Evolving Best-Practices through Simulation-Based Training

Training the Field Operator of the Future

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ABSTRACT

Simulators are widely recognized as essential to process control training as they facilitate the propagation of a company's standard operating procedures (SOPs). This paper explores the use of process control simulators by Chevron Products Company to challenge existing corporate SOPs and to help achieve improvements in overall production performance.

INTRODUCTION

Simulation software has proven highly valuable to modern computer-driven businesses. The growth of Computer-Aided Design technologies in the 1960s enabled engineering and architectural firms to quickly explore new products and novel approaches. The impact was a dramatic reduction in the time and cost associated with then-current best-practices for product innovation and design. Computers became more affordable in the 1990s and software became more powerful. This facilitated widespread acceptance of simulation tools within educational spheres, particularly within universities. Simulators allow an instructional designer to construct realistic tasks or situations that elicit the behaviors a learner needs to function effectively within a domain (Mislevy, 2002). Simulation tools have been used as a means of exposing students to complex concepts and have inspired higher level learning activities including novel research. Through the use of two- and three-dimensional models, the theoretical was more easily examined and the proven more readily understood. Similarly, simulation models can be used for individual or team-based problem solving. In their research, Mislevy, Steinberg, Breyer, Almond, and Johnson (2002) describe the importance of capturing data from a simulator that directly relates to real-world performance and production. This helps instructors to connect the student's interactive simulation experiences with known best-practices for advanced learning.

Simulation software has become an increasingly important tool for industry practitioners. Instructors within the manufacturing sector use simulation software to train staff to perform tasks for three primary reasons. Simulation is the best methodology for measuring task performance where cost and safety are contributing factors. The development of learning modules allow for the construction of curriculum that is learner centered. Additionally, simulation affords the opportunity to create curriculum that can be used by both novice and expert learners. Savery and Duffy (1995) suggest a basic premise of constructivism, citing that the basis for understanding is determined by how the learner interacts with his or her environment when solving real-world problems; this interaction is the basic stimulus for learning; and knowledge and higher level learning evolves as the learner interacts with their environment both cognitively and socially.

According to process industry estimates, nearly $8 Billion in annual losses are due to human error. A significant part of these losses are attributed to inadequate or ineffective training. Simulation software permits trainees to gain the skills and experience necessary to effectively respond to abnormal conditions and to apply their experiences continuously without the cost of lost production, damage to the environment, or exposure to unsafe conditions. As simulation software has become increasingly less expensive and easier to program, more and more training curricula have been developed for production staff. Simulation-based curriculum allows production staff to engage in solving real-world problems were existing knowledge is activated, serving as a foundation for new knowledge and allowing the learner to integrate that new knowledge into the learning domain (Merrill, 2002). Beyond exposing trainees to abnormal situations on the plant floor, simulation technologies are integrating new knowledge by creating, testing and validating the Standard Operating Procedures (SOPs) that production staff uses to trouble-shoot and respond to abnormal situations.

Control Station and other technology vendors have developed tools that create first-principles simulations by utilizing data from real-world production processes. A process-based simulation can be developed by conducting bump tests on various plant processes, capturing the associated process data, and presenting the information on a simulation control panel. The user interface allows the instructor or student to manipulate the process and view the expected response, thereby providing a high-fidelity learning experience based on a real-world process. Learning applications and curriculum can be developed that permit trainees to examine, practice, and improve SOPs. As such, training becomes an important part of a company's process improvement effort, allowing trainee and instructor alike to evaluate the efficacy of accepted norms for attaining operational excellence. For example, in a case cited by Rutherford, Persad, and Lauritsen (2003), learners participating in simulation-based operator training uncovered potential process and operational problems before unit startup and recommended corrective action, thereby preventing potential safety and environmental problems.

