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# Improving Thinking Skills in the Unit Operations Laboratory*

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*A programme to develop and improve thinking skill in the Unit Operations Laboratory as related to other skills is presented. The programme is divided into three areas: having the right attitude, practicing thinking techniques and tools, and recognising and avoiding thinking errors. It also considers the role of the instructor and the assessment method, emphasises inquiry-oriented and reflective activities, and maintains continuous interaction and immediate feedback from the instructor. The paper includes practical examples on exploring knowledge and experience and on troubleshooting.*

## INTRODUCTION

IN THE UNIT OPERATIONS LABORATORY (UOL) chemical engineering students learn to understand and apply principles and theories, and to acquire and practice a variety of skills such as:

- experimentation,
- instrumentation,
- sampling,
- error analysis,
- statistical and mathematical modeling and computation,
- report writing.

The programme also stresses other skills required by industry that gives students opportunity to appreciate the world of industry. Typical examples include safety aspects, equipment startup and shutdown, troubleshooting and problem solving, and practical maintenance issues [1, 2]. Greater emphasis is placed on practical issues than on lectures in courses at UOL.

There is increasing concern about improving engineering education in general and chemical engineering in particular [3, 4]. It has become evident that there is a growing need to concentrate more on personal skills and attitudes as the amount of knowledge is increasing at a tremendous rate. The thinking process is one such skill that is receiving attention, although currently more in classrooms [5–7] and less towards labs [8]. Thinking is a skill like any other, and skills can be taught, and therefore learnt, acquired and improved in classrooms, labs, and everyday life [9–14].

This paper introduces a concept related to the development and improvement of the thinking process and thinking skills specifically in its adaptation in chemical engineering laboratories by proposing a programme that promotes thinking in the context of laboratory content. The programme takes as its foundation the principle of building the right attitude by introducing methods of acquiring and practising various thinking techniques and tools, and recognising and avoiding thinking errors. This programme also considers the role of the instructor and the assessment method, emphasising inquiry-oriented and reflective activities, maintaining continuous interaction and requiring immediate feedback from the instructor. There are typical practical examples based on the concepts of exploring knowledge and memory, and application of the techniques to troubleshooting. The examples show that students can develop thinking skills and simultaneously understand and apply what they have learned in the classrooms and from their textbooks.

## THINKING PROCESS AND THINKING SKILL

Without a clear concept of the thinking process, it would be difficult to assimilate thinking processes and to propose a procedure to improve thinking skill. It is convenient to consider the process of thinking in terms of its components:

- the perception of a situation
- the related information (knowledge)
- the experience (skills and familiarity with the subject).

The brain processes all these components in a complex manner for a purpose that could involve a number of cognitive activities such as understanding, learning, problem-solving, decision-making, design, planning, humour, and others. This implies that thinking is an activity that not only requires

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effort, it also has a goal. The achievement of that goal requires a serious, careful, and persistent attitude.

Thinking skill involves the ability to operate the brain effectively. As with any skill there is opportunity for improvement, development and a level of investment that involves the acquirement of knowledge and other skills. Attainment of these becomes possible with the possession and practice of thinking tools and techniques in the context of curriculum content. The ultimate goal, however, is to bring the skill to an automatic level, where the expectation for students is that they behave skilfully, like experts. Students need to be skilful both in creative and critical thinking, an achievement that requires motivation, reinforcement, praise, and the opportunity to make use of their thinking skill.

## IMPROVING THINKING SKILL

As is the case with other skills, thinking skill development and mastery requires practise and time. Students need to be both creative and critical, as both types have common tools and objectives and work together most of the time. It would be more appropriate to develop both types of thinking in an integrative approach.

*Critical thinking*

Certain criteria establish a foundation for critical thinking, (i.e. thinking that is convergent, logical, analytical or vertical). It is self-regulatory in the sense that one monitors cognitive activities and improves them by self-correction, as well as considering the constraints and limitations. It is characterised mostly by being able to:

- identify
- interpret
- analyse
- hypothesise
- explain
- evaluate

to understand and to make a good judgement.

