data and compare theory and experiment, write a report and
give an oral presentation.

Rotation 3: The troubleshooting rotation receives the reports of Rotations 1
and 2. Rotation 3 uses the data in these reports to compare with
the data they are given that was taken from the equipment when
it was malfunctioning. Here the GSIs devised a fault (e.g., valve
turned the wrong way) and collected data during this faulty
operation and give it to Rotation 3. The students use the trou-
bleshooting skills they learned in lecture to troubleshoot the
equipment to find the fault and reproduce the GSIs data.
Previously Rotation 3 carried out an economic analysis of the
material generated/separated in their given equipment.

2. Learning Stations

Every experiment is linked to a computer in order to change settings and record
data. The computers not only record data, they also serve as a resource learning
center that contains videos, interactive computing modules (ICMs), access to the
laboratory web site, and the Equipment Encyclopedia CD (the equipment CD was
developed by Dr. Susan Montgomery). The videos show how to start up and oper-
ate the equipment as well as presentations from the previous class on potential
safety and operational problems on the experiments. There are two ICM’s, one on
planning and one on troubleshooting. The planning module contains a review of
Gantt charts, critical paths and deployment charts and an interactive scenario the
student must solve. The ICM troubleshooting module will be discussed later in
this paper.

The students can go on-line to review the lecture notes and detailed operating
instructions pertaining to their experiment. The students can also connected on-
line to Jim Henry’s Unit Operations Laboratory at the University of Tennessee in
Chattanooga. Here they were able to make live on-line changes to the variables
and take on-line measurements on UT’s tray distillation column in Chattanooga.
The UT data were compared with data taken from the packed bed column at the
University of Michigan.

IV. Practicing Critical Thinking and Troubleshooting Skills

A. Critical Thinking

In his book on Critical Thinking, R. W. Paul portrays Socratic questioning as
being the heart of critical thinking. In keeping with this premise, students are
asked to formulate critical thinking questions on homework problems and explain
why the question involved critical thinking, drawing on R.W. Paul’s six types of
Socratic Question. The six types are as follows:

Table 2 Six Types of Socratic Questions

(1) Questions for clarification: Why do you say that? How does this relate to our
discussion?
(2) Questions that probe assumptions: What could we assume instead? How can
you verify or disprove that assumption?
(3) Questions that probe reasons and evidence: What would be an example?
(4) Questions about viewpoints and perspectives: What would be an alternative?
(5) Questions that probe implications and consequences: What generalizations can
you make? What are the consequences of that assumption?
(6) Questions about the question: What was the point of this question? Why do
you think this question was asked?

The following are two examples of the students’ critical thinking questions (CTQ)
on reaction engineering and their reasoning as to why the question involves critical
thinking:

CTQ1 “Problem 8-9 concerns a non-adiabatic dimerization reaction that was
solved using Polymath. Compare the plots of entering temperature versus conversion
for P8-9 parts (c) and (l). What is similar about the plots? What is different?
How would you explain the variation in plots (i.e., what are the contributing
conditions)?” If you were to run this reaction, what conditions would you specify?

Reasoning: These are critical thinking questions because they apply many of the
Socratic questions. It incorporates questions about perspective, probes assumptions,
and probes implications and consequences. It is important to think about how
problem P8-9 can be applied to the real world.”

CTQ2 “In problem P4-26 butanol was fed to a semi-batch reactor containing
ethyl acetate. A fellow engineer proposes to pull a vacuum within the semibatch
reactor. The engineer believes that lowering the pressure inside the reactor will draw
ethanol out of the liquid phase, driving the reaction further to the right. Discuss the
validity of this proposal given the present reactor temperature and the relative
volatilities of the other species present. Assume the butanol feed enters the bottom
of the reactor.

Reasoning: This is a critical thinking question that uses the Socratic question
“What would be an alternative? designed to develop new viewpoints and
perspectives. The question draws on the chemical engineer’s previous knowledge of
LeChatelier’s principle, Boyle’s law, as well as how a reactor will behave under
various conditions.”

*Paul, R.W., Critical Thinking (Published by the Foundation for Critical Thinking, Santa Rosa,
CA, 1992)

Scheffer and Rubenfeld* discuss critical thinking habits and critical thinking skills. For each of the critical thinking skills shown in Table 3, they give a number of activity statements.

### Table 3 Critical Thinking Skills

**Analyzing:** separating or breaking a whole into parts to discover their nature, function and relationships.
- "I studied it piece by piece"
- "I sorted things out"

**Applying Standards:** judging according to established personal, professional, or social rules or criteria.
- "I judged it according to..."

**Discriminating:** recognizing differences and similarities among things or situations and distinguishing carefully as to category or rank.
- "I rank ordered the various..."
- "I grouped things together"

**Information Seeking:** searching for evidence, facts, or knowledge by identifying relevant sources and gathering objective, subjective, historical, and current data from those sources.
- "I knew I needed to lookup/study..."
- "I kept searching for data."

