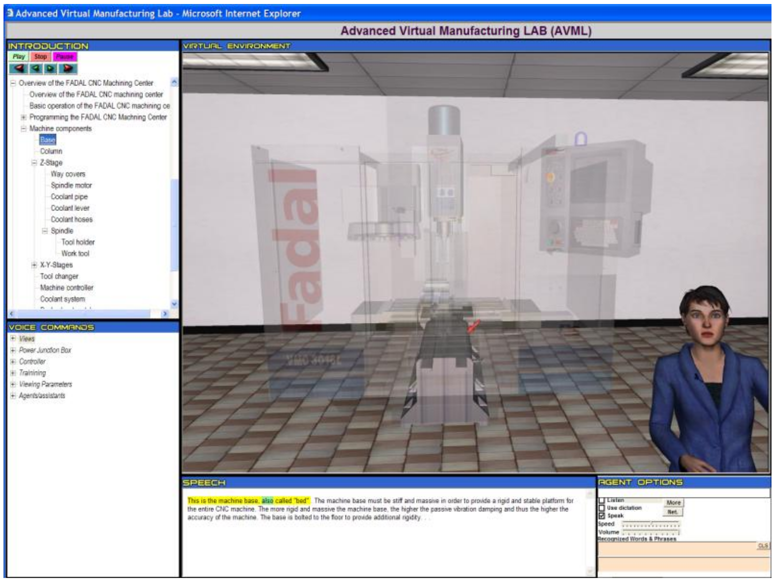
2.1 LEA (Learning Environment Agent)

LEA is an intelligent-agent engine which includes facilities for speech recognition and synthesis, a rule-based expert system natural-language interface (NLI) for recognizing the user's natural-language commands[9], a hierarchical process knowledge base engine[10], and an unstructured knowledge base engine. LEA is the engine behind the AVML's web-based framework. It is encapsulated in an ActiveX control which can run in a web-page and can display various user defined, sizable and movable mini-web browsers sub-windows (that can display any web content such as HTML, Flash, etc.)

Two introductory lecture modules were developed using LEA: CNC milling and the FADAL CNC machine. Snapshots of the two modules are shown in Figures 1 and 2.

A three axis machining center has programmable x and y axes in the plane of the table and a z axis in the spindle's direction . This is the most basic type of machining center, and they start at about 30,000 dollars . Three axes machines can machine one surface of a cube with the end of the cutter and four additional surfaces with the side of the cutter . Typically, three axis machines are in the vertical configuration shown here . Please note that the tool changer, control, and enclosure are not shown in the schematic drawing . . .

Figure 1. Snapshot of the introductory lecture on CNC milling.



This is the machine base, also called "bed". The machine base must be stiff and massive in order to provide a rigid and stable platform for the entire CNC machine. The more rigid and massive the machine base, the higher the passive vibration damping and thus the higher the accuracy of the machine. The base is bolted to the floor to provide additional rigidity. . .

☐ Listen
☐ Use dictation
☑ Speak

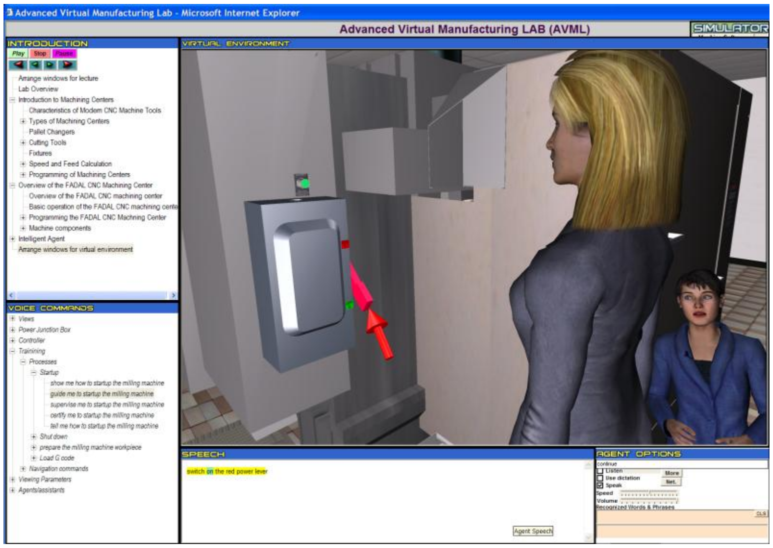
Figure 2. Snapshot of the introductory lecture on CNC machine components.