*Creative thinking*

Creative thinking (divergent or lateral) looks for the novel, generates many ideas by different ways, and frequently elaborates, causing unusual responses and techniques. Creative thinking changes assumptions, it might or might not consider the criteria, and it looks from different angles.

Both types of thinking have common tools and purposes. For example, in problem solving and decision-making we need both types of thinking to generate alternatives and to choose the most appropriate or promising.

I believe that gaining and improving thinking skills is possible by getting and maintaining the right attitude, by identifying the tools and practising various thinking techniques, and by recognising and avoiding thinking errors. Having the right attitude requires:

1. *An interest in the subject* recognised by being curious and questioning things.
2. *A serious attitude*, i.e. having a goal (determining your direction and monitoring progress), making a continuous effort, and acknowledging things that make sense.
3. *Openness and flexibility:* listening to others and considering their ideas (accept or reject); consulting others; being ready to change mind; not jumping quickly to conclusions.
4. *Confidence and the ability to come to conclusions.*
5. *Consistent, sufficient and understandable thoughts.*

Experience in thinking is developed by becoming accustomed to the situation through the use of practical thinking techniques and tools. Thinking tools are versatile [5, 9, 11–14], but can be conveniently categorised as follows:

*Senses and memory*

- Guiding senses according to the background and purpose, for example, so that students learn to think in terms of safety when troubleshooting or analysing potential situations.
- Listening, observing carefully, and linking with experience to gain reliable thinking.
- Widening perception and looking from different angles.
- Memorising and recalling by practising mnemonic strategies (asking questions, using patterns, key facts, easy-to-remember rules, and brainstorming).

*Information and situation*

- Rearranging available information: (combining, classifying, following correct procedures).
- Gathering information (searching it out in literature, researching, asking experts).
- Presenting information in a convenient and useful way (using simple terms, plot, sketch, graph, tables).
- Seeking patterns and relationships (order, sequence, cause-and-effect, modeling, analogy, and metaphor).
- Looking for meanings (getting inside, deriving, summarising).

*Troubleshooting*

- Defining the problem:
  - feeling and recognising the difficulties;
  - gathering information (symptoms, deviations, data) and exploring them;
  - talking about the problem (to yourself and to others using your words in simple terms);
  - Is there a problem? Can you feel it? Can you define it? Is there a solution? Do you know how to implement it?

- Setting goals and strategies to generate alternatives by using thinking techniques and tools such as: analysing:
  - synthesising;
  - seeing patterns;
  - using analogy;
  - predicting using rules and laws;
  - challenging methods, definitions, and assumptions.
- Practicing attitude: being ready to change goals and plans; (and if you are stuck leave it for a while, take a walk, or ask for help, depending on the degree of emergency).
- Choosing and implementing the best solution.
- Evaluating the effectiveness of the solution.
- Reflecting on the procedure and the key factors.

*Thinking errors*
- Perception (sensing and attention):
  - focusing attention on one part of the situation, (or looking at the situation from an inappropriate;direction), while ignoring others;
  - seeing the ego only;
  - considering the present time and ignoring the future.
- Information:
  - lack of information;
  - false information;
  - extra information;
  - Examples include closed-problems with extra data, open-ended problems with lack of data, and troubleshooting with false information.
- quick judgments
- being arrogant or not serious
- false information can best be seen in troubleshooting equipment;
- quick judgements: superficial thinking, lack of deep processing and evaluation;
- being arrogant, not serious, and not careful (not making your own judgement).