**Logical Reasoning:** drawing inferences or conclusions that are supported in or justified by evidence.
- "I deduced from the information that..."
- "My rationale for the conclusion was..."

**Predicting:** envisioning a plan and its consequences.
- "I envisioned the outcome would be..." "I was prepared for..."

**Transforming Knowledge:** changing or converting the condition, nature, form, or function of concepts among contexts.
- "I improved on the basics by..."
- "I wondered if that would fit the situation of..."

Scheffer and Rubenfeld maintain that critical thinking is an essential component of professional accountability. These also give critical thinking habits that not only apply to nursing, but to any discipline. These habits are shown in Table 4.

### Table 4 Critical Thinking Habits of the Mind

| Confidence: | assurance of one's reasoning abilities |
| Contextual Perspective: | consideration of the whole situation, including relationships, background and environment, relevant to some happening |
| Creativity: | intellectual inventiveness used to generate, discover, or restructure ideas, imagining alternatives |
| Flexibility: | capacity to adapt, accommodate, modify or change thoughts, ideas and behaviors |
| Inquisitiveness: | an eagerness to know by seeking knowledge and understanding through observation and thoughtful questioning in order to explore possibilities and alternatives |
| Intellectual Integrity: | seeking the truth through sincere, honest processes, even if the results are contrary to one's assumptions and beliefs |
| Intuition: | insightful sense of knowing without conscious use of reason |
| Open-mindedness: | a viewpoint characterized by being receptive to divergent views and sensitive to one's biases |
| Perseverance: | pursuit of a course with determination to overcome obstacles |
| Reflection: | contemplation upon a subject, especially one's assumptions and thinking for the purposes of deeper understanding and self-evaluation |

### B. Troubleshooting

1. **Some General Guidelines**

Troubleshooting is a problem-solving process to find the root cause of a problem. While troubleshooting is far from an exact science there are some guidelines and heuristics (e.g., K-T® analysis) that can prove quite useful. Successful troubleshooting starts with a solid understanding of engineering fundamentals, the process and the specific unit questions. It also requires paying attention to detail, developing good listening skills, viewing the problem first hand, and understanding the symptoms. These and other troubleshooting guidelines are summarized by Laird et al. and shown in Table 5.

### Table 5 Troubleshooting Guidelines

| 1. | Gather information. |
| 2. | Apply solid engineering fundamentals. |
| 3. | Separate observations from hypotheses or conjectures. |
| 4. | Independently verify data using field measurements and observations, when possible. |
| 5. | Make rigorous comparisons with satisfactory operations. |
| 6. | Spend time in the unit making direct observations – even if you are not sure what to expect. |
| 7. | Consider the entire system related to the problem. |
| 8. | Practice good listening skills. |
| 9. | Do not reject serendipitous results. |
| 10. | Do not fall in love with a hypothesis – seek to reject, as well as to accept. |

---


Gathering relevant information is a key in any troubleshooting process. Learn how to ask the critical questions. See if you have the necessary information to make a “ballpark” calculation. Walk the plant, talk to the operators, compare data from malfunctioning unit with that of normal operation. The very useful K-T algorithm for making this comparison is discussed next. Make sure you define the real problem instead of the perceived problem as discussed in Fogler and LeBlanc.\textsuperscript{11} (see http://www.engin.umich.edu/~cre).

2. Kepner-Tregoe\textsuperscript{®} (K-T\textsuperscript{®}) Analysis

The unit operation laboratory was built on a critical thinking and troubleshooting foundation. In the lecture part of the course, the Kepner-Tregoe (K-T) algorithms and Professor Don Woods’ troubleshooting guidelines from his forthcoming book on Process Trouble Shooting\textsuperscript{12} were introduced. An excellent set of Rules of Thumb for troubleshooting can be found in this book, along with guidelines for polishing data gathering and developing critical thinking and interpersonal skills. The critical thinking and troubleshooting focus was then applied in the laboratory experiments. The complete K-T Strategy is shown in the following figure.

Figure 2. The Four Components of the Kepner-Tregoe\textsuperscript{®} Approach

\begin{center}
\begin{tikzpicture}
  \node[anchor=north] at (0,0) {Situation Analysis (Where are we?)};
  \node[below of=Situation Analysis,anchor=north] {Problem Analysis};
  \node[below of=Problem Analysis,anchor=north] {Past};
  \node[below of=Past,anchor=north] {What is the fault?};
  \node[below of=Past,anchor=north] {Decision Analysis};
  \node[below of=Decision Analysis,anchor=north] {Present};
  \node[below of=Present,anchor=north] {How to correct the fault?};
  \node[below of=Decision Analysis,anchor=north] {Potential Problem Analysis};
  \node[below of=Potential Problem Analysis,anchor=north] {Future};
  \node[below of=Future,anchor=north] {How to prevent future faults?};
\end{tikzpicture}
\end{center}

In my mind the K-T strategy is one of the very best heuristics one can use in troubleshooting applications. Each of the four components has a heuristic or work sheet that is filled out in order to resolve the issue at hand. Outlines of these worksheets are shown in Figure 3.

