Session 3486

Deploying Computer-aided Cross-training of Technicians and Engineers for Semiconductor Manufacturing

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1. Abstract

A consortium consisting of three universities and three community college systems, in three contiguous states, each with semiconductor manufacturing as an economic backdrop, is implementing "cross-training" of technicians and engineers for semiconductor manufacturing. The expectation is that "cross-training" technicians and engineers, such that they better understand the roles and skill sets of the other, will enhance their effectiveness as team members in real factory settings. The modules cover basic semiconductor unit processes (e.g., lithography, metalization, etch) and their facility demands, design of experiments, and factory-level dynamics, from both technician and engineering perspectives. The modules include interactive, schematic-based simulator panels for selected manufacturing machines, to support a need-based, top-down learning paradigm. In addition, the modules have structured exercises that require interactive roles between technicians and engineers. The "side-by-side" presentation of text, graphics, animations, videos, simulations and exercises will give technicians enhanced exposure to math and science, and it will give engineers enhanced exposure to machine (tool)

operation issues. The multi-media modules are designed to operate stand-alone or coupled to a multi-level manufacturing simulator package. They can be used for training or evaluation. The modules can serve training needs in real, mock or virtual factory-like labs.

The consortium, to date, has developed a suite of six computer-based training (CBT) modules to be integrated into factory-like labs and related courses, for cross-training technicians and engineers. The modules cover lithography, metalization, etch, chemical vapor deposition, statistical process control and design of experiments. Over 280 students have used the modules, in CD-format, in a variety of teaching settings, with expanded deployment in progress.

The participating organizations include the Univ. of New Mexico, Albuquerque Technical Vocational Institute, Maricopa County Community College District, Austin Community College, Arizona State Univ., Univ. of Texas-Austin, plus a curriculum consultant, an industrial advisory board, and industry partners.

2. Introduction

The relationship of technicians and engineers in the semiconductor manufacturing industry is somewhat unique in the manufacturing workforce. Typically, in manufacturing settings, engineers (product and process designers, and process support) and technicians (assemblers, processors, and maintainers) have only minimal if any technical exchanges. However, for the semiconductor industry, process technicians and engineers working in a fabrication plant (fab) have frequent exchanges in order to keep the process stream "on track". Furthermore, as the technical and role demands for technicians increase, their core knowledge in the areas of statistics and unit-process operations increasingly overlaps that of engineers in a semiconductor plant. Conversely, new engineers, who may become responsible for technician oversight in a factory setting, need to better understand the job-scope of technicians, as well as receive more hands-on training during their academic program. Historically, technicians and engineers work together as team members in real fabs, but they are not trained together as team members in academic labs.

The semiconductor (S/C) manufacturing sector of the U.S. economy is ever-changing. New technologies, such as new interconnect methods, deep-UV lithography, copper metalization, low-dielectric materials, chemical-mechanical polishing, failure analysis, on-line metrology, automation, etc. [SIA, 1997; Feindel, Marteney and Francis, 1999], are sweeping through the S/C industry at ever-increasing rates. As a result of these technologies and heavy competition, the cycle-time for introduction of new products continues to shorten. Because of the expanding supply of complex facilities and new equipment, the nationwide bottleneck in delivery of wafer product is and will be the ability to supply a well-trained, specialized, workforce for this major hi-tech economic sector [Marsh, 1995; SEMATECH, 1995; Sidener, 2000; Riggs, 2000]. Out of technical necessity, some S/C companies are continually raising the educational requirements of their manufacturing-line personnel. However, industry attempts to increase advertising and salaries have not drawn in the necessary set of skilled employees because of labor-pool depletion. Competition between S/C companies, for the foreseeable future, will be as much for new workers as for new customers.

Given the above circumstances, pertinent to the semiconductor industry, it is thus advantageous to cross-train semiconductor engineers and technicians in shared factory-like settings for selected equipment-intensive labs and courses, without artificially forcing complete articulation between respective curricula (which are typically disjointed because of different requirements in math and science, not to mention different semester schedules). A direct benefit is that such side-by-side cross-training, broken into unit modules and related exercises, nurtures a teamwork discipline and respect between the different student types. Another direct benefit is that new hires need less “in-plant training” by industry in order to integrate them into the production environment. A derivative benefit is that sharing expensive fab-lab space decreases the per-student lab costs and thus training costs. This combined core understanding within a company should lead to increased efficiencies of manufacturing execution as the complexity of operation increases at ever greater rates [Blake, 1990; Bolton, 1999; Brown, 1994; Kempf, 1994; Pence, 1993].

