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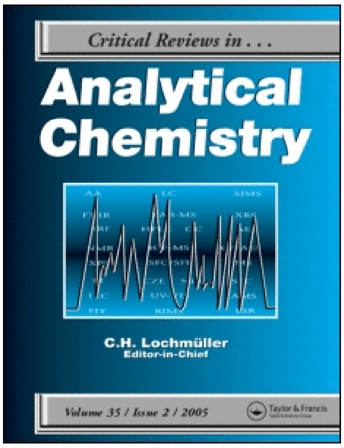

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Industrial Analytical Operations: Organizational Implications of Automation

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Industrial Analytical Operations: Organizational Implications of Automation

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ABSTRACT: In an age when speed-driven automation is displacing a large proportion of the workforce, the analytical laboratory will not be spared cutbacks. The greatest potential gains in productivity, however, may be in changing corporate culture to best use the human talent available. This article demonstrates that conditions of high sample variability or low throughput are best handled through leveraging the human resources in the industrial analytical laboratory. The analytical laboratory of the future will be even more dynamic than that of the present, requiring an environment conducive to learning. Management techniques are discussed.

KEY WORDS: laboratory automation, learning theory, technical management.

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I. INTRODUCTION

At a chemical company producing a polymer, a routine quality control assay by high performance liquid chromatography indicated the product did not meet specification. Since the production process had been successfully run for many years, the chromatographic column, which had been recently installed, seemed like a likely suspect. The analyst contacted the column manufacturer and was offered a replacement column, which gave the same results. The column fabrication department stated that there had been no change in processing. A crisis began to mount, as tank cars filled with polymer piled up on the railroad siding of the production facility. Weaknesses in the calculation procedure used in the analytical method were uncovered, consuming more days, but the weaknesses in the calculation did not account for the failure to meet specifications. Eventually, the company determined that the column manufacturer had introduced a subtle change into the column fabrication process that was responsible for a minor, but crucial, alteration in chromatographic behavior. In an excess of secrecy, the product change had been concealed from all but a few.

This anecdote illustrates the central role of human observation and behavior in affecting the pace of industrial development. Were industrial development simply the repeated analysis of virtually identical samples with identical equipment, the entire laboratory could be automated, people and their attendant complications banished, and the entire operation controlled by a computer. In many industries, elimination of labor has become a routine story in the news.[1] Not only blue collar workers or middle managers

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but also senior executives and scientists are being displaced by consolidation and automation. Automatic synthesizers are displacing traditional organic and medicinal chemists. Sample-preparation robots are replacing laboratory technicians. Automated injection, sample analysis, reporting, and database maintenance are replacing analytical work functions and therefore analytical jobs.

Mechanization of analytical chemistry has many attractions, not only in increasing the speed of analysis but also in improving the precision and repeatability of results and in managing the flow of information. Some of the key technical aspects of automation have been discussed elsewhere.[2] One limitation is that not all instruments are equipped for bar code reading. Lack of standardization of sample containers is another problem because samples often arrive in nonstandard containers and must be transferred to injection vials. Self-optimizing instruments are likely to be available soon.

At one extreme of the industrial analytical environment is quality control, where the numerous samples are virtually identical in composition, available in large quantities, and easily analyzed according to well-defined protocols. The precision required of analyses is high because the costs of an error in analysis are high, as illustrated by the anecdote mentioned above. At the other extreme is research, where samples are highly variable in composition, often available in limited quantities, and protocols to handle and analyze the samples have yet to be developed. The precision required for analysis is often low relative to that required of quality control, and the economic costs of error are correspondingly low (at least in the short-term). The quality control laboratory and the research laboratory are also very different in function. The quality control laboratory serves to answer well-defined questions about sample composition whereas the research laboratory is involved in framing the proper questions to be asked about sample composition. In the research laboratory, judgment has a crucial impact on the pace of development. Quality control and research represent contrasting paradigms of environments for which automation is easy or difficult.