We begin with situation analysis. K-T Situation Analysis not only helps us decide which problem to work on first; it also guides us with respect to what is to be done. Do we need to learn the cause (Problem Analysis, PA), make a decision (Decision Analysis, DA), or plan for success to avoid future problems (Potential Problem Analysis, PPA)? That is, in situation analysis we classify the problem into one of these analysis groups. In Problem Analysis, the cause of the problem or the fault is something unknown that happened in the past and we have to find it. What is it that happened in the past that is causing the current trouble? In Decision Analysis, the cause of the problem has been found and now we need to decide how to correct the fault. In Potential Problem Analysis, we want to anticipate and prevent future problems from occurring.

Figure 3. Outline of K-T worksheet for each of the K-T components.\textsuperscript{13}

\begin{center}
\begin{tabular}{|c|c|c|c|}
\hline
Problems & Timing (H,M,L) & Trend (H,M,L) & Impact (H,M,L) & Process (PA, DA, or PPA) \\
\hline
1. & & & & \\
2. & & & & \\
3. & & & & \\
\hline
\end{tabular}
\end{center}

\begin{center}
\begin{tabular}{|c|c|c|c|c|}
\hline
Problem Analysis & IS & IS NOT & Distinction & Probable Cause \\
\hline
What & & & & \\
Where & & & & \\
When & & & & \\
Extent & & & & \\
\hline
\end{tabular}
\end{center}

\begin{center}
\begin{tabular}{|c|c|c|c|c|}
\hline
Decision Analysis & A & B & C & \\
\hline
Musts & 1. & GO & NO GO & GO \\
2. & GO & & & GO \\
\hline
Wants & WT & Rating & Score & Rating & Score \\
\hline
1. & & & & & NO GO \\
2. & & & & & \\
\hline
Total A= & & & & \\
Total B= & & & & \\
Total C= & & & & \\
\hline
\end{tabular}
\end{center}

\begin{center}
\begin{tabular}{|c|c|c|}
\hline
Potential Problem Analysis & Possible Causes & Preventive Actions & Contingency Plan \\
\hline
A. & 1. & & \\
& 2. & & \\
B. & 1. & & \\
& 2. & & \\
\hline
\end{tabular}
\end{center}

\textsuperscript{13}Fogler, H.S. and S.E. LeBlanc Lit. Cit.
a. Potential Problem Analysis

Safety is a major concern in any situation. Abu-khalaf presents an excellent discussion of safety in the laboratory and activities the students can practice in the laboratory to assimilate and understand safety issues. One excellent way to promote safety is the application of the K-T Potential Problem Analysis (PPA) approach. Use of this heuristic can decrease the possibility of a disastrous outcome both in the lab and on the job. Before starting their first laboratory experiment, students applied potential problem analysis to the experiment that they had been assigned by completing the PPA worksheet shown below. The PPA Table delineates potential problems and suggests possible causes, preventive actions, and contingent actions.

Table 6 Structure of K-T Potential Problem Analysis

<table>
<thead>
<tr>
<th>Potential Problem</th>
<th>Possible Causes</th>
<th>Preventive Action</th>
<th>Contingent Action</th>
</tr>
</thead>
<tbody>
<tr>
<td>A.</td>
<td>1.</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>2.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>B.</td>
<td>1.</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>2.</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

In PPA the students are asked to brainstorm all the things that could go wrong with their experiment, possible causes of the problem, and the preventive actions and contingency plans that could be undertaken. The following potential problem analysis was carried out by students on the distillation equipment.

Table 7 Application of Potential Problem Analysis to Packed Bed Distillation Experiment

<table>
<thead>
<tr>
<th>Potential Problem</th>
<th>Possible Causes</th>
<th>Preventive Action</th>
<th>Contingent Action</th>
</tr>
</thead>
<tbody>
<tr>
<td>Product off-</td>
<td>Column is flooding</td>
<td>Lower vapor flow rate</td>
<td>Shut off re-boiler and consider other causes</td>
</tr>
<tr>
<td>specification</td>
<td>Pump overheating because no liquid supplied to pump seal ring</td>
<td>Always open liquid supply to pump as the first step</td>
<td>Do not operate</td>
</tr>
<tr>
<td></td>
<td>Mechanical seal in pump is shattered</td>
<td>Check seal</td>
<td>Do not operate</td>
</tr>
<tr>
<td>Pump failure</td>
<td>Vent valve (V-1 valve) is opened during operation</td>
<td>Make sure to close vent valve after condensate starts to form in condenser</td>
<td>Immediately close vent valve open outside door and evacuate laboratory</td>
</tr>
<tr>
<td></td>
<td>Liquid containing methanol is discharged into sinks or drains</td>
<td>Dispose of methanol solutions in hazardous waste containers</td>
<td>Flush sinks or drains with large amounts of water</td>
</tr>
<tr>
<td></td>
<td>Pressure build up in the column</td>
<td>Closely monitor re-boiler heating rate</td>
<td>Shut off re-boiler</td>
</tr>
</tbody>
</table>

b. K-T Problem Analysis

In using the K-T Problem Analysis to troubleshoot problems, one of the most important steps is to apply critical thinking in making the troubleshooting distinctions in what, when, where and extent of the problem compared to normal operation. Filling out the K-T algorithm shown below displays all known information in such a way to more easily find the fault. An example of the application of the K-T PPA techniques to a real life problem is given in Appendix 1.