2.2 IVRESS (Integrated Virtual Reality Environment for Synthesis and Simulation)

The manufacturing lab component consists of fully functional virtual CNC machines which were developed using IVRESS™ commercial software. IVRESS[11] is an object-oriented scene-graph-based virtual-reality display engine. The resulting environment involves three main elements: a simulator for a CNC milling machine and a CNC lathe, a virtual-environment display engine, and an intelligent-agent engine. The virtual environment provides training on different operating procedures. An intelligent virtual tutor, with the help of a virtual lab assistant, provides training in different modes. Operating procedures are enhanced with the use of movies showing real-life illustration. Figure 3 shows a fully functional CNC Vertical machining center that was modeled.

Figure 3. Vertical CNC milling machine in the virtual environment

Four CNC milling machine training processes were developed with IVRESS: 1) machine start-up; 2) machine shut-down, 3) load G-code from disk, and 4) running an existing G-code. Figure 4 shows a snapshot of a training step in the machine start-up process.



switch on the red power lever

Figure 4. Snapshot taken of step 2 of the machine start-up procedure

III. Assessment of the AMVL

3.1 Research Design

As part of the process to validate the content of the AVML as an effective tool for educating students and workforce in Advanced Manufacturing, a quasi-experimental post-test only study was conducted. Use of the AVML, which provides educational content for theory (lecture) and specific machine tool applications (laboratory) related to CNC machining, was tested in two courses during the fall semester of 2007 in the School of Engineering and Technology at IUPUI. The two courses chosen for this study were a graduate course in Mechanical Engineering on “CAD/CAM Theory and Applications” (ME 456) and an undergraduate course in Mechanical Engineering Technology on “Manufacturing Processes II (MET 242). ME 546 is a graduate course, also taken by undergraduates as an elective, introducing the basic principles and tools of CAD/CAM. MET 242 is a sophomore level technology course focused on the capabilities, selection, and applications of material removal processes including both manual and CNC machine tools. Students in these two courses served as subjects for the study, forming a convenience sample. Institutional Review Board approval was obtained for the study.

Both lecture modules and lab training modules were assessed. Lecture materials and training on the use of the CNC machine were provided using three teaching methods (the treatments) throughout each course: traditional classroom training, virtual training using the AVML, and both, resulting in 6 measurements (see Table 1). This framework was designed so that the effectiveness of the AVML can be compared to traditional classroom training, evaluated as a stand-alone tool, and as a supplement to traditional classroom training for both lecture and laboratory components.

Table 1. Research Design

	Treatment		
Component	Classroom Training	AVML	Both
Lecture	Task 1	Task 2	Task 3
Lab	Task 4	Task 5	Task 6

After each task, student learning was evaluated. The lecture modules in ME 546 covered basic NC Programming, safety measures in a machining lab, and CNC machining including a lecture video from the Society of Manufacturing Engineers pertaining to CNC machining. The students were then assessed on these modules via a quiz. For the MET 242 class, the lectures modules included NC Control Systems, NC Programming, and a lecture on CNC Machining. The students in this class were assessed via a section of questions in a scheduled test and a written lab project.

The laboratory modules for ME 546 included a live demonstration of CNC System, downloading NC Code and running a machining operation in the AVML, and the basic CNC operational procedures. Due to lack of time, the students were not assessed on the last two modules. A quiz was used to assess the first laboratory module. For the MET 242 class, the laboratory modules included Hurco machine axis configuration, jog and spindle controls, and the basic operational procedures. The students were assessed via observation while performing operations learnt previously.

The assessments used (quizzes, tests, and observations) were all part of the regular educational components of each class, and not standardized instruments. Thus the reliability and validity of each assessment cannot be assured. However, the classes have been taught for many years, by experienced instructors and so we can safely assume that the assessments were as valid as any used in normal classroom activities.

All scores were converted to percentages to allow for comparative analysis across observations. Analysis of variance was used to compare performance on both the lecture and lab tasks across treatments. Effect size was calculated using eta-squared (η^2).

3.2 Results

Of the 44 students registered in both courses, 34 agreed to participate in this study. 88.2% were male and 11.8% percent female with 85.3% undergraduate and 14.7% graduate students. Due to time constraints, few of the students in the graduate course completed the lab tasks in this study. Other data is missing due to variation in student attendance.