The urge to accelerate industrial development is based on a true premise, namely, that development time is extremely valuable. The rush toward automation in analytical chemistry, however, is based on a false premise, namely, a presumption that more sample analysis necessarily means faster development. In a quality control laboratory, the speed of detection of unexpected variation may be a reasonable measure of productivity. More generally, however, the best measurement of productivity is not how many samples are run, but how quickly an answer can be given to a question. Subsequent sections categorize sample types according to ease of automation, and then focus on laboratory operations in cases where it is difficult to automate. It will be shown that in laboratories where automation is difficult, leveraging human resources by developing a learning environment is vital for productivity.

II. CATEGORIZATION OF LABORATORIES BY SAMPLE TYPES

Sample analysis can be categorized according to several schemes. Research samples are of highly variable composition, samples from a process under development are of controlled but variable composition, and samples from an established production process are of highly controlled composition. Another means of categorization is according to the precision required in the results of the test. An assay for concentration of a major component may require a precision of only a few percent, whereas an assay for

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purity may require a precision of a few tenths of a percent for the major component. A third means of categorization may be according to the consequences of a failed assay. An error in the assay of a research sample may lead to some hot words. An error in the assay of a pharmaceutical sample destined for the clinic, on the other hand, may lead to a costly recall, the scrapping of a multimillion dollar batch, or human illness and death, with the attendant liabilities. Therefore, a second important measurement of productivity is ensuring the match of the precision and reliability of a result to the need. There are complex trade-offs in analysis between precision, reliability, throughput, cost, and flexibility, such that not all can be simultaneously optimal. As the ultimate measurement of analytical laboratory performance is the value of the answers provided in bringing a product to market, the human contribution in prioritizing resource utilization has significant value.

In a typical analytical sample queue, one may find samples of the following kinds:

- Overflow from the quality control laboratory requiring a stringent protocol
- New product development for which no assay exists
- A research project for which the composition is virtually unknown
- Process development urgently required to justify a production change
- Validation work to research the precision of an existing assay
- Production work to characterize sidestreams

We can characterize these samples according to throughput and sample-to-sample variability according to a two-dimensional scheme, similar to that by Meyers and Athaide developed to describe the learning requirements involving customers and selling firms in the new product development process:[3]

		THROUGHPUT	
		Low	**High**
VARIABILITY	**Low**	Assay Validation (moderate learning)	Quality Control (low learning)
	High	New Product Development and Research (high learning)	Process and Production Research (moderate learning)

In a typical development pathway, sample analysis begins at low required throughput, and high sample-to-sample variability. With the decision to enter development, higher sample throughput and higher sample uniformity are achieved. A marketed product will require very high throughput but exhibit very little sample-to-sample variability. The development pathway usually proceeds

Low throughput-high variability (research samples)
↓
High throughput-high variability (bench scale-process optimization)
↓
Low throughput-low variability (large-scale pilot runs; validation)
↓
High throughput-low variability (full-scale production)

Clearly, when sample-to-sample variability is low and throughput is high, as in a quality control laboratory, the assay should be automated. When throughput is high, but sample variability is also high, partial automation may be achieved. When throughput is low, the investment required for automation may better be directed to optimizing the performance of human labor. As the analytical function is responsible for driving the process through these stages, the analytical team of the future is likely to be small, highly trained, highly flexible, accustomed to automation but not dependent on it. The team will need to be able to take highly idiosyncratic analyses, such as those developed for research samples, and convert them into fully automated operations suitable for quality control.

III. SUGGESTIONS FROM THE MANAGEMENT LITERATURE

Automation is most useful for situations of high-throughput and low sample variability, but may be counterproductive when samples are highly variable and throughput is low. Human resources become critically important whenever there is high situational complexity. Administration of human resources therefore reduces to an understanding of learning — at both the individual and organizational levels. As Ray Stata, Chairman of Analog Devices observed, "The rate of learning may be the only truly sustainable competitive advantage."[4] This is especially true in industries in which technology and market needs are often evolving simultaneously, as is the case in most science-based companies. The ability to learn quickly can shift the competitive advantage in these situations very quickly,[5,6] and can often mean saving critical time in the product development process, during which cash is being consumed without revenue flowing in. In high learning situations, the organization needs to leverage its learning resources most intently in situations involving high variability or low throughput.

