DEVELOPING TROUBLESHOOTING SKILLS

In the Unit Operations Laboratory

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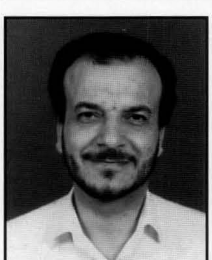
The unit operations laboratory (UOL) course is aimed at exploring previously learned knowledge, acquiring new knowledge by practice, and developing various skills and attitudes. To successfully complete this course, students are expected to acquire, in an integrated approach, a variety of skills, such as experimentation, communication, instrumentation, mathematical modeling and statistical analysis, troubleshooting, startup and shutdown, safety, and maintenance. These and other objectives have been reviewed extensively in the literature.[1,2] Developing and improving thinking skills in the UOL is another objective that has been considered recently.[3,4] Although some of these objectives have been elaborated upon,[5-7] others (such as troubleshooting[1,8] and maintenance) still need further study. The objective of this attempt is to bridge the gap between the expectations of industry and the education our graduates receive. Our approach is to expose students to some reality and allow them to experience and solve real problems.

This paper shows how to develop troubleshooting skills in the UOL. It presents the concepts of problem solving and troubleshooting, the approaches to troubleshooting in industry, and how to acquire troubleshooting skills in the UOL. A strategy for troubleshooting is developed that is based on understanding thinking skills, problem-solving heuristics, and the approaches to troubleshoot in industry. A program is used to develop these skills in an integrated approach with other skills. This paper emphasizes the troubleshooting part of the program, the details of which are presented elsewhere.[4,7] Students are expected to develop and improve troubleshooting skills by practicing, monitoring their actions, considering feedback, and reflecting to check the effectiveness of the method.



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PROBLEM SOLVING AND TROUBLESHOOTING

A problem is a difficulty that is viewed as a gap between the present state and a desired state or a conflict between what is observed and what is expected. Our goal is to overcome the difficulty by deciding its cause, knowing what operations are required to reach the desired goal, and how to correct the situation. This is problem solving.[9-12] It requires exercising the mind in every step of its sequence and being skillful at both critical and creative thinking.

Troubleshooting is the ability to solve problems related to the processes, the equipment, and the environment in order to restore normal conditions. Typical troubles of this kind indicate inadequate performance of equipment and processes and the inability to meet specifications and standards. This is usually reflected by the operating conditions and the product quality. Restoring normal conditions usually requires that corrective action be taken immediately, safely, and with minimum cost.[13,14] Obviously, troubleshooting is problem solving and hence, is thinking. By understanding and practicing thinking techniques and tools, problem solving heuristics, and how experts troubleshoot, students can develop troubleshooting skills and become much more efficient troubleshooters. Regular exercising in the UOL can accomplish sharpening and upgrading troubleshooting skills.

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TROUBLESHOOTING IN INDUSTRY[13-21,31-34]

Troubles in industry can be attributed to operators, equipment, processes, and the environment. Sometimes these troubles are obvious; at other times they are hidden. It is usually assumed that operators are highly proficient, knowledgeable, and familiar with the equipments' operation and limitations. Misoperation, false alarms, equipment and chemical failure, inadequate equipment design, and process failure can all cause troubles of this kind. Sometimes it is necessary to deal with a process that has never worked, a process that deviates from the expected, or a situation that requires a change in the capacity. The objective is to locate the problem, find the cause of the problem, and make repairs, usually with prompt action and quick feedback (see Table 1). A troubleshooter is a specialist who is called in when all other measures have failed.

ACQUIRING TROUBLESHOOTING SKILLS IN THE UOL

Troubleshooting skills can be developed in an integrated approach with other skills by following a program[4] that is aimed at fostering the right attitude, acquiring and practicing various thinking techniques and tools, and recognizing and avoiding mental errors. This program considers the role of the instructor and students, emphasizes inquiry-oriented and reflective activities, and maintains continuous interaction and immediate feedback from the instructor. Students practice various activities in a cooperative way, learn to think for themselves, acquire various skills, and understand in a way that makes content a permanent acquisition.