Table 8 The Four K-T® Dimensions of a Problem

<table>
<thead>
<tr>
<th>What: Identify:</th>
<th>What is the problem?</th>
<th>What is not the problem?</th>
<th>What is the distinction between the yes and the no?</th>
<th>What is a possible cause?</th>
</tr>
</thead>
<tbody>
<tr>
<td>Where: Locate:</td>
<td>Where is the problem located?</td>
<td>Where is the problem not found?</td>
<td>What is distinctive about the difference in locations?</td>
<td>What is a possible cause?</td>
</tr>
<tr>
<td>When: Timing:</td>
<td>When does the problem occur?</td>
<td>When does the problem not occur?</td>
<td>What is distinctive about the difference in the timing?</td>
<td>What is a possible cause?</td>
</tr>
<tr>
<td>Extent: Magnitude:</td>
<td>How far does the problem extend?</td>
<td>How localized is the problem?</td>
<td>What is the distinction?</td>
<td>What is a possible cause?</td>
</tr>
<tr>
<td>Extent: Duration:</td>
<td>How many units are affected?</td>
<td>How many units are not affected?</td>
<td>What is the distinction?</td>
<td>What is a possible cause?</td>
</tr>
<tr>
<td>Extent: Extent:</td>
<td>How much of any one unit is affected?</td>
<td>How much of any one unit is not affected?</td>
<td>What is the distinction?</td>
<td>What is a possible cause?</td>
</tr>
</tbody>
</table>

3. Troubleshooting Exercises

Three lecture class periods were devoted to in-class exercises on troubleshooting. Six troubleshooting problems, similar to the one shown in Figure 4 were chosen from a group of over 40 actual case histories compiled by Professors Tom Marlin and Don Woods at McMaster University. These troubleshooting exercises were carried out using a modified version of Woods' "Trouble Shooter/Observer/Expert System." The observer was not used in the UOL because the troubleshooters and experts evaluated each other. In this exercise, the class divided up into groups of three and each group was designated either a troubleshooter group or an expert systems group. Each troubleshooter group was paired with an expert systems group (See Figure A-1 in Appendix 3). The troubleshooters were then given a problem similar to the one that follows.

**Abu-khalaf, A.M., “Introducing Safety in the Chemical Engineering Laboratory Course,” Chemical Health and Safety, 8(1), 8-11 (2001).**

TRoubleshooting: The Boiler Feed Heater Case #1

Waste flue steam from the ethyl acetate plant is saturated at slightly above atmospheric pressure. It is sent to the shell of a shell and tube heat exchanger to preheat the boiler feed water to 70°C for the nearby boiler house. The boiler feed heater is shown in the figure below.

Condensate is withdrawn through a thermodynamic steam trap at the bottom of the shell. The water flows once through the 3/4" nominal tubes. There are 1000 tubes. "When the system was put into operation 3 hours ago everything worked fine," says the supervisor. "Now, however, the exit boiler feed water is 42°C instead of the design value. What do we do? This difficulty is costing us extra fuel to vaporize the water at the boiler." Fix it.

![Diagram of the boiler feed heater system](image)

Figure 4. Example of In-class Exercise from Marlin/Woods Case History.

The expert system group was given the complete solution in order to fully understand the cause of the malfunction and to be able to answer any questions posed by the troubleshooters group. After receiving a written question from the troubleshooters, the experts wrote out the answer and assigned a time to that question. The time assigned is the time it would take for a plant operator or a technician to find the answer. For example, if the troubleshooters were in need of a temperature or pressure measurement it would not take a plant operator very long to walk over and read the gauge, so five minutes would be the assigned time. If the answer required an analysis of the gas stream or disassembling the equipment, then four to eight hours might be the assigned time.

Typical questions from the troubleshooter to the expert system are shown in the following table.