THE VALUE OF SIMULATION BASED TRAINING

The time value of simulation-based training is multifold and among the most important of its many positive attributes. One time-based feature of simulation-based training is characterized in terms of the ability to present training asynchronously. Computer-driven simulation media permits an instructor to present and a trainee to experience engineering phenomenon when convenient. With a handful of key strokes, feed flow to a Distillation Column can be increased and the associated product composition undermined; or temperature within a Reactor can be ramped beyond acceptable production tolerances, fouling the contents of the batch. Another time-based factor is the time between abnormal situations. Without simulation, the learner cannot experience an event or abnormal situation unless one actually occurs. Today's improvements in reliability and fewer upsets increasingly diminish the effectiveness of experiential-based training where staff learn through a combination of mentoring and "hard knocks". A real-world experience is completely at the discretion of the process and other factors outside the instructor's control. The chances of an event occurring when an instructor is present to direct learning is small, resulting in a negative learning experience as stimuli is received beyond the trainee's capacity to assimilate it. Alessi (1988) points out that a real life learning event or high simulation realism often leads to novice user frustration and a decrement in learning when they do not have the appropriate knowledge and skill level to function effectively within the context of the real-world or simulated problem. Asynchronous simulation software tools overcome this aspect of time, allowing trainees to interact with a make-believe Simulation Column or Reactor and to better prepare for an actual occurrence that may result on the plant floor.

Speed is another time-based attribute of simulation technologies. Although the dynamics of a typical flow loop will respond rapidly to changes in control, there are many temperature-based process loops for which responses are sluggish at best. The pre-heat section of a common brick kiln will take 2-3 hours to respond to a 5% change in Set Point. The dynamics of such a system require multiple disturbances and days of patient waiting to explore experientially, but by using simulation-based technologies the nuances of a complex system can be revealed within a matter of seconds and alternative control strategies validated and implemented without loss of production. Trainees can direct their learning environment in order to expose themselves to a variety of tasks, witness the reaction to a process change, test a variety of actions within a compact period of time, and discover new solutions to increasingly complex problems. Related to the speed attribute of these tools, Swaak and DeJong (2001) describe the use of simulations in a discovery environment where a learner must use their base knowledge to plan and execute their own learning activities. Task exposure consists of exposing enough of the material to provide the learner with the least amount of knowledge necessary to begin task performance. Model progression starts with a simple version of a model and presents increasingly complex versions as the student progresses through the curriculum or lesson.

Consider the many cost- and safety-related qualities of simulation technologies. Training that involves the use of actual production inputs is anything but economical. In an increasingly competitive global market, minimizing waste is among the most important factors in achieving bottom-line plant profitability. More importantly, the safety of both process control instructors, trainees and other staff working nearby is always the central concern. Curriculum based on conceptual and operational simulator models allow learners to experience principles, concepts and facts with operational models going a step further by allowing the learner to perform sequential operations (i.e. procedures) on a simulated system. Learners can manipulate parameters and visualize the results of their interaction over time as feedback (Rose, Eckard, & Rubloff, 1998). A high fidelity simulation can provide a near real-world experience without the real-world consequences. It is understood that most production environments are volatile. The recent tragedies at BP's Texas City Refinery offer more than ample evidence of the potentially grim realities in manufacturing. The loss of life in Texas City points to the precariousness of manufacturing and suggests that simulation technologies should be used to help reduce these risks, where possible.

The simulation of complex production processes has proven highly valuable in the training of a difficult and abstract subject – process control. The dynamics of any given production process can be difficult to describe let alone to depict two-dimensionally on a chalkboard.

Simulator software allows for the construction of realistic tasks or situations that elicit the behaviors the learner needs to demonstrate in order to function effectively within the domain (Mislevy, 2002). Further, Noble (2002) describes simulation fidelity as "the degree to which a simulator or simulated experience imitates the real world." It is true that basic process dynamics associated with feedback control schemes are largely intuitive and can be easily conveyed; and adjustments to a simple, single variable system oftentimes result in predictable and proportional responses. Process dynamics can quickly become too complex to explain effectively, without the use of simulation, as topics progress to more sophisticated feed-forward schemas and as common anomalies such as stiction and the like are introduced into a system. The challenge of training individuals on the nuances of such abstract concepts can be significant for educators regardless of their years of experience and expertise as an instructor.