TABLE 1
Troubleshooting Steps Followed in Industry

* ***Being aware of the problem*** • Symptoms and deviations from normal conditions indicate the presence of a problem. They are determined by real observations and measurements obtained from the control room and from the field.
* ***Clarifying the situation by developing information-gathering and communication procedures*** • Organizing a multifunctional team composed of engineering, research and development, and plant representatives to conduct an around-the-clock information-gathering effort; using visual aids such as videotapes, photos, and charts; hearing personal testimony from operators; monitoring the operation for a certain amount time to define the actual performance and conducting empirically designed experiments to define the expected performance; knowing the characteristics of the chemicals being processed and the equipment being used for processing and using the process know-how report, the process design report, and the detailed engineering report.
* ***Looking for problem causes and various remedies*** • Considering the use of formal diagnostic tools, e.g., comparison, exclusion, substitution, and identification of evidence; using common sense and engineering judgment; considering various levels of sophisticated computer simulations or statistical design methods; using the case-based expert system in which enough observations are gathered until only one cause explains all symptoms.
* ***Correcting the situation*** • Implementing the best solution that is expected to restore normal operations.
* ***Checking the results for normal operation*** • Withdrawing samples, testing them, collecting instrument readings on a regular basis, and checking them against standard data.

The program used for this purpose should provide an environment that simulates industrial work and facilitates the information-gathering process. The following considerations, which are related to troubleshooting, need to be emphasized:

- *Providing a thorough understanding of the processes and equipment—how they work or how they are supposed to work. Students need to be frequently referred to their texts and other sources.*
- *Developing engineering and common sense by acquainting students with the equipment, the processes, and the available systems. Students should spend enough time in the laboratory working on the available equipment; they should feel and live in the practical environment.*
- *Understanding and practicing safety procedures and regulations and touring the facilities. Using a program that is based on practicing the role of the safety officer, the safety committee members, and performing safety assignments[5,7] has been found to work best.*
- *Facilitating access to historical data, calibration data, maintenance and troubleshooting records, specifications of the experiments, the flowcharts of the equipment and processes, and the operating manuals and testing procedures.*
- *Emphasizing skills related to troubleshooting, such as listening to the technicians, operators, and instructors.*

TROUBLESHOOTING STRATEGY

One approach for tackling closed-ended problems or exercises is to consider what is required from the problem, step back to explore the required information, and apply the pertinent tools and techniques required to solve the problem. Another approach is to explore the problem and available information first, followed by answering the questions. Open-ended problems, on the other hand, require setting up a strategy to get started, determining the direction and course of action, monitoring progress, and choosing the best solution among alternatives that satisfy the required goals.

Since troubleshooting is problem solving and problem solving is thinking, it would be appropriate and useful to develop a strategy that is based on thinking techniques and tools, problem-solving heuristics,[9-12,22-25] and industrial methods of troubleshooting. Thinking tools are related to the perception of a situation, the related information, processing, and thinking errors. A heuistic is a series of steps that guides us toward the solution by determining the starting point, the direction, and the course of action. Troubleshooting in industry is approached by collecting data, thinking of the problem to identify causes and solutions, correcting the operations, and checking the results for normal operation.

For this strategy to be a success, the student must foster the right attitude and maintain it during the troubleshooting process, must recognize and avoid thinking and troubleshooting errors, and must offer feedback and reflect on each step of the sequence. Asking questions proved to be an effective method to explore knowledge and alternatives in order to arrive at the best solution. The steps of our proposed troubleshooting strategy are:

- ***Identify the problem (recognize the symptoms and arrive at the causes by exploring the situation and the pertinent information):*** *feel and recognize difficulties, gather information (symptoms, deviations, data) and pertinent knowledge (definitions, theories, principles); explore this information and knowledge to reveal patterns and to determine what is missing and what is extraneous (present in a convenient form, analyze, ask insightful questions); collect missing information (search and research); talk about the situation and listen to others to know what happened, when it happened, and how it is compared to previous conditions; check the timing, the degree of urgency, and flexibility of specifications; think of possible causes and screen them using critical thinking tools and the elimination technique.*
- ***Set goals and strategies to generate alternative solutions*** • *Recall or learn pertinent theory and principles; determine if the problem should be resolved, or just live with the situation as it is; recall similar problems (if a solution is available, implement it); apply pertinent thinking techniques and tools such as: analyzing; synthesizing; seeing patterns; using analogy; predicting using rules and laws; brainstorming; breaking methods, definitions, and assumptions; eliminating by substitution; and restating the problem in different ways.*
- ***Check the attitude*** • *Maintain the will, the confidence, and the belief that the problem can be resolved; be ready to change goals and plans; leave the problem for a while or ask for help (depends on the timing and urgency of the problem); be aware of and avoid thinking errors (thinking blocks). One should consider reviewing his/her attitude during and after each step of the strategy.*
- ***Choose and implement the best remedy*** • *Decide the appropriate solution based on technical, economical, and safety considerations; implement the solution gradually, allowing enough time for adjustments to take place; collect new data from tests and readings from instruments; compare these with expected conditions and specifications.*
- ***Evaluate the effectiveness of the remedy*** • *Have normal situations been restored? Has the real problem been resolved, or is it the symptom that has been treated? Have the criteria and constraints been satisfied? Does the solution cause other problems? (Are there any side effects?)*
- ***Reflect on the procedure and the key factors*** • *What thinking techniques and tools were applied? How was the solution started? Was it fast or slow? What were the crucial factors (safety, economics, etc.)? How do you classify this problem? What do you think about the steps you followed? What suggestions do you recommend?*