### Table 9 Typical Troubleshooter Questions And Expert Systems Responses
(from Woods and Marlin)

<table>
<thead>
<tr>
<th>Q#</th>
<th>Question from Troubleshooters</th>
<th>Answer from Experts</th>
<th>Cost to Answer</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Steam Pressure at P100?</td>
<td>Higher Than Design.</td>
<td>5 min.</td>
</tr>
<tr>
<td>2</td>
<td>Steam Temperature at T100?</td>
<td>Design Value.</td>
<td>5 min.</td>
</tr>
<tr>
<td>3</td>
<td>Amount of Condensate Drained from Tubes Via the Bypass Valve?</td>
<td>About 0.5 Pints of Condensate.</td>
<td>30 min.</td>
</tr>
<tr>
<td>4</td>
<td>Feedwater Exit Temperature After 10 min. of Bleeding?</td>
<td>68 Degrees Celsius.</td>
<td>40 min (120 min. if Drain Valve Already Opened)</td>
</tr>
<tr>
<td>5</td>
<td>Feedwater Exit Temperature 3 Hours After Bleeding Pipes?</td>
<td>45 Degrees Celsius.</td>
<td>3 Hours.</td>
</tr>
<tr>
<td>6</td>
<td>Bleed Gas Analysis Results.</td>
<td>20% Air, 2% Carbon Dioxide, Traces of Oil.</td>
<td>8 Hours.</td>
</tr>
</tbody>
</table>

During the troubleshooting exercises, the participants playing the part of the experts system might receive an action request not listed in the problem description. The expert systems are asked to use their best judgment for how to respond to the request and refer to the suggested cost estimates are shown in Table 9.

### Table 10 Typical time Penalties

<table>
<thead>
<tr>
<th>Action</th>
<th>Cost (time)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Read meter</td>
<td>2 min</td>
</tr>
<tr>
<td>Check history</td>
<td>5 min</td>
</tr>
<tr>
<td>Make manual measurement</td>
<td>30 min</td>
</tr>
<tr>
<td>Adjust operating conditions</td>
<td>30 min</td>
</tr>
<tr>
<td>Disassemble equipment</td>
<td>4 hr</td>
</tr>
<tr>
<td>Install new equipment</td>
<td>5 day</td>
</tr>
</tbody>
</table>

The total time (which could be translated into a cost) for all the questions is an indication of how effectively the students were in troubleshooting the problem. The time penalty causes the troubleshooter to think critically by being precise and asking themselves,

"What will I learn if I ask this question?"

"How will I use this information to find the fault?"

The troubleshooters are told to always keep four or five working hypothesis as to what could be causing the fault as they work through the exercise. Woods’ stresses this point of brainstorming to generate a number of potential explanations.16 For the previous example shown in Figure 4, possible explanations might be...

---

16Woods, lit. cit.
1) The steam trap is blocked causing liquid condensate to back up in the heat exchanger so the steam does not contact the pipes in the exchanger.

2) The entering water is sub-cooled.

3) The steam pressure and temperature have dropped.

4) The heat exchanger has become fouled.

5) The steam is dirty, i.e., contains non-condensable gases.

Techniques for brainstorming (e.g., Osborn's Vertical Thinking, DeBono's Lateral Thinking) can be found in Fogler and LeBlanc. During these troubleshooting exercises the students often fill out a K-T problem analysis such as the one shown in Table 12.

Table 12 K-T Problem Analysis of Case 1 Boiler Feed Heater

<table>
<thead>
<tr>
<th>IS</th>
<th>IS NOT</th>
<th>DISTINCTION</th>
<th>CAUSE</th>
</tr>
</thead>
<tbody>
<tr>
<td>Low exit temperature</td>
<td>Normal or too high exit temperature</td>
<td>Insufficient heat supply to raise the temperature to 70°C</td>
<td>Build up of non-condensable gas from waste steam or shell filled with water</td>
</tr>
<tr>
<td>Correct water and steam temperature measurements</td>
<td>Wrong temperature measurements</td>
<td>Current temperature driving force should be sufficient to heat water to 70°C as condensing steam has high heat transfer coefficient</td>
<td>Increase in heat transfer resistance</td>
</tr>
<tr>
<td>Normal water feed rate</td>
<td>High water feed rate</td>
<td>Current temperature driving force should be sufficient to heat normal water flow rate to 70°C</td>
<td>Increase in heat transfer resistance</td>
</tr>
<tr>
<td>Filter and steam trap open</td>
<td>Blocked filter or steam trap</td>
<td>Tubes not surrounded by liquid condensate</td>
<td>Something other than liquid increasing resistance</td>
</tr>
<tr>
<td>Three hours after startup</td>
<td>Immediately after startup</td>
<td>Decrease in heat transfer</td>
<td>Build up of non-condensable gas from waste steam or shell filled with water</td>
</tr>
<tr>
<td>Inside heat exchanger</td>
<td>Outside heat exchanger</td>
<td>Entering temperatures normal</td>
<td>Insufficient heat transfer between shell and tubes</td>
</tr>
<tr>
<td>Abnormal entering water or steam temperatures</td>
<td>Temperature driving force not affected</td>
<td>Heat transfer resistance increased</td>
<td></td>
</tr>
<tr>
<td>Only part of the equipment, some tubes not affected</td>
<td>All tubes not affected</td>
<td>Heat exchange takes place between shell and tubes</td>
<td>Insufficient heat transfer between shell and tubes</td>
</tr>
</tbody>
</table>

The problem in this example turned out to be “dirty steam” containing non-condensable gases blanked the heat exchange tubes in the shell of the heat exchanger. Consequently, the condensing steam, which has a high heat transfer coefficient, could not effectively reach the tubes carrying the water.