In an attempt to enhance the relevancy and proficiency of technicians and engineers for the semiconductor manufacturing sector, a consortium of three universities and three community college systems, in three contiguous states, is developing a suite of computer-based training (CBT) modules to be integrated into factory-like labs and related courses, for cross-training of technicians and engineers [Lawson, 1999; Wood et al., 1999; Wood et al., 2000]. The expectation of the consortium is that co-training and “cross-training” technicians and engineers, such that they better understand the roles and skill sets of the other, will enhance their effectiveness as interactive team members in real factory settings. The participating organizations, each of which has semiconductor manufacturing as an academic track and as an economic backdrop, include the University of New Mexico (UNM), Albuquerque Technical Vocational Institute (TVI), Maricopa County Community College District (MCCCD; includes Glendale CC (GCC) and Pima CC), Austin Community College (ACC), Arizona State University (ASU), and the University of Texas at Austin (UTA). The project also utilizes consultants and an industrial advisory board. It is noted that each of the three community colleges has a somewhat standardized Semiconductor Manufacturing Technology (SMT) Associates Degree program, although they have different sets of pre-requisites.

The computer-based curriculum modules cover basic semiconductor unit processes (e.g., lithography, metalization, etch and oxidation) and their associated facility demands, statistical process control and design-of-experiments methods, and factory-level dynamics, from both technician and engineering perspectives. The presentation of the materials uses a “side-by-side” format that not only contrasts the conventional coverage of topics, but also indicates where “hand-offs” of assignments or responsibilities are required, from technicians to engineers and visa versa, during the normal routine of factory processing. As a generic example, an engineer may design or modify a process, and the technician might implement the process, with technicians and engineers jointly poring over the test results. As a didactic example, technicians might notice a high “particle” count (and an associated “pattern”) on a lot of reused test wafers, that in turn cause a high rejection rate; however, an engineer notices that elements of the “particle” pattern mimic the mapping of the test probes. The “side-by-side” presentation of text (accessed by tabs in some cases), interactive graphs and panels, animations, simulations and exercises will give technicians enhanced exposure to math and science, and it will give engineers enhanced exposure to machine (tool) operation issues. In addition, the modules have “hand-off” sidebars and structured exercises that require interactive roles between technicians and engineers. All materials are generally tabulated under roles and skills, tutorials, simulations and exercises. Under the simulation tab, interactive control panels that represent the “anatomy” and essential functions of the various tools, provide the focus of the need-based learning paradigm.

The multi-media modules are designed to operate stand-alone or coupled to a multi-level Manufacturing Enterprise Training Simulator (METS) so that the consequences of line-level tool interactions, or factory-level dynamics, can be explored [Wood, et al., 1997]. The modules can be used for training or assessment. The modules can serve training needs in real, mock or virtual factory-like labs. The modules, though utilizing tool-specific data, control panels and video, are designed to allow easy swap-out with other tool-specific features. For example, the control panel variables and data associated with one brand of etcher could be swapped for another brand of etcher. Thus, the modules can be customized to the available tool set of a particular educational institution, or the students can contrast and learn the features of different tools for a given unit-process step.

3. Participants and Organizational Structure

The FY-00 and FY-01 participants of the project include faculty, technical staff, consultants and students. These persons are listed below:

FACULTY PARTICIPANTS

Tom Edgar	Assoc. V.P Academic Computing	UTA
Ch. Fleddermann	Prof. EE	UNM
John Fowler	Assoc. Prof. IE	ASU
Louis Frenzel	Prog. Coordi. SMT	ACC
Eric Krosche	Instructor, SMT	TVI
Alfred Lavender	Instructor, SMT	TVI
Michael Leeming	Professor	Pima CC
Luke Lester	Ast. Prof. EE	UNM
Fabian Lopez	Instructor, SMT	TVI
Bassam Matar	Professor	Glendale CC
Dwayne Rollier	Assoc. Prof. IE	ASU
George Runger	Assoc. Prof. IE	ASU
Isaac Trachtenberg	Professor	UTA
John Wood	Prof. ME & Dir. Mfg. Engr. Prog.	UNM
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STAFF

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STUDENT PARTICIPANTS

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Milton Lau	Grad Student	UNM
Anders Nilsson	Grad Student	ASU
Michele Pfund	Grad Student	ASU
J. Ranganathan	Undergraduate	UTA
Katina Skinner	Grad Student	ASU
Jon Ulrich	Grad Student	ASU

CONSULTANTS/CONTRACTORS

David Hata	Dept. Chair Microelec. Techn.	Portland CC
David Vick	Computer Programmer	dynaVu, Inc.

In addition, industry participants provide review and evaluation of the module materials and cross-training methods. These persons are affiliated with Allied Signal, AMD, Hyundai, Intel, Motorola, ON Semiconductor, Sematech, Sumitomo, and Philips Semiconductor (see acknowledgements).