APPLICATIONS

The UOL provides a variety of problems: straightforward and more difficult ones, naturally or deliberately occurring problems, and those given in the form of assignments (*e.g.*, accident investigation). Sometimes, incorrectly worded problems are given to alert students to thinking errors. Problems occur during normal operation and during startup and shutdown, and can be regarded generally as errors in design or malfunction, *e.g.*, impurities, leakage, streams off specifications, inefficient cooling or heating, etc.

The given assignments should be performed during the lab session and within the allotted time, and could include the following:

1. *Safety assignments such as accident investigations, root-cause analysis, and reducing the level of operation equipment noise.*
2. *Retrofit and maintenance assignments such as modifying a batch reactor to be operated as a CSTR, replacing corroded steel pipes with PVC pipes, and replacing a manually operated level indicator by a gage glass.*[26]
3. *Startup and shutdown tasks; for example, how to mix the reactants, which facility (mixer, heater, measurement) to start with in order to start up the reactor,*[27] *and how to drain the reactor.*
4. *Treating the errors of others. While operating the cooling tower, leakage was detected. A loose screw was tightened and leakage stopped for a while, but resumed later. Thorough investigation showed that the float was disassembled for corrosion checkup, cleaned, painted, and reassembled. The paint increased the weight of the float, and that was the cause of the leakage. This group reversed the above*

steps and the problem was fixed.[4]

A typical example showing the steps followed in UOL troubleshooting is given in Table 2.

TABLE 2
Practical Example of Troubleshooting
A Dry Wick in the Cooling Tower

- ***Feeling the problem*** • After starting up the cooling tower, measurements showed that the dry-bulb and wet-bulb temperatures were the same for a long time—an abnormal condition, at least for incoming air. Occasionally, the instructor needs to direct students' attention to this situation.
- ***Exploring the situation*** • The problem should be solved quickly, within the allotted session time. The situation was discussed with the group that operated the tower during the last session, with the technicians, and with the instructor, and they all confirmed that the situation was normal during that session. Unfortunately, no historical record was available.
- ***Preliminary action*** • More measurements were collected and compared with previous data. This was necessary for confirming available data.
- ***Exploring the data*** • Data followed the same trend—no change was detected.
- ***Thinking of the causes*** • A logical move was to suspect the source of data, so an independent measurement was taken and the measuring equipment and the controlling mechanism were checked, but all were found to be in order. Another suggestion was to stop the fan and check the measurements, but this was quickly discarded because it would interrupt the operation. The next step was to consider the symptom itself. The students asked the following questions: *What was wrong with this situation? Why was it not normal to have a wet-bulb temperature that equals the dry-bulb temperature? What is the wet-bulb temperature and how is it actually measured?* The wet-bulb temperature depends on the dry-bulb temperature and air humidity; therefore, if the air is saturated, the wet-bulb and the dry-bulb temperatures will be the same.[28] This generated two ideas: first, the air was saturated, and therefore the two temperatures were equal. Second, students had to check the mechanism of measuring wet-bulb temperature. The independent measurement of the wet- and dry-bulb temperatures, combined with hot weather, contrasted the first argument. After checking the thermocouples, the student were able to identify the problem: the wick was dry. Therefore, the dry-bulb and the wet-bulb temperatures were equal.
- ***The remedy*** • The solution was obvious. The wick should have been wetted.
- ***Correcting the situation*** • Wetting the wick required adding water to it and taking certain precautions. The students were aware of the precautions and knew where to find them:[29] 1) the wick should be completely wet so no dry areas of the wick are in contact with the gas, and 2) the makeup liquid should be at the wet-bulb temperature.
- ***Checking the results*** • To check the effectiveness of the solution, data were taken for a while and normal conditions were successfully restored without any side effects.
- ***Reflecting on the procedure*** • In reflection, students realized that things should not be taken for granted, *e.g.*, measurements and measuring equipment should be suspect and historical records of the equipment should be available. The steps to be added to the troubleshooting list[1] for this problem are: check the measurement, make sure measuring equipment is working well, check to see if air is saturated, and check whether or not the wick is wet. The lessons pertinent to the attitudes and thinking errors learned from this problem are: be persistent and confident, do not jump to conclusions, and be able to break the assumptions.