Once the group has identified the fault, a new problem is given, and the group roles are switched: Troubleshooters become the expert systems group, the expert systems group members become the troubleshooters. In addition to K-T analysis, topics from Don Woods' Process Trouble Shooting,4 were included such as the distracting/enriching characteristics of troubleshooters (Appendix 2).

4. Interactive Computing Module (ICM) on Troubleshooting

The students also can hone their troubleshooting skills using an interactive computer module (ICM) on troubleshooting. A number of ICMs have been developed for Chemical Reaction Engineering (CRE)12 and for Problem Solving, and are available from the CACHE Corporation. These modules have been received enthusiastically by students across the nation.13,14

In the ICM troubleshooting module the students are asked to troubleshoot a microplant that manufactures styrene from ethyl benzene and is not operating properly. This troubleshooting module is included in the attached CDROM.

The plant consists of two preheaters to the reactor, a reactor, a condenser, a liquid gas separator, a liquid-liquid separator, an adsorption system, and a distillation column and is shown in Figure 5.

This ICM is included on the CDROM that is taped to the inside of the back cover of this Lectureship book.

Figure 5. Computer screen shot of microplant

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There are a number of potential faults in each unit, any one of which could be causing a problem. Two faults are chosen randomly each time the student logs on the ICM. After the student logs on the ICM, they can access two sets of simulated data. One set gives instrument measurements such as temperatures, pressures, and flow rates, for a number of the streams for normal operation. The other set gives the same readings for faulty operation.

![Table 5. Flowsheet and Component Mole Fractions](image)

**Figure 6.** Computer screen shot showing comparison of actual measurements and expected measurements for stream 5.

The student must find the two faults by interacting with the computer to obtain measurements and operating conditions of each piece of equipment. Each time the student makes a request of the computer, the student is charged a specified amount of money, depending on the complexity of the request, along the same lines as the Troubleshooter/Expert System technique. The student can choose one or more pieces of equipment on which to make measurements(s) and obtain the result. A list of instrument readings and measurements typically available on the chosen piece of equipment is provided to the student. Figure 7 uses the reactor as an example to show the type and cost of the measurement that can be carried out.

![Figure 7. ICM Screen Shot of Measurements Available to Make on the Reactor and Adsorbers](image)

The students are limited in the amount of money they have to spend, so they must be prudent in the measurements they choose to make. Consequently, they are encouraged to use the same troubleshooting procedures they used with the in-class exercises with the expert system.

5. **Troubleshooting the Lab Equipment**

The last three weeks of laboratory sessions are devoted to the students applying the troubleshooting skills they learned and practiced in the lecture part of the course. In Rotation 3 the students work in groups of three on one of four different pieces of equipment: Packed bed distillation column, Double effect evaporator, Advanced Reactor Safety Screening Tool (AR SST), and the CSTR/PFR apparatus. In the final rotations, the Graduate Student Instructors (GSIs) generate a specific fault in each one of these pieces of equipment and collect the data. The students are given two sets of data. One set is contained in the reports of the first two rotation groups that operated the equipment under normal conditions. The second set of data contains these measurements for the same equipment, but this time obtained under faulty operation planned by the GSIs. After the students of the 3rd rotation familiarize themselves with their particular piece of assigned equipment they were asked to do the activities in Table 13.

**Table 13 Laboratory Troubleshooting Procedure**

1. Compare the data obtained under normal operation with that obtained under faulty operating conditions.
2. Brainstorm all the things that could explain the faulty data.
3. Use K-T® analysis (either PA or PPA in modified form) and other troubleshooting strategies to deduce what happened during the faulty run. Present an analysis in the form of a table or chart.
4. Choose the most likely cause or set of conditions that produced the data and run the equipment at these conditions to attempt to reproduce the data to verify the hypothesis.
5. Suggest a new troubleshooting scenario. After supervisor approval, collect data and describe how another engineer should approach the problem.

During their troubleshooting exercises in Rotation 3, the students are allowed to submit three questions in writing to the Professor/GSI regarding the data supplied to them. Grading criteria for Rotation 3 can be obtained from [http://www.ingen.umich.edu/class/che460/safetyguide.html](http://www.ingen.umich.edu/class/che460/safetyguide.html) and then downloading “Criteria for Rotation 3”.

a. **Equipment Faults Fall 2002**

1. **Double Effect Evaporator**

   As an example of Rotation 3 troubleshooting, let’s discuss the fault generated in the double effect evaporator. The memo to the students can be obtained from the web at
3. Distillation and ARSST Faults Fall 2002

For the fault in the distillation apparatus, the valves were turned so as to send most of the feed to the reboiler. In the ARSST, the stoichiometric feed conditions were reversed. That is, in Rotation 1 and 2, the feed was 2 moles of A per mole of B and in Rotation 3 it was 1 mole of B per mole of A.