The University (U) and Community College (CC) members are paired -- with one pair per State. These pairs establish a regional group by which to test cross-training methods in different venues. The relationships of the various participants are schematized in Fig. 1, below. Activities of the consortium include the development of computer-based training modules; implementation of the modules in labs and courses at community colleges and universities; formation of teams of technician and engineering students to perform cross-training exercises; continued acquisition of competency expectations from industry; a review of modules by industry representatives; assessment and evaluation within labs and classrooms across a wide spectrum of community colleges (and other universities); and marketing of CD materials.

Although there is a U/CC pair in each of three states (regions), each U/CC pair utilizes the computer modules in different ways, by design, so that their effectiveness in different venues, once the modules are distributed widely, may be evaluated. For example, UNM and ATVI have used the modules during shared fab-labs; UTA and ACC have used the modules to supplement existing technician and engineering courses; and ASU and MCCCD have used the modules to supplement existing courses, utilizing the "virtual lab" features of the modules. UNM, TVI, ASU and UTA have cleanroom facilities/labs in which students can get hands-on training. All members anticipate enhanced cross-training implementation, particularly as new cleanroom facilities come on-line at ASU-East and ACC (to supplement ACC's existing equipment labs).

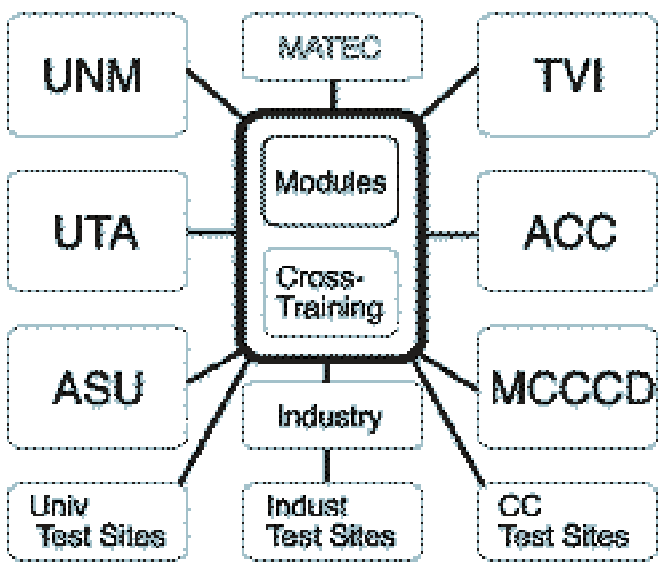

Fig. 1. Schematic of roles and relationships of project participants. MATEC is an NSF ATE Center, located in Maricopa County (AZ), devoted to semiconductor manufacturing.

4. Module Content

The development of each module is led by an appointed Community College and University consortium member, representing technician and engineering viewpoints, with inputs from the other project members as appropriate. The computer integration of all materials, into a CD format, is by UNM. In more detail, the modules cover:

- Lithography (lead by MCCCD and UTA): lithography methods (contact, proximity, projection, optical, x-ray), steppers, resist types, coating methods, surface preparation, soft and hard bake, wafer loading, alignment, exposure methods, developers, wet and dry strip, instrumentation and measurements, equipment, automation steps, inspection, masks, reticles, and waste streams.
- Sputter & Metalization (led by TVI and UNM): thermal vacuum evaporation, e-beam evaporation, sputtering, metal deposition rate theory, concepts of gases, plasmas, terminology of vacuum pumps, evaporation issues, conductors and semiconductors, interconnects, electromigration, film quality, and instrumentation and measurements.
- Design of Experiments (led by MCCCD and ASU): input/output variables for each of the unit processes (e.g., litho, sputter, etch, etc.), factorial design, response surfaces, optimization, and statistical package linkages.
- Plasma Etch (led by ACC and UTA): etch flow, dc-bias, end point signal, spectroscopy, selectivity, power, RF power, anisotropy, RF discharge, voltage, plasma chemistry, etch profiles, residue and cleaning.
- Thin-Film Deposition (led by MCCCD and UNM): ellipsometry, nitrides, oxides, epitaxial silicon, polysilicon, dielectrics, instrumentation and measurements.
- Characterization & Control (led by TVI and ASU): statistical control charts, gauge capability, sampling plans, process capability; equipment productivity, equipment teams, impact on factory operations and costs.

We anticipate the development of three new modules that would cover:

- Diffusion and Oxidation
- Implant and Rapid Thermal Processing
- Factory Dynamics

The entire set of modules will be sufficient to cover the key unit steps of an NMOS or CMOS process, depending on the user's curriculum.