A 2 (course component) x 3 (teaching methods) repeated-measures factorial ANOVA was conducted comparing student scores based on course component (lecture vs. lab) and teaching method (classroom, virtual or both). Only those students who completed all 6 tasks were included in this analysis (n=10). (Average scores earned on each task are shown in Table 2.) A Bonferroni correction was applied to all pairwise comparisons.

Table 2. Average Scores by Task

Task	Treatment	Mean	Std. Deviation
1	Lecture-Classroom	88.3%	9.0%
2	Lecture-Virtual	90.0%	10.5%
3	Lecture-Both	99.0%	3.2%
4	Lab-Classroom	66.0%	24.1%
5	Lab-Virtual	80.7%	21.8%
6	Lab-Both	98.6%	4.5%

A strong significant main effect for course component was found, $F(1,9)=8.84$, $p<.05$, $\eta^2=75.4\%$. Students performed better on the lecture component ($\bar{X}$ =92.4%, *sd*=9.2%) than the lab component (*m* =81.8%, *sd* =4.2%). A strong significant main effect for teaching method was found, $F(2,18)=11.89$, $p<.01$, $\eta^2=98.5\%$. Students performed better when both the AVML and classroom teaching were used (*m* =98.8%, *sd* =3.8%) than either classroom (*m* =77.2%, *sd* = 21.1%) or the AVML ($\bar{X}$ =85.4%, *sd* =17.4%) alone.

There was no significant interaction effect, $F(2,18)=2.91$, $p>.05$, $\eta^2=49.6\%$. Student scores across the teaching methods were not influenced by whether it was the lecture or lab component. See Figure 5.

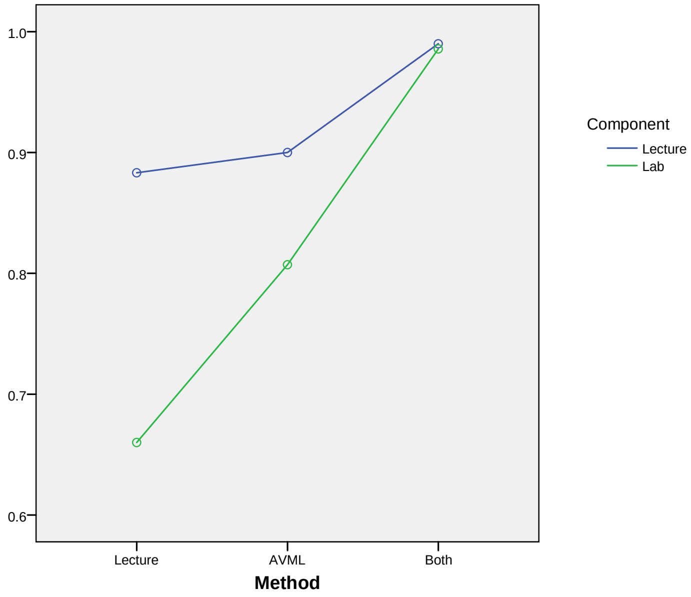


Figure 5. Plot of Means by Course Component and Teaching Method

Since there was no significant interaction effect between the course component and the teaching method, a one-way repeated measures ANOVA were conducted separately for the lecture course component. This allowed for a stronger analysis of the lecture component as there was no missing data for that course component (n=34). Average scores for these tasks (1-3) are given in Table 3.

Table 3. Average Lecture Scores by Method

Task	Treatment	Mean	Std. Deviation
1	Classroom	59.1%	28.7%
2	Virtual	59.9%	28.5%
3	Both	75.6%	29.3%

A one-way repeated measures ANOVA was calculated comparing lecture component scores across the three teaching methods: classroom, AVML and both. A significant effect was found. Because Mauchly's test of sphericity was significant, the Greenhouse-Geisser correction is reported: $F(1.64,54.19)= 12.2$, $p< .01$, $\eta^2=94.7\%$. Follow-up protected t-tests revealed that students scored better when both lecture and AVML teaching methods were used ($m=75.6\%$, $sd=29.3\%$) than using lecture alone ($m=59.1\%$, $sd=28.7\%$) or the AVML alone ($m=59.9\%$, $sd=28.5\%$). See Figure 6.