Feinstein and Cannon (2001) assert that the effectiveness of simulation-based training rests on simulation fidelity, verifiability and validity. The highest or total-fidelity simulation is neither the most effective method for teaching novice learners nor is it the most cost-effective method for simulation strategy (Alessi, 1998; Longridge, 2001; Noble, 2002; Feinstein, 2001). Feinstein and Cannon (2001) describe simulator verification as making sure that a simulator operates the way it is intended. Verifiability of a simulation suggests that a simulator model has been thoroughly tested by subject-matter experts and errors have been eliminated (p. 58). Validity refers to how well the simulator accurately reflects real-world results and how its responses are based on the manipulations of the user (p. 61). The fidelity, verifiability, and validity are three key factors that lend credibility to a simulation and thereby determine its value to the user and to the learning group as a whole (Couture, 2004, p. 47).

Simulation software is not a replacement for real-world experimentation or practical experience. Actual tests performed on the plant floor and the knowledge and understanding that result from hands-on experience are fundamental to the learning process. Even so, simulation software does provide a valuable training tool. In his article *Simulation Nation*, Marc Prensky wrote: "Computer simulation technology is a way of looking at objects or systems that encourage a learner not only to wonder 'What would happen if…?' but also to try out those alternatives virtually and see the consequences. It is a way for learners to acquire experience about how things and systems in the world behave, without actually touching them." Providing virtual exposure to the "what-if" offers significant value as it helps staff to look for the signs characteristic of process failures, and it enables them to consider appropriate corrective actions. In this manner, simulation technologies allow staff to anticipate the application of SOPs and to assess the efficacy of those very same procedures.

INDUSTRY LEADERSHIP

Chevron is one of the largest integrated energy companies in the world. Headquartered in San Ramon, California, they conduct business in approximately 180 countries, and are engaged in every aspect of the oil and natural gas industry, including exploration and production, refining, marketing and transportation, chemicals manufacturing and sales, geothermal and power generation. Chevron's strategy of investing in people, leveraging technology, and investing in peoples has led them to invest in the use simulation technology to deliver training. Chevron considers the successful implementation of simulation based curriculum as a critical success factor in preparing the company's staff for success in the operation of increasingly complex production processes.

Advances in process automation have led to increased complexity in the control of automated production systems. In addition, a large segment of the work population is at or near retirement causing the process industry to experience "brain drain" or the loss of knowledge through worker attrition. These challenges, combined with limitations to existing trade school, college and university curricula, require companies like Chevron to develop plans and strategies designed prepare their workforce to tackle today's challenging production environment. Process industry facilities, such as Chevron's El Segundo Refinery, have begun to proactively develop improved work processes, competencies, and training in the areas of control loop reliability and performance.

Skills development workshops such as Control Station's *Practical Process Control*© have helped Chevron to equip production staff with training that teaches the skills they need to make better decisions and maintain improved control over business-critical production processes. Beyond learning the basics of process control, these workshops are designed to work effectively within the community of practice in which the simulation was developed to encourage the analysis, improvement, and creation of better SOPs that are accepted by the community. Wenger, McDermott, and Snyder (2002) describe a community of practice as a keeper of knowledge in that acceptable practice and conditions for membership are developed and ratified by the work domain practitioners. Resnick (1987) believes that much of the knowledge present in a work domain is kept in the form of tools developed by the domain. A simulation is a type of tool developed by a community of practice that can be used to transfer basic domain knowledge or be used for higher level learning activities such as evaluation and creation of knowledge. These higher level learning activities are built in to a workshop; designed to encourage continuous improvement of the knowledge base; and to coalesce the community of practices in the form of cross-functional teams around this new knowledge as a best practice. A cross-functional team consists of different positions within a workgroup that combine efforts to get a job done. An example of this might be a console operator, process engineer, and control engineer working together to solve a process control problem. A workshop organized around a cross-functional team that reflects a company's work environment is more likely to produce the long term benefits of integrating proven industry best-practices into existing work processes.