5. Module Features and Formats

Materials and features contained in the CBT modules created to date include tutorial text, roles and competency specifications, figures, equations, equipment panels and schematics, process simulations, interactive graphs, active SPC charts, process data, step-throughs for practice exercises, self-paced exams, embedded how-to video segments, animation, graphical user interface (GUI) control panels, “knobs” and “sliders” for data input, “hand-off” dialogues, and cross-training exercises. Technician content covers process execution, science and math elements of the process, and statistical monitoring of processes, as well as standard operating procedures, tool simulations, normal and abnormal equipment operations, alarms, fault detection, diagnostics and effect of run-to-run control systems. Engineering content covers the physics of the unit-process, equipment engineering and modeling issues, design of experiments (DOE) for selected processes, waste-stream analysis, and process simulation. Unit-process CBT modules can also be concatenated for “short-loop” operations (a short sequence of related, recurrent process steps, such as lithography and etch). Some modules address factory-level operational issues [Hopp and Spearman, 1996]. In addition to supporting lectures and hands-on lab exercises, the CBT modules also enable stand-alone, self-paced “desk-top” learning.

The graphical user interface (written in Visual C++ [Microsoft]) for the multi-media materials starts with a navigation menu covering the basic processing tool groups and related topics for semiconductor manufacturing (Figs. 2 and 3). These “toolboxes” include oxidation and diffusion, lithography, etch, doping and implant, thin-film depositions, heat treatment, test-sort-packaging, DOE, SPC, factory dynamics, and safety. Within each module, materials are generally tabulated under simulations, theory, methods and technologies, quality issues, roles and skills, and exercises. The presentation format is scrolling text divided, when appropriate, into technician material on the left side and engineering material on the right side (narratives are merged when materials are essentially similar). The lab-exercises are divided into on-line exercises (labs and simulations), off-line exercises, and DOE exercises [Drain, 1997a, 1997b; Montgomery and Runger, 1999].

Fig. 2. Entry point of the CD. [Courtesy of UNM et al.].

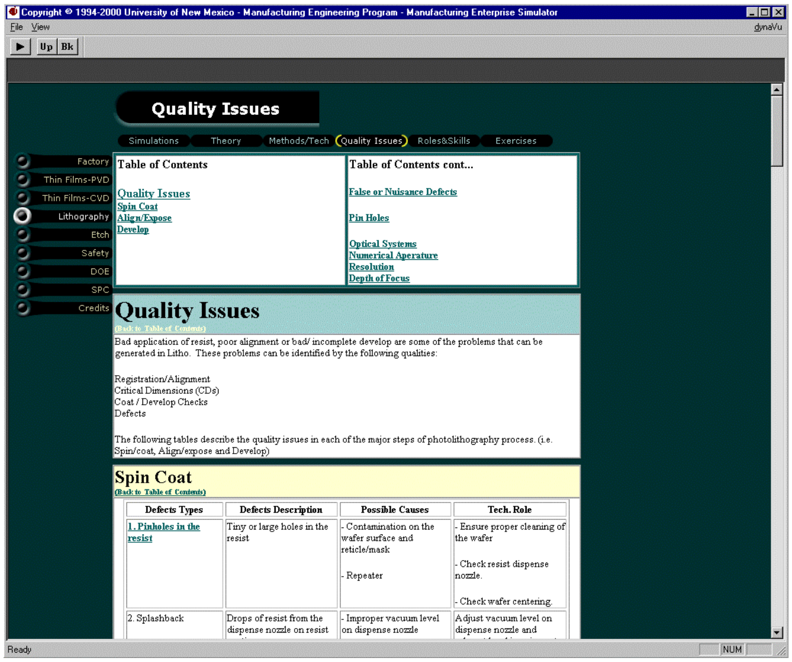

Fig. 3. Graphical User Interface for a typical module, showing tabs. [Courtesy of UNM et al.]

Multi-media segments illustrating tool use or tool operations are laced throughout the side-by-side (technician vs. engineer) presentation format of the GUI structure (see Fig. 4). Some of these are video clips (e.g., thermal evaporator), while others are animations generated by project members (e.g., step coverage, and step-and-repeat).

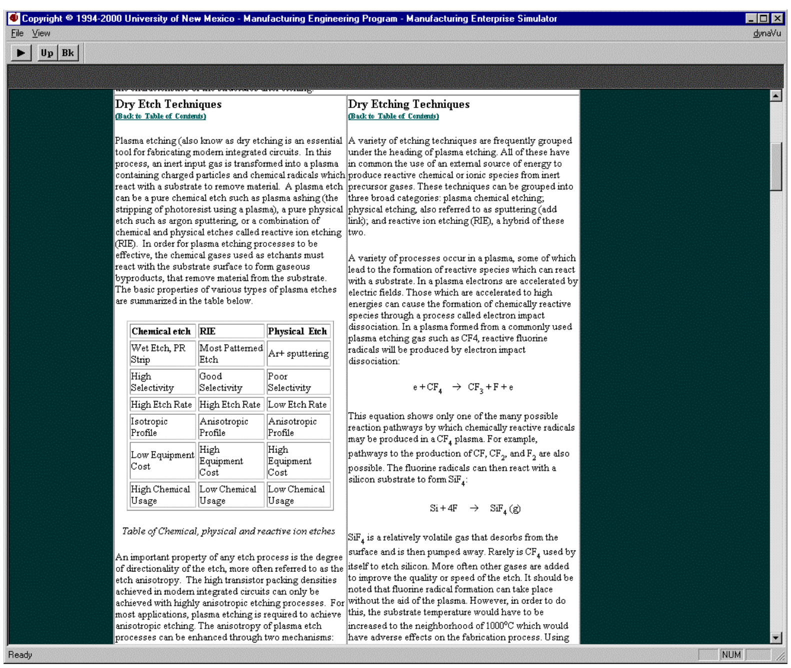

Fig. 4. Graphical User Interface for a typical module, showing technician (left column) and engineer (right column) views of a topic. [Courtesy of UNM et al.]