Learning is critical because of the uncertainties in technology and market noted above and to facilitate the development and implementation of total quality management (TQM). Barrow[7] argued that learning is integrally linked to TQM because learning is a byproduct of continuous improvement and because learning facilitates process improvement. Two learning issues are salient here. First, how do individuals learn? Second, how does individual learning become part of the organization's memory and thus part of its competitive advantage? Individuals are the primary learning entity in the organization,[6,7] yet organizational learning differs from individual learning because it results in organizational histories and norms that are transmitted to others.[8]

Previous literature identified three phenomena in an organization that block the translation of individual learning to organizational learning:[6,9]

- Situational learning: learning that is used by the individual to solve a particular problem, but not generalized to solving other problems.
- Fragmented learning: learning that is not passed on to others in the organization after an individual learns.
- Opportunistic learning: learning that is based on the models of an individual or small group, rather than the shared models of the organization. This can be valuable in cases where the organization's models are inadequate to cope with a changing environment.

Optimizing and sustaining learning require effective organizational structure and values if learning at the individual and organizational levels. These include

- Valuing teamwork: Stata indicated that his corporation, Analog Devices, elevated teamwork to a virtue in the organization.[4] This, in turn, required that the culture be open (i.e., honest and free of hidden agendas) and objective (i.e., searching for answers based on reasoned and objective criteria). If it is important that learning occur at the bench level, and that this learning is translated into lessons for the organization, an atmosphere of trust should be developed so that employees feel that results are important to the organization and that they are expected to share their discoveries. Moreover, they should have confidence that their results will be evaluated honestly.
- Linking expectations to incentives: the organization's reward system should be consistent with expectations. Stata[4] and Dodgson[6] both noted the importance of reward systems in the development of a

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learning organization. This is consistent with the relationship observed between the reward structure and market orientation, that is, the ability to collect, disseminate, and use market information in the organization.[10] If learning and disseminating information are important, then a key challenge for the organization is to develop a system of incentives that reinforce these behaviors. The firm may develop a group reward structure so that individuals perceive that discovery and dissemination increase the likelihood of group success. For high technology, the strongest incentives may be freedom for creative expression, the social value of the work, and opportunities for variety in work, rather than simple financial carrots and sticks.

Developing a sense of efficacy in the organization: Bandura[11] reported that the likelihood of behavior is a function of reward and the perception that the behavior that can yield the reward can be performed (i.e., efficacy). Efficacy has been related to a wide variety of managerially relevant behaviors such as effort expenditure, goal commitment, work attitudes, and risk taking.[11–13] These phenomena have implications related to the reward structure. Not only do individuals need to understand that behavior yields certain results, but also they need to believe that they can perform that behavior. Thus, the manager has two challenges. First, she/he needs to ensure that scientists are confident in their own abilities to discover variation. Second, and related to the discussion of trust, they need to feel a sense of organizational efficacy, that is, that their information will be used effectively.

Another critical area affecting the scientist's role in the organization is the likelihood that his/her insights will be accepted and used by colleagues in the organization. Previous literature on market research use provides some insight into the use of information. In the industrial environment, dissonance between organizational goals and scientific practice may develop. Science and scientists rely very greatly on the credibility of information. Even small errors are not tolerable. Previous research on marketing research use and information processing suggests that the technical quality of the report[14,15] and credibility of the source affect the acceptance of the information.[16]

Although credibility is essential to the acceptance of information, organizations are more likely to act on information if it is politically acceptable as well.[14,15] Also, trust has an impact on the quality of the relationship between the researcher and user of information, which, in turn, affects the use of the information.[17] Trust, in turn, is related to a number of characteristics of the researcher: sincerity, integrity, tactfulness, timeliness, and ability to keep information confidential.[18] The implication of these results is that scientists need to have a high degree of political sensitivity and must learn to frame data in a form that is nonthreatening to the organization. Also, they need to develop effective working relationships with people in the organization to develop their trust and cultivate high-quality interactions that will enhance the use of results.