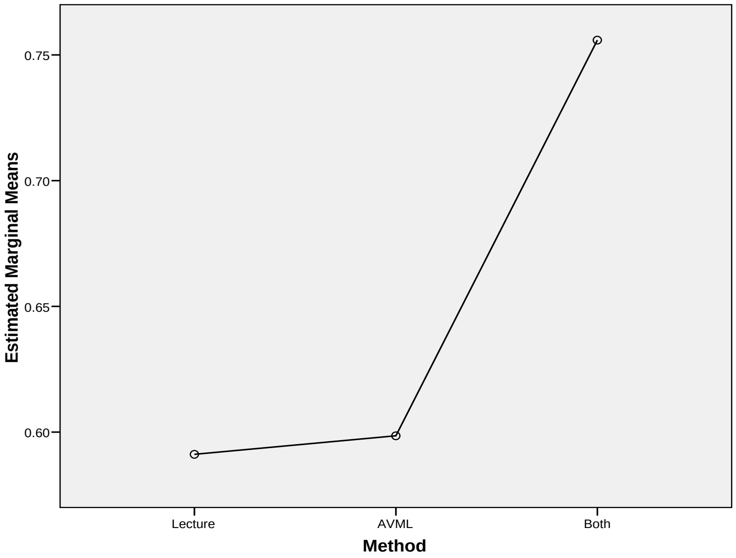


Figure 6. Plot of Means by Teaching Method

IV. Discussion

Results support the content validity of the AVML. There was no significant difference in student learning using the AVML and traditional classroom lecture in either lecture or laboratory tasks. This is consistent with Russell's No Significant Difference[5] and subsequent studies[6,7,8]. However, this result has limited power due to the small sample size and the mix of graduate and undergraduate students in the sample. Plans are underway to repeat this experiment with a larger sample of students.

Not surprisingly, using the AVML as a supplement to classroom teaching produced significantly better results than either method alone. Repetition of content undoubtedly plays a part. In addition, using both methods provides more information in different ways to the student providing support for a variety of learning styles. This is consistent with previous research[12] that shows using a combination of Web-based instruction with classroom/lab strategies is an effective teaching medium.

Because no pre-tests were administered, it is difficult to ascribe the learning effect completely to the lecture or AVML. However, when considering the lecture component of the class, it is unlikely that all 34 subjects had prior knowledge of this particular advanced manufacturing machine. In addition, the effect size of all significant results was very high (>90%). This bolsters the results found for the lecture component.

In conclusion the AVML is an excellent supplement to, and an adequate substitute for, classroom teaching for either lecture or lab settings. This offers many advantages including 24-7 access to educational materials and support for self-paced learning. In addition, lab safety is guaranteed when practicing in a virtual lab, cost is lower when the training facility is in the cyberspace, and changes/upgrades are easier to make when dealing with electronic material / virtual classrooms/labs.

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VI. Biographical and Contact Information

Dr. Fernandez holds a B.S.E in Mechanical Engineering from Worcester Polytechnic Institute, a M.S.E in Computer and Control Engineering from The University of Michigan and a Ph.D. in Management Information Systems from Purdue University. As a member of the Indiana University Faculty Colloquium on Excellence in Teaching, a board member of The Mack Center at Indiana University for Inquiry on Teaching and Learning, and an editor for the

Journal of Scholarship of Teaching and Learning, she has made significant contributions to the scholarship of teaching and learning, her current area of research. Email: efernand@iupui.edu

Professor Workman-Germann holds B.S. and M.S. degrees in Mechanical Engineering from Purdue University. She is an Associate Professor of Mechanical Engineering Technology and the director of the Materials Science and Manufacturing Processes Laboratories at IUPUI. One area of Professor Workman-Germann's scholarship revolves around the development, application, and effectiveness of multi-media technological aids in student learning. Email: jkworkma@iupui.edu

Dr. El-Mounayri received his B.Sc. in Mechanical Engineering and Master's in Materials Engineering from the American University in Cairo, and his PhD in advanced manufacturing from McMaster University (Canada). He is the co-founder of the Advanced Engineering and Manufacturing Laboratory at IUPUI and the co-developer of the AVML. Dr. El-Mounayri has been conducting research in process control, including modeling, simulating and optimizing the machining process since 1992. He currently teaches design and CAD/CAM and is involved in the development of the AVML and its application as an effective tool in training students and workforce in advanced manufacturing. Email: helmouna@iupui.edu

Chirag Padalia is a senior in Mechanical Engineering in the Purdue School of Engineering and Technology at IUPUI. Chirag hails from Indianapolis, IN and expects to graduate in May 2008. Email: chpadali@iupui.edu