## APPLICATIONS IN THE UOL

Thinking skill is developed and improved in an integrated approach that facilitates the acquirement of knowledge and other skills, and is based on the components required to improve thinking skill. A program that addresses these issues might involve the following issues:

1. Working within a randomly selected team, preferably of three members in an atmosphere similar to industry. This team is free to cooperate with the instructors, the technicians, and the safety staff, and consult any available source. Every student is individually responsible, however.
2. Understanding setups, startup and shutdown, and maintenance through inquiry-oriented and reflective activities. Students use critical thinking tools such as definition, analysis, hypothesis, evaluation, and explanation.
3. Troubleshooting as follows: solve problems that occur naturally; solve problems that are set deliberately; think of expected problems; and learn from errors. Link with industrial and everyday life problems (home, street, and car).
4. Practicing the role of the safety officer and the safety committee members. This committee takes decisions on safety issues. Every one should attend and participate in the decision-making, and submit memos and reports on safety.
5. Working on closed-ended experiments and projects within a time limit. Students are required to face problems of recognised pattern type, with well-defined short-term goals.
6. Thinking of situations of the closed-ended type with insufficient information, and on open-ended projects and experiments with no upper limit on time. Students set their goals, invest their experience, and work according to their own plan.
7. Assessment and grading policy that considers the progress of student's work, together with both personal and teamwork abilities.

Consideration of the programme details aids the achievement of good results. For example, regarding experimentation, the following scheme is suggested:

1. Running experiments as described in the handout. This includes classical experiments such as distillation, absorption, chemical reactors etc.
2. Running small experiments such as batch drying, diffusion, conductivity measurement, and fluidization.
3. Designing and running certain experiments from scratch. Think of similar experiments such as drying in a microwave; liquid fluidisation.
4. Working within a multi-departmental group on small projects. (This process is not fully developed yet, and needs further processing and coordination.)

According to this programme students practice a number of activities such as:

- working within a team
- understanding through asking questions and reflection
- designing and running experiments and projects
- troubleshooting
- practicing safety procedures
- participating in developing plans and decision-making
- teaching and assessing each others
- relating things to everyday life.

Students acquire the right attitude because they have certain goals to achieve; they should work within a time limit; they have to get a good grade; they work within a team that requires each member to make their own conclusions, to listen to others, and avoid making unnecessary mistakes. Students also practice the process of thinking within the context of lab content [15, 16].

*The role of the instructor*

The Instructor facilitates the student's work by guiding them in the right direction and by monitoring them to ensure that they achieve the right results. Asking the students questions helps them to explore their knowledge and skills, promoting reflection; it also encourages interaction and immediate feedback. The work of the instructor also involves consultation as a source of information. To perform the job effectively, the instructor must have the interest and the willingness to coach, must obviously have the related background and the appropriate skills. While they do not need to be an expert in every aspect of the field, it is important to maintain an attitude of supervision, guidance, and leadership.

*Assessment method*

By developing and improving thinking skill of students, the aim is to raise their proficiency to the level of skilful practitioners in thinking and as well as other skills. The application of appropriate measurements will assist them to achieve a reasonable standard. We base our assessment on a method that considers both personal and team-based abilities and monitors the progress of students' work both in the process (subtext or skills) and content (text). This method places emphasis on the achievement of the goals and considers the details in a diagnostic manner to highlight strengths and weaknesses. Important issues in this context include continuous follow up, immediate feedback, and reflection. Students need to show progress in acquiring knowledge, application, skill and attitude. Instructors track the work of the students, who will not achieve a grade unless their work is fully acceptable.

Our assessment method also examines the following issues:

1. Exploration of students' knowledge and skills gained during each session.
2. A requirement for each student to express briefly in his words the main ideas and concepts mentioned, or procedures practiced, during and at the end of each conversation.
3. An investigation of the students' ability to train others under the direction and observation from the instructor, looking at both strengths and weaknesses.
4. Checks on the students' ability to assess and upgrade each other's work in terms of level of knowledge and skills.
5. Comparing students' performance against case studies
6. Monitoring their development through writing memos, reports and articles.
7. Observing students' performance in safety assignments, and noting any improvements in the lab, the experiments, and staff.
8. Observing the performance of the team [17], checking what each member gains from the team; what each member gives to the team and what each team give the whole class.