Simon (1993) suggests that the simulation must be placed in a real world context involving situated action to be considered truly authentic, and to be truly authentic the human machine interaction should be transparent to allow the user to function effectively without concern for the details of the interface itself (p. 14). In this respect, a simulation based workshop needs function within a community of practice in order to be effective because it is the community itself that validates its authenticity and gives it contextual validity. Workshops built around the use of simulation tools, such as Control Station's LOOP-PRO Product Suite, have enabled refinery staff to easily and consistently learn, practice, and improve SOPs and daily work processes around PID tuning parameters that support optimal plant performance.

OPERATOR ORIENTATION

A Process Control Operator is the position that is closest to a facilities process control system. Support positions such as process engineers, control engineers, maintenance, and computer support are generally fewer in number and typically not on site 24/7. The ratio of Operators to Engineers is estimated at 28:1 and on night shift this ratio increases well above 100:1. A mid-size refinery, such as Chevron's El Segundo Refinery, can have a production infrastructure that covers several square miles with several hundred operators actively patrolling the infrastructure, monitoring equipment reliability, troubleshooting abnormal situations, and optimizing production performance. Activities at the facility take place around-the-clock requiring work processes and SOPs that function effectively around-the-clock, including training. The development of an effective array of simulation-based training (24/7) modules and skills development workshops (dayshift) is an important investment that can pay huge dividends in the form of incident reduction and increased process optimization.

A well designed simulation-based training program around process control can serve to elevate the Operator's role in SOP and work process performance; and improve communication and coordination between operations (24/7) and support team members such as control engineers, process engineers, maintenance, and computer support. Process control curriculum should produce operators that are technically-minded and procedurally-oriented. Among operator capabilities required by the process industry, including Chevron, suggest operators should possess proficient computer and problem-solving skills, work independently with little or no supervision, and demonstrate the ability to analyze and apply trouble-shooting techniques. New operators, in today's process industry, are quickly immersed in a highly sophisticated, computer-based environment requiring a high-level of training geared toward the application of the technology to company SOPs and work processes. Simulation based curriculum and workshops have a proven track record of producing high performance in a shorter period of time. Simulation training modules and workshops used together can produce a community centered learning environment that includes aspects of social context and the community of practice as part of a well designed curriculum. Introducing a new operator to the learning community through successful completion of learning modules and participation in workshops as a contributing member helps establish the context of their knowledge and allows them to participate with that community in higher level learning activities (Wenger et al, 2002).

Through simulation-based training and their role in recommending and implementing changes to work processes and SOPs, Operators improve the quality of their interactions with support teams. Gibson (1986), in his theory on ecological psychology, explains that knowledge is created by the capabilities of the learner to act on the physical environment in a *socially created* context. This theory suggests that the three conditions of 1) a learner's ability, 2) a physical environment, and 3) a social context must be present for learning to occur. Barad et al (1998) goes on to suggest that a learning task, such as on a simulator, cannot be truly authentic unless it contains the aspects of the social environment in which the real world task would take place (p. 25). Creating familiarity with a facilities SOPs by channeling a learners ability to manipulate a physical environment in a social context assures that structured procedures are followed and risks reduced by instilling a sense of ownership through membership in the community of practice. It is for this reason that simulation based curriculum must instill fundamental knowledge and skill; provide sufficient fidelity to provide authentic results; and establish the learning within the social context of existing production processes and all associated SOPs.

SOFTWARE-APPROPRIATE FRAMEWORK

Although simulation software has been widely touted as an integral part of effective training and skills development, it must be consistent with the manufacturer's processes and training framework. If a key benefit is the fidelity of a simulation to the actual process, then the simulation software must provide adequate fidelity to accurately reflect common production processes and realistic operational challenges. In terms of achieving a realistic process simulation, process control simulation tools must interface with the facilities standard process architecture and utilize accepted nomenclature. The simulated process dynamics must be consistent with the real-world, and process disturbances must impart a similar (if not exact) and even violent impact on the process to achieve fidelity. The more a simulation software reacts like its real-world counterpart, the better prepared trainees will be for addressing such challenges on the plant floor.