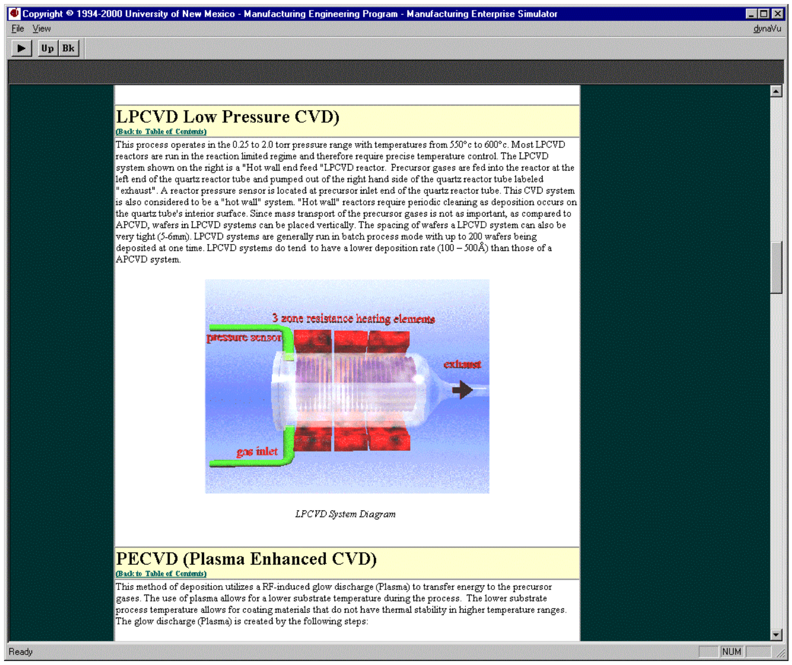

Fig. 5. Example of text and graphic. [Courtesy of UNM et al.]

The GUI panel is backed by equations, parametric models and/or data sufficient to "close the loop" for a design of experiment exercise (see Fig. 6; Czitrom, et al., 1997; deVore, et al. 1992). An example of "closing the loop", in this case for a thermal evaporator, is shown in Fig. 6. The salient control (input) variable for an evaporator is the "current" (to the "boat"), which a technician sets on the machine panel. The output of the process is the "deposition rate" (and associated film quality). This overall input-output relationship can be characterized by a "curve-fit" of actual tool-generated data, or it can be obtained from a concatenation of physics-based models and simulations, or it can be a mix of physics-based models and parametric models. The later case is seen in Fig. 6, which uses a concatenation of data (curve-fits) from Current (I) to Boat Temperature (Tb), and simulations (equations) from Tb to Deposition Rate (R). Once the forward input-to-output pathway is quantified, in whatever fashion, run-to-run data can be generated, with process noise and drift superimposed on the process "model". Then, SPC and DOE factorial analysis can be performed (as a simulation) using commercial DOE software packages to explore optimum factors. Moreover, engineering students, for an exercise, can refine the physics-based models, while technicians, for an exercise, can refine the parametric representation.

The notion of need-based learning is supported by interactive "function panels" for each of the major process tools. For example, a panel for a plasma etch tool is shown in Fig. 7. Clicking on features of the tool (as represented by the panels) takes the learner to the relevant tutorial and exercise sections. Logic tables that control events during a tool simulation back the panels. The speed of the simulation is a user-selected parameter. The user can monitor the sequence of events to understand functional relationships of the tool subsystems. The panels also emulate machine malfunctions or typical process problems. The user can then perform simulated troubleshooting exercises, either individually or jointly (as engineer-technician exercises).