The criteria for grading this rotation are shown in Appendix 3 and the guidelines for the final report are given in the following table.

**Table 14 Guidelines for Troubleshooting Reports**

- The final report should be 3 pages (not including charts and tables) and should include:
  1. the ideas generated from your brainstorming session (organized in a table or chart).
  2. your K-T® Analysis (including PA/PPA).
  3. what you believe caused the inconsistent data and whether you were able to replicate it. Include relevant graphs, experimental conditions, etc. pertaining to runs where you attempted to replicate the faulty data.
  4. text describing your process and the conclusions you reached.
  5. your idea for a potential problem/situation to troubleshoot and the process by which you would go about troubleshooting it. Provide hard copy and .xls file(s) of the data collected.
  6. References and Appendix.

V. The Creation of a Virtual Human Resources (HR) Department to Ease the Transition to the Workplace

A. Rationale

In an effort to operate more like a typical industrial company, Brown Industries added a virtual HR department in 2001. I assumed the role of the entire HR Department. This simulated HR department was patterned after one I observed while consulting for 26 years at Chevron Oil Field Research. Here the purpose of the HR department was to help the employees grow professionally and personally.

1. Provide short courses on technical material that the students can use to develop and practice their critical thinking and troubleshooting skills.
2. Provide short courses on non-technical subject matter that contributes to the students’ professional development.

The topics discussed during the lecture periods can be thought of as short courses offered to the employees. This simulated HR department was designed to help students make the transition to the workplace by building confidence in their communication, negotiation, troubleshooting and professional skills. The following nine short courses were offered during the lecture time allotted to the course.
Table 15 HR Lectures as Short Courses

1. Safety (1 hr)
2. Theory and operation of laboratory equipment (4 hrs)
3. Design of experiments (1 hr)
4. Developing presentation and technical communication skills (5 hrs)
5. Negotiation skills (2 hrs)
6. Kepner-Tregoe® exercises (3 hrs)
7. Outside speakers (4 hrs)
8. Troubleshooting exercises (3 hrs)
9. “7 minute” non-technical presentations by students (3 hrs)

B. Non-technical Professional Development
The non-technical professional development had three components: outside speakers, negotiating exercises, and 7-minute presentations.

1. Outside Speakers
   Three lectures were devoted to invited outside speakers. Two of the speakers were from industry and one was a financial planner. During the Fall 2002 term the outside speakers were Dr. Robert Sandstrom from ExxonMobil Upstream Research Company and Dr. Sarah Mancini from Pharmacia Corporation. Each used their background in these two very different industries to talk on the topic of “Industry’s Expectations of a New Engineer on the Job.” Both technical and non-technical advice were given. The previous term Dr. George Quarderer from Dow Chemical talked on the same subject. The students were given sample evaluation forms which companies use to evaluate its employees on a yearly basis. In addition to the industrial speakers, Mr. Mike Albayya talked to the class on “Financial Planning for a New Graduate.” The students requested that Mr. Albayya’s time be increased to two lectures in coming years.

Table 16 gives advice to new graduates that was not only given by the outside speakers but was also collected from industrial colleagues, namely Sid Sapakie, Dave Rosenthal, Gavin Towel, Mike Ramage, Mayur Valanju, and Rakesh Agrawal.

Table 16 Advice from Industry to New Engineering Graduates

1. Evolve - Be prepared for change in your career and remember that every change brings new opportunities. Challenge yourself. Find useful problems to work on. Be willing to work on different problems.
2. Enjoy - Find a job where you enjoy what you do. Feel good about what you do or else do something different. Find time for health care. Work hard but have fun. Life is short, leave time for yourself.
3. Learn - Continue to learn and renew and expand your skill set. Build a network of peers and mentors and never stop asking questions. Listen, question, learn. Recognize what you know and what you don’t know and don’t pretend to know what you don’t. Take advantage of other peoples knowledge. Don’t reinvent the wheel. Learn how to take feedback, positive and negative, listen, listen, listen. Learn how to communicate and “market” yourself and results.
4. Communicate - Develop strong communication skills - oral, written, listening. The best work is of little value if you can’t communicate it clearly and succinctly. Develop “active listening” skills. When you have something of value to say, say it. Develop a network of colleagues as they can provide excellent advice and guidance. As your experience grows, share your knowledge with others. Peers are great sounding boards.
5. Plan - Manage your own career. You own your career and nobody cares as much about you as yourself. Figure out what you want to do in your career/life. Talk to people that are doing what you want to do 10 years from now to learn what experiences you will need to get there. Pick a job (or series of jobs) that meet your objectives. Will they help you be where you want to be in 20 years from career, financial and personal points of view?
6. Work hard - Be proactive in everything you do, but especially in your career plans. The harder you work the better you’ll do. Most effective results come from synergy of team efforts, not individual efforts. Focus on results. Learn about the business, the culture and politics of the organization you are in. Figure out what it takes to succeed. Learn to manage up and down. If the criteria for success at an organization are incompatible with you and your style, maybe that is not the place for you.
7. Share - Find a way to give something back to society.