IV. APPLICATION

We have identified several key features of highly dynamic environments, and indicated in general terms how optimal performance can be achieved. Emphasizing learning and sharing of learning, and promoting teamwork through openness and objectivity and making a consistent incentive structure help to maintain productivity in a highly dynamic environment. In a learning environment, continuous improvement of skills, effective management of stress, and coordination with other organizational functions are corollary. Acknowledging individual accomplishments, committing to developing employees, and fostering individual initiative have also been recognized as important.[19] This section describes approaches to achieving these ends.

Trust is a critical issue in learning,[18-20] because without trust, information will not be shared. An element of trust is predictability, and predictability is the result of long-term planning. The analytical manager should make it a point to forecast for the group members the numbers, types, and priorities of samples expected. Where new analytical methods are likely to be needed, this information should be shared with junior associates. Another element of trust is that evaluation of work should use criteria that are fair, consistent, and widely accepted. This is particularly true in performance evaluations, which are often emotionally trying for employees. Standards of acceptable conduct should also be applied consistently, independent of level. This can be achieved through building "internal guarantees," in which penalties for late arrival at meetings or other corrosive behavior are applied to high and low alike.[21]

Another aspect of creating a learning environment is continuous training to upgrade employee skills. It has been noted that "employee investment is a low priority for managers."[22] Continuous training can take many forms, including formal courses, rotation among tasks, employee involvement in interdepartmental contacts, and group meetings in which each member presents an article from the literature. Concrete expressions by management of interest in continuous training may be sufficient to spur this effort, no matter how modest the resources available.

The incentive structure has been noted as important in developing a learning environment, and no incentive structure can function without measurement of achievement. Analytical scientists will be familiar with the principles behind diagnostic controls,[23] which are quantitative measures used in tracking. These are already in place in many analytical laboratories in the form of, for example, sample tracking systems to ensure timely turnaround. Because it is extremely difficult to compare the quantity of work performed in different analytical tests, the fairest diagnostic system may be measurement of current vs. past employee performance.

The manager also needs to modulate behavior, which can be accomplished through belief systems, boundary systems, and interactive control systems.[23] Belief systems are the genuinely held beliefs of the corporate culture. Full transparency in belief systems is an important component of corporate organization.[24] In the analytical laboratory, it is essential that those performing the analyses know why the samples are important, what question needs to be answered by a given analysis, and what level of precision is required for the answer. Boundary systems are explicit prohibitions. In the analytical laboratory, this means that the junior staff must be fully empowered within certain clear guidelines. In the dynamic environment of the analytical laboratory of the future, one of the key prohibitions may be against reporting results until they have been reviewed. Interactive control is discussion between different corporate branches. This could take the form of giving junior staff members a tour of a production facility to give them a clear understanding of methods of sampling. Given clear prohibitions, clear definitions, and clear understanding of the use to which analytical results are put, employees should be left free to take initiative.

The manager also needs to deal effectively with employee efficacy. As noted above, efficacy perceptions affect the behavior of the individual employee. When behaviors are important to the organization (e.g., information dissemination), employees should perceive that they can implement

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the behavior under question. This may mean that the manager finds herself in a "coaching" role if an employee has the ability to perform the behavior but does not believe that he can perform the behavior. Thus, skill training may be augmented with attempts to improve individual efficacy through recognition.

V. CONCLUSION

The analytical laboratory of the future will be highly automated, particularly in quality control. Some analytical functions, particularly in research, will remain nonautomated. The scientific performance required of staff will likely rise to match the demand for coping with a workload that includes more samples that cannot be handled by automation. Building trust and teamwork are essential to cope with the highly dynamic laboratory of the future. As Purser and Pasmore concluded:

> "Human behavior and technological progress are inseparable. How people feel about each other, what they focus attention on, the methods that they use for decision making, and the expectations they set for themselves influence directly and profoundly the rate of knowledge work. To view science as separate from human behavior is a grave error."

The good news is that automation of development can create jobs as well as destroy them. As costs of development come down, opportunities for servicing smaller markets become attractive. Customized products, produced on a smaller scale and in greater diversity, may be profitable. Therefore, the need to achieve maximum productivity through the human element will still be necessary, both in the early stages of development and in development of niche products.

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