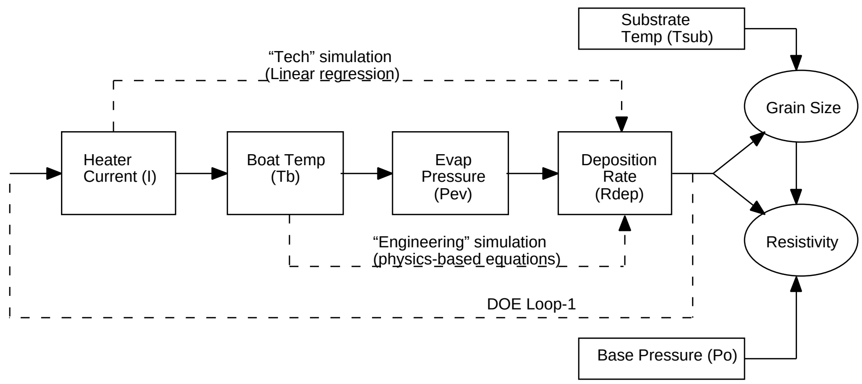

Fig. 6. Input-Output flow diagram for thermal evaporator. The technician input-output relationship is a linear regression model. The engineer input-out relationship is a mix of approximations from current (I) to Boat Temperature (Tb) and physics-based equations from Tb to deposition rate (R). [Courtesy of UNM et al.]

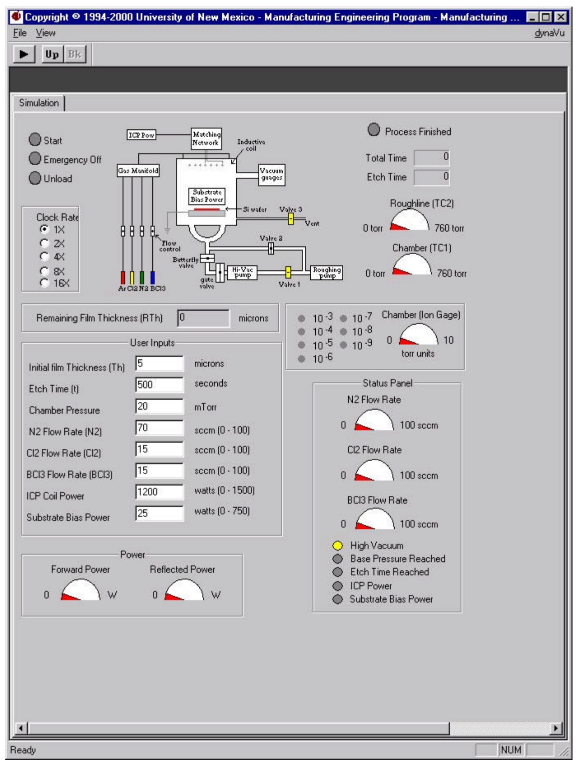

Fig. 7. Simulator panel for plasma etch machine. [Courtesy of UNM et al.]

A representative example of the GUI for the DOE sections is shown in Fig. 8. The panels have a self-paced, multiple-choice "question and answer" tutorial entry-point. This is augmented with panels that illustrate the controlled variables (and their ranges) relevant to the simulations in the walk-through tutorials. The DOE sections also have examples of the various statistical plotting and data analysis methods commonly used for DOE. In addition to DOE sections for engineers, the CD also has a unique set of sections devoted to priming technicians for DOE concepts (see Fig. 9).

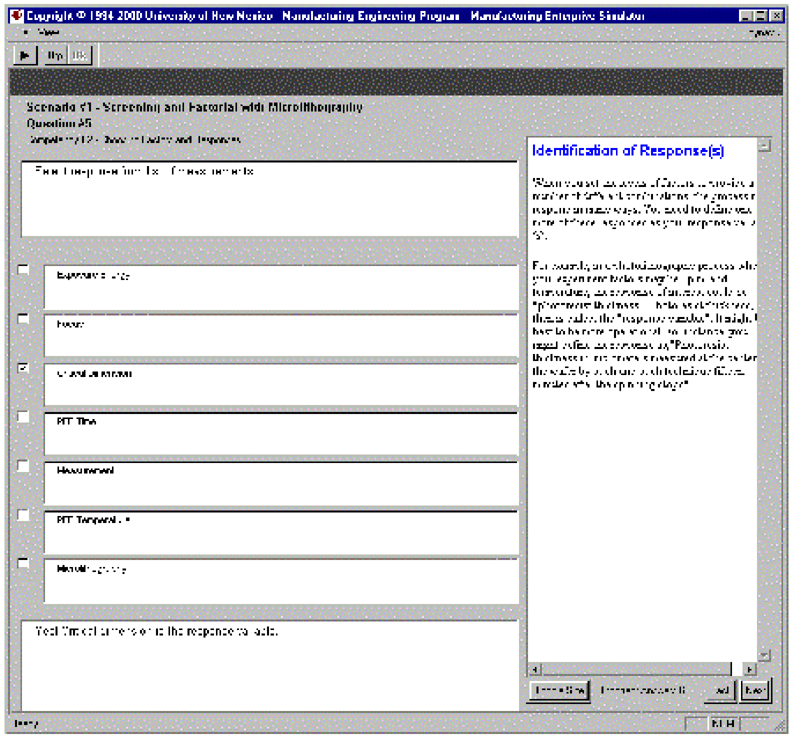

Fig. 8. GUI panel for DOE "Q/A" section, with window for tutorial. [Courtesy of UNM et al.]