Bransford et al (1999) suggest that learning assessment is a critical part of any learning curriculum. According to Messick (1994), a learner's skill, knowledge, or performance is assessed because it has some value to society. A simulator provides an excellent platform for assessing a learner performance or real-world tasks and problem solving skills because it represents the real world and requires users to apply existing SOPs to situations that they may experience at some point in the future. A performance-based assessment has the capacity to place greater emphasis on learning problem-solving and critical thinking skills but challenge lies in developing a performance and assessment strategy that requires the learner to demonstrate those skills and provides a valid measurement of the results of the learner's performance (Linn, Baker, & Dunbar, 1991). Chevron and other standards-based companies require that process operators demonstrate the ability to apply existing best-practices and to effectively diagnose and correct abnormal situations. Mislevy et al (2002) suggests that simulator software, such as Control Station Loop Pro, must allow the construction of realistic tasks or situations that elicit the behaviors the learner needs to demonstrate to function effectively within the domain and then capture data that can be used to construct an accurate representation of the learner's performance. The data captured by the simulation software program needs to include the measurement of both a learner's performance, or how a learner arrives at a condition or state; and the learner's product, or the final state itself (Messick, 1994). Bennett (1999) suggests that software programs designed to assess learners must possess the ability to perform complex calculations designed to measure the behaviors elicited by the performance of complex tasks and thereby accurately determine the difference between a novice and expert performance.

In terms of bridging the gap between Operators and Engineers, the ability to document analysis prior to implementing change creates a valuable resource from which both Operators and Engineers can mutually benefit. With pre- and post-analysis information on hand, both types of staff can determine an appropriate solution using a common, acceptable, and complete set of data that has been augmented and validated through results assessment. This form of interaction, in particular, has been useful to Chevron and other leading process companies to test and refine existing SOPs and work processes. Further, the documentation becomes an important element in the company's knowledge repository as possible enhancements to SOPs are first proposed, new approaches are subsequently tested, and changes ultimately codified and disseminated.

In collaboration with Connecticut-based Control Station, Chevron's El Segundo Refinery is currently testing the principles discussed in the document to identify opportunities for the improvement existing SOPs and work processes around process control. The proposed changes involve developing and teaching process operators to use new work processes and SOPs for troubleshooting control loop performance; recording, evaluating and reporting abnormalities; and working as a member of a cross-functional team to optimize control loop performance. These changes can empower operators to perform duties previously done by engineers to evaluate underperforming process control loops and recommend improvements based on this analysis. The result of simulation-based training around control loops has the potential to produce a "super" operator that can free support staff to concentrate on the most difficult problems. For example, the newly recommended reporting capabilities target has improved coordination and communication between the operators and support staff resulting in fewer requests for tuning intervention. Anticipated outcomes from the trial include: 1) operator driven rapid response and recommendations for corrective action, 2) resolution of control issues versus short-term fixes, and 3) sustainable ownership for these broader responsibilities by the operations personnel.

CONCLUSION

Simulation technologies have enabled manufacturers to move beyond the fundamental objective of maintaining a trained workforce. When operated in concert with existing SOPs and operating communities, manufacturers gain insight into the ongoing relevance of those procedures. Chevron Products Company has employed a variety of simulation technologies, including those supplied by Control Station, to test established practices and to identify improvements in the company's procedures.

BIOGRAPHIES

Ronald Smith is Training Coordinator and Global Training Team Member for Chevron Products Company, a global energy supplier. Mr. Smith has been instrumental in the implementation and improvement of training services delivered at Chevron's El Segundo, California refinery. In particular, he has led the design and management of training programs that target the needs of over 200 operations staff. Mr. Smith holds a BS from the University of Phoenix and an MS in Instructional Design and Technology from California State University, Fullerton.

Dennis Nash is President and CEO of Control Station, Inc., an award-winning provider of easy-to-use process diagnostic technologies and practical simulation-based skills development workshops. Since joining Control Station in 2004, Mr. Nash has architected the collaborative development of simulation-based training and skills development materials with both Chevron Products Company and Hershey Foods. Additionally, under Mr. Nash's leadership Control Station has been recognized with multiple awards for innovation and for its contribution to the advancement of the process industries, including Chemical Processing Magazine's Vaaler Award. Mr. Nash holds a BA from University of Notre Dame and an MBA from University of Connecticut.

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