## PRACTICAL EXAMPLES

*Understanding by asking questions and reflecting*

Questioning is an effective technique that is used in the exploration of knowledge and promotion of the thinking process. In order for this to work effectively, it requires immediate feedback, with subsequent reflection by the students on what they have learned. It is a useful aid to help them to recognise and avoid errors in thinking. There are students of many types and levels in UOL because it draws on many activities from several other courses; some students easily forget what they learned, others find application difficult. Use the following strategies to develop the students' awareness:

1. Explore students' background through conversation, asking questions at the beginning of the lab session, during experimentation, and at the end of the lab session. This helps to expand the background and build on it.
2. Draw attention to concepts, equipment and procedures by mentioning names and reminding the students of appropriate thinking tools. Identifying names helps them to distinguish things, directs their attention, and assists students to develop a questioning attitude.
3. Give students more exposure to the subject by exploring definitions of concepts and objects, seeking patterns in the information and procedures, and relating to other subjects.

Here are few examples with typical questions and answers.

*Understanding the setup and the process*

Using a cooling tower as an example; the students stand in front of the equipment

Q 'This is a cooling tower, are you familiar with it?'
A 'We studied about it in the classroom with schematic diagrams'.

Q 'What type of operation is this process?'
A 'Humidification.'

Q 'Is it mass or heat transfer?'
A They give different answers and some do not know.

Q 'In which course did you study it?'
A 'In Che 316.'

Q 'What was the title of that course?'
A Then they quickly gave the right answer, because this course is called *Simultaneous*

*Heat And Mass Transfer*. After that it was easy to draw from them most of the information they were given in the classroom.

Q 'Can you think of similar processes in our life?'
A 'Water circulation in the car.'

Q 'But this is a heat exchange process.'
A 'Cooling in clay utensils.'

Q 'What else? Think of a familiar scene you see every morning on your way to the university.'
A 'Cooling towers in the campus.'

Q 'Each one of you should try to draw a simple, but detailed flow chart of the setup.'
A 'We do not know which type of tower this is.'

Q 'What are the types you know?'
A They give the right answer.

Q 'Where is the fan located?'
A They quickly realised the type of the tower, a forced draught type. After they identify the type of cooling tower, we can choose to follow up their drawings, and show how to startup and shutdown using the charts they draw [2].

*Recognising thinking errors*

- Before starting up the cooling tower, wet bulb thermocouples need to be wetted. Few students pay attention to wetting the wick. We start by mentioning the terms wet bulb and dry bulb temperatures. Thereafter, students run the experiment, collect the data, then I suddenly wet the bulb. Readings will change, few students might note the difference, and they start thinking about this situation.
- To give more exposure I continue exploring their knowledge asking their response this change. They give several explanations, but none is related to the wet bulb. I ask them to look at the thermocouples to see what the difference is between them. They recognise that one has a wick and one without a wick; then I ask them why we use a wick. This is usually enough for them to recognise the answer: 'The wick should be wetted'. Now they understand what happened.
- Often there is a lack of sufficient data. This frequently happens in studying flooding effects in fluidisation, startup of a reactor, and in establishing stress strain curves. The curve details require a lot of data to ensure the correct gradient. Asking questions helps the students to realise the fault and correct it. Some times they might have to repeat the runs, but they never repeat again.
- The pump and the compressor for the absorption tower are connected. One is a centrifugal pump the other is a centrifugal compressor, but few students can initially tell the difference between the pump and the compressor. We point out the equipment, its size and where it is connected. This aids the students' concentration, directs them to look and think. Some might not know; others get the names wrong because they do not think; some recognise the pump because it is connected to the water feed tank and a liquid flowmeter; some might see the specifications of a centrifugal pump written on the pump body, others might notice that it is of smaller size than the compressor. Some students might notice that the compressor has an air filter on it similar to that we see in cars, but it does not have an inlet pipe connected to it because it takes air in directly, from the lab (and is connected to a gas type flowmeter).
- The distillation experiment was running well, but the results were not satisfactory. They checked every step critically, revised the calculations repeatedly and every thing was OK. A need to break the patterns was in order. I suggested that they consider the assumptions, the methods and the definitions and they found that the calibration curve was completely wrong.
- A similar situation happened with the reactor experiment. The students found the order of the reaction was five, an impossible figure. The problem needed creative thinking to identify the cause; assimilation of certain conductive compounds did not occur during development of the formula used to calibrate conductivity concentration.