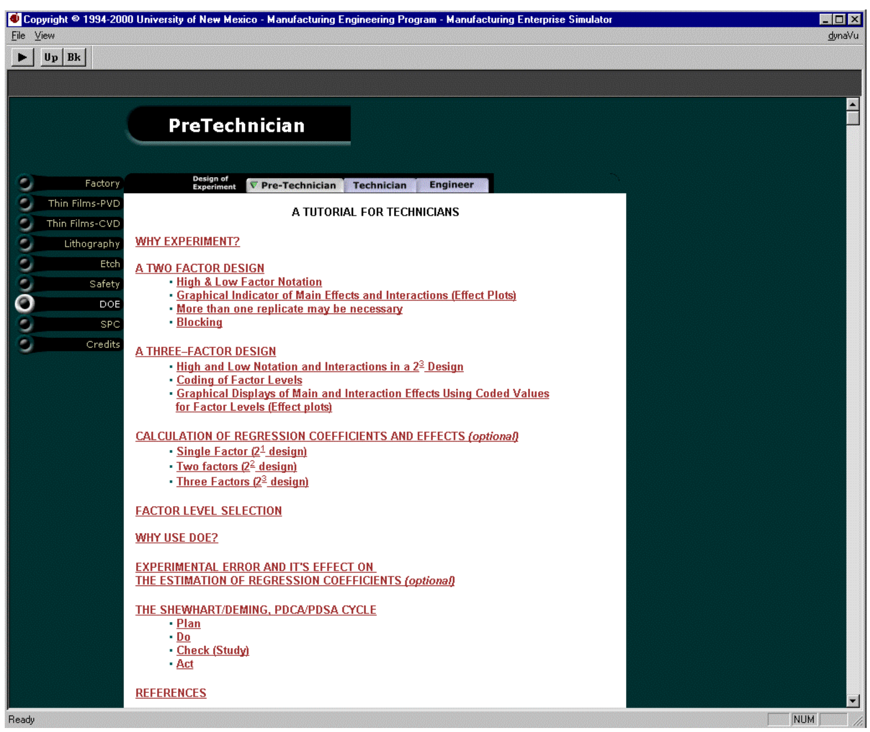

Fig. 9. GUI to DOE primer for technicians. [Courtesy of UNM et al.]

6. Evaluation and Assessment

The goal of the project is to produce engineers and technicians who more effectively communicate and function on a team within a real factory. The primary approach of this Advanced Technological Education Project, to meet that goal, is to cross-train semiconductor (S/C) manufacturing technicians and engineers side-by-side, module-by-module, in factory-like settings for selected equipment-intensive courses. The secondary approach is to utilize the materials in educational settings where side-by-side training of technicians and engineers is not an available option. An intended educational outcome of the means is that the "side-by-side" presentation of text, graphics, animation, simulations and exercises will give technicians enhanced exposure to math and science, and it will give engineers enhanced exposure to machine (tool) operations. The salient, measurable objectives are the education and training of engineers and technicians who, within factory settings: (1) communicate more effectively, (2) perform team-tasks more efficiently, (3) understand overlapping roles, (4) exhibit increased math and science literacy, (5) exhibit increased understanding of principles of machine operations, and (6) require reduced in-plant training preparation at the outset of being hired. The objectives are in turn quantified by detailed Performance Criteria, per the Rose-Hulman methodology [Rogers and Sando, 1996; Frechtling and Sharp, 1997; and Stevens, et al., 1993]. These were the basis for a survey instrument, to be completed by users of the CD, to collect evaluation and assessment data for the project. The survey instruments asked the CD user to evaluate the following items, each on a scale of 1 to 10: coverage of material, technical level, math/science background, ease of use, visual aids, simulations, exercises, and understanding of role of their counterpart. The CD, in various stages of development, has been tested by each of the organizations of the team (UNM, TVI, ACC, UTA, ASU, Glendale CC and Pima CC), in classroom and lab venues. Since Spring 1999, over 280 students, in cross-training and conventional classroom modes, have used the CD.

During Spring Semester 1999, the University of New Mexico and the Albuquerque Technical-Vocational Institute ran a pair of semiconductor process training labs (UNM: EECE-472 and TVI: SMT-211) wherein cross-training was introduced, supported by a preliminary version of the lithography and evaporation modules. The instructors (UNM: L. Lester; TVI: E. Krosche) selected and paired 7 engineering students (senior/graduate level) with 7 technician students, to perform selected lab exercises over a 5-week period. The exercises, that required demarcated roles for the tasks, included the resistivity measurement of a patterned and etched aluminum thin film as a function of evaporator base pressures. The students in each pair were required to work together, cross-train their partner, explain decisions to the other, and critique their teammate's effectiveness in their role.