RECOGNIZING AND AVOIDING THINKING ERRORS

Thinking errors prevent the troubleshooter from correctly defining the trouble or arriving at the correct solution. These errors are known to occur in perception, information, and attitude. Being aware of and avoiding these types of errors greatly improves thinking skills. It is important for students' attention to be directed toward these errors by asking questions and reflection.

Errors in perception result from established patterns of the brain that control attention that need to be directed in order to change these patterns.[30] The errors include failure to see the situation (*e.g.,* considering the symptoms instead of the real problem, and the opinions instead of the facts), seeing one side only (*e.g.,* seeing only one solution to the problem), and considering only part of the time scale. Practical examples include failure to challenge the assumptions (*e.g.,* calibration curves), failure to wet the wet-bulb thermocouple before starting up the cooling tower, draining the reactor directly into the sewage without paying attention to the products, and assuming that the reaction was complete.

Lacking sufficient data, using false information, or having extra information are potential sources of errors in information. This frequently happens in studying flooding effects in fluidization, in startup of a reactor, and in establishing stress strain curves.

Negative attitudes resist thinking or direct it in the wrong direction. This happens when there is a lack of genuine curiosity, when others are not listened to, and when things are taken for granted. Practical examples include ignoring straightforward reasons and considering complicated ones, ignoring minor things that might indicate a developing problem, and jumping to the conclusion that a particular thing is at fault because it is a common type of failure.

DISCUSSION

Problem solving has gained much attention in the chemical engineering literature, though more toward the classroom and less toward the laboratory. The UOL is one place to develop and improve troubleshooting skills that can be developed and mastered with intensive practice and time. Students are expected to acquire a pattern of thought and to gain the traits of expert troubleshooters. The troubleshooting strategy we use requires that students maintain the right attitude during the troubleshooting process, and that they reflect on their actions. This motivates the process and facilitates forming the troubleshooting list,[1] which will hopefully be used as the basis for a computerized case-based system.

Acquiring problem solving, and hence troubleshooting, skills enhances problem-based learning (PBL), which is defined as any learning environment in which the problem drives the learning process.[22] Our program provides an opportunity for students in the UOL to explore previously learned knowledge, to learn new knowledge, to acquire an orderly pattern of thought in solving practical problems in a critical and creative manner, and to develop the traits of skillful practictioners. It requires continuous feedback and reflection from the students as well as involvement of the instructor. Therefore, troubleshooting in the UOL motivates learning and facilitates memorization (storage and retrieval of information).

To assess students' performance, we use a method that considers both personal and teamwork abilities and monitors the progress of students' work both in the process (skills) and content (text).[4] This method emphasizes the achievement of goals and considers the details in a diagnostic manner (to reveal the strengths and weaknesses). Continuous follow-up, immediate feedback, and reflection are essential parts of this method.

The background of the instructor is important in the sense that he can choose to widen the scope of troubleshooting to include several types of problems and situations. Instructors track the work of the students, which is not going to be graded unless it is fully acceptable. They guide and monitor the students in the right direction, encourage interaction and immediate feedback, and provide consultation as required.

Overall, students enjoy such a program and find the UOL an interesting and attractive place to work. They have the opportunity to think effectively, to reenforce and emphasize what they have learned elsewhere, to acquire and maintain the right attitude, to appreciate the cost and effort used to search and research the data, and to link with everyday life. They practice this in an interactive, collaborative, and non-competitive endeavor, with immediate feedback from the instructor on their performance. The instructor, however, must be aware of the goals he wants to accomplish and rank them according to the way they are achieved. For productive results, projects and procedures should be updated regularly.

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