2. Negotiating Skills
   Because more and more students are either joining small start-up companies (or forming their own) or going into technical sales, a short course (1 hour lecture/1 hour exercises) was given on negotiation skills. The material was based on Charles Karrass’ book “In Business as in Life You Don’t Get What You Deserve, You Get What You Negotiate”. In December of 2001, I flew to Cleveland to attend a two day short course given by one of Karrass’ team. The homework for the evening between the first and second days was to find a fixed price item at a store and try to negotiate it using the techniques discussed in the
class. Over 50% of the class was successful in the assignment. One class member went into a gas station and paid $3.23 for milk from the cold storage and set it on the check out counter and discussed the overpricing of the milk and that he could get it much cheaper in the grocery store. After a minute or so of negotiating and telling the clerk he could get it much cheaper in the grocery store, he finally told the clerk you've heard my reasoning. "I'll give you $3.00 for the milk, take it or leave it." The clerk took it!! A large part of the course was devoted to exercises in which the students negotiated one-on-one using the principles discussed in the lectures. I developed similar exercises for the students to use during their in-class exercises. The negotiating skills course pack can be found on the web at http://www.engin.umich.edu/class/che460/negotiating.html.

3. Community Outreach—7 Minute Presentations
The goal of the 7 Minute Presentation was two-fold
(a) to give students practice in making non-technical presentations
(b) to provide information of a non-technical nature that will help the students with professional/people skills. The presentation subject matter was chosen from the following books.

Table 17  Reading for 7-minute Presentations


One student wrote about the 7 minute presentation, "Our 7-minute presentation allowed me to reflect on my days here at the University of Michigan. We presented a topic called 'Sharpening the Saw' from Steven Covey's book, The Seven Habits of Highly Effective People. 'Sharpening the Saw' was an analogy used to describe the ways to help yourself. The chapter talked about ways to improve one's mental, spiritual, physical and social aspects. The benefit of doing this presentation is not gained so much from the information presented in the chapter itself, rather the chapter reminds one of things often forgotten or neglected. Allow me to explain. The chapter reminds us to workout everyday to sharpen our physical saw. Similarly, the chapter stresses the importance of sharpening the mental saw through reading. What I am trying to say is that we are all aware of the things mentioned in this chapter. At the same time, do all of us get the necessary exercise? Do all of us read enough to expand our mind? I think the answer is most certainly NO. Our goal in presenting this chapter towards the end of last semester was to remind everyone to 'wake up and smell the roses.' We wanted people to stop taking things for granted, things such as their body, mind, and friends. We wanted people to take a proactive approach to sharpen their mental, physical, spiritual, and social saws." —Prashanth Katrapati — student in the class.

Each of the presentations was video taped and critiqued by someone in the Technical Communications Department at the University of Michigan.

VI. Student Response
At the end of the term a questionnaire was passed out to the class asking what they learned, like, and didn't like about the course. A consensus of the most important things mentioned in the two most important categories is shown in Table 18.

Table 18  Student Responses to Questionnaire

Five most important things you learned in the class:
1. Oral Presentation/Communication Skills
2. Negotiation Skills
3. Troubleshooting
4. Kepner-Tregoe/PA/PPA/SA
5. Learning about Unit Operations

Three things you would not change about the course:
1. Guest Lecturers
2. In-class Troubleshooting Exercises
3. Troubleshooting Lab
4. Financial Planning
5. Negotiation Skills

In fact, one graduating senior sent an unsolicited email to the department chair that was the best CHe course he had taken in the department. The students were less enthusiastic about all the paperwork they had to fill out to evaluate the outside speakers, the work place evaluation, and having the K-T exercises carry over to outside of class. Future offerings will cut down on the paperwork and have the K-T exercises be completed during class. Also, a few felt that the case for the connector between the HR department and the laboratory experiments had not been made and that these should be two separate courses.
VII. Conclusions

Overall, the goals of preparing the students to be critical thinkers, troubleshooters, and professional engineers were achieved through a diverse mix of skill development presented in this Unit Operations Laboratory course. Troubleshooting, which is an important skill that needs to be taught and practiced, was developed by using in-class exercises and laboratory experiments. Both semesters, most teams were able to find the equipment fault successfully in Rotation 3 in the laboratory as well as turn in a report that showed a logical approach (heuristic) to troubleshooting the fault. The professor, GSIs, and the students themselves all commented that significant gain had been made in the students' analysis and troubleshooting skills. The students were enthusiastic about the outside speakers from the Virtual Human Resources Department, the unit on negotiating skills, and the in-class troubleshooting exercise. While, as with all the courses I teach, the students complained it was too much work, they did feel that the course format was very good and that they grew in both technical and non-technical areas.

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Note: The enclosed Interactive Computer Module (ICM) can be adopted for classroom use by contacting the CACHE Corporation – cache@uts.cc.utexas.edu.