The UNM/TVI cross-training exercise was tried again for Fall 1999, bolstered by improved computer-based modules. Engineering students from the University of New Mexico and technician students from Albuquerque TVI were again assigned to teams and assigned a metal evaporation project. Specifically, the Sputter and Metalization (PVD) Module on the CD supported this lab project. UNM/TVI had 16 graduate-level engineers and 9 second-year technicians in these cross-training exercises. The engineers and technicians did thermal evaporation, photoresist application on a coat-track station, contact lithography, and electrical probing. The engineers had related exercises in making up process flow sheets, vacuum science calculations, lithography and pattern transfer resolution estimates, and analysis of probing errors.

Based on completed assessment forms, the technicians and engineers rated their math/science backgrounds as adequate (except for, perhaps, chemistry) for understanding the material on the CD-ROM. The level of the material was rated "Just Right" by both groups of students. UNM engineering students felt comfortable working within the assigned teams, actively participating in team activities. They felt that communication between team members was effective and perceived team members as being supportive. In general, they thought the laboratory activity enhanced their understanding. However, engineering students felt that a stronger chemistry background would have better prepared them for the laboratory exercise. Likewise, TVI technician students felt comfortable working in teams, and similarly, they felt that their chemistry and math background was marginally adequate. Both groups found the CD-ROM easy to use although some students asked for better navigational aids. The technician students rated the visual aids, simulations, and exercises as very good, but the engineering students rated these categories lower. In a standalone setting, both groups found the CD-ROM helpful in understanding their counterpart.

It is noted that an unexpected team dynamic was detected when comparing the Spring 1999 UNM-TVI cross-training exercises with the Fall 1999 exercises. Since the Fall 1999 engineering group consisted of graduate-level students (who had considerable hands-on experience due to either their research work or job experience), the gap in understanding and experience between technicians and engineers was larger than for the Spring 1999 group. Consequently, the technicians felt that their engineering counterparts could have been their “instructors”, instead of an “equal partner” in the exercises. This led to some discouragement within the technicians when trying to explore ideas or solutions, since the graduate students seemed to already know the answers. Our recommendation, based on this experience, is to pair undergraduate engineering students with technicians, so that both types are working in an exploratory mode.

ASU used the CD during two Spring 2000 statistics courses as a tool to support a DOE lab exercise. Respondents were a mix of junior/senior undergraduates from EECE-380 (generic statistics) and graduates from IEE-591 (semiconductor-oriented statistics). The graduate students, relative to undergraduate students, rated the content and coverage of the PVD section more complete (perhaps because the graduates were buffered by a semiconductor-oriented course), however, the graduates rated the level of the PVD section a bit lower (not surprisingly). Likewise, the graduates, relative to undergraduate students, tended towards a higher rating for the benefit of the CD to their understanding of DOE and factory dynamics (again, perhaps, because of the semiconductor slant of the DOE examples, which would have been of more use and greater interest to the graduate students). Both groups suggested that additional (and better) video segments and examples would be helpful.

In addition to the surveys collected, Dr. Mike Leeming was able to incorporate some of the DOE materials for technicians into a course, TEC 151 at Pima Community College, during Spring 2000. He obtained data, based on four hours of “quality-related” tutorials, that suggests that the DOE material (which is typically not a part of SMT curricula) is *not* above the capabilities of technician students. The students were given exposure to the basic terminology and concepts. This yielded a starting sense of what DOE is about, including operations such as blocking, randomization and replication. They observed how treatment combinations are indicated, they know what “standard order” means, and they can identify a factor and response variable. By this “primer”, the technicians are now less intimidated by Sigma type summation notation. It is expected that these students, with additional direction, could calculate estimates of regression coefficients, using matrix multiplication, and sums of squares and mean sums of squares if necessary.

The team intends to continue its use of the CD in courses and labs in order to acquire additional feedback with which to refine the materials. The team has sought other community colleges (and universities) throughout the U.S. where it can apply the CD for assessment and evaluation purposes.

7. Summary

To date, the project has contributed to the education of technician and engineering students on a limited experimental in-house basis, as a preliminary test of the software and methodology. The feedback to date is encouraging. The data and comments from students suggest that the CD is presented at the intended level, i.e., slightly above a technician, but lower than required by an engineer. This level is consistent with the intent of the NSF Advanced Technological Education (ATE) Program, which seeks to focus its benefit primarily on technicians and to enhance the math and science understanding of technicians. The data also suggests that visuals and interactivity can be enhanced, and that the exercises on the engineering side of the CD-ROM can be improved. Eventually, we expect the project to generate educational tools to enable a better-trained workforce for the semiconductor manufacturing industry.

8. Acknowledgements

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Figures 2 through 9 in this paper, each taken from copyrighted media, are provided courtesy of the University of New Mexico and Consortium members.

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