*Troubleshooting*

Troubleshooting is the ability to characterise or diagnose a problem and to present a corrective action to resolve it [2]. It is a special type of problem solving in UOL involving experimentation, startup and shutdown procedures, maintenance, and safety. Troubleshooters need to use both creative and critical thinking in their approach to solve problems; they need to follow the right steps, (mentioned above), and learn by practice. Problems in the lab both occur naturally or deliberately, and can be simple and obvious, (solved by comparing what is normal to what is abnormal), or complex and hidden, (requiring thorough study). Students learn to look backwards and forwards and to break the patterns. For example, when temperature readings are not sensible, they might choose to start from the indicator, or from the thermocouple back to the indicator, or to substitute an alternative thermocouple.

In industry, the typical approach to troubleshooting involves data collection, thinking about the problem, correcting the operation, and checking the results for normal operation. Data is the result of real observation and measurement from the control room and from the field. Currently, troubleshooting is conceived as a process of observation gathering until only one cause explains all symptoms. This process is known as the case-based expert system [18].

To continue with the Cooling Tower problem. *Water does not flow down the cooling tower:* I moved the float of the rotameter to a level not sufficient for water to flow down the tower then started the cooling tower. A few students realised that something was not right, but did not consider it a problem until I asked them to change the flow rate of water. At this point, the float in the rotameter did not move. They realised that water was not flowing down the tower by looking at it. Unless you recognise a difficulty, you do not have a problem. When they realised the extent of the problem, they were asked to explain it in their own words. Most of the students thought that the problem was an air lock in the rotameter. The leader of one group called a technician without considering other team-members' ideas, and asked him to dismantle the rotameter.

I suggested that they might have to reconsider, and change their viewpoint, then suggested that they should consider the flowchart and trace the water flow. The students suggested a number of alternatives:

a. a problem in the inlet pipe to the tower;
b. the feeding tank is empty;
c. the pump is not working;
d. there is a blockage at feed tank outlet.

I asked them to look from different angles and consider other possibilities without jumping quickly to conclusions; maybe they should check other symptoms?

- check water level in the feed tank;
- release the inlet tube to the tower and checking it;
- release the inlet tube to the pump;
- listen to the pump;
- consider opening the rotameter fully.

They noticed that the pump was making a strange sound, like cavitation; but cavitation has to do with vapour pressure, which is unlikely. They thought that it might be a priming problem; it is important to screen the available alternatives.

Once they identify the problem, the next step is to look for a solution or corrective action. Again they have to be open and flexible and consider possibilities and we encourage them to talk about the problem, consult others including their colleagues, to look around in the lab for analogies, read books, etc. During one session, just releasing the inlet tube to the tower solved the problem, and things went smoothly.

In other situations this was not the ideal solution. Here are typical suggestions, (recognising that the set up problem was air lock or priming):

- releasing air by blowing into the tubes;
- forcing water into the inlet tube from a tap;
- priming the pump—but it is not designed for priming;
- making a priming opening;
- changing the pump;
- making a by-pass;
- installing a check valve at the pump inlet;
- increasing input head in the feed tank;
- using a trap similar to sanitary trap;
- keeping a level of liquid above pump inlet;
- not allowing full drain of the tank.

Once they have identified the problem, it is time to evaluate and choose the most promising solution. Here discussion is vital, and they have to base their screening on the lab capabilities, safety, ease, effectiveness, etc. For example, it would not be safe to blow the tubes or use back pressures from tap water; perhaps we do not have a similar pump to replace the original, or there is not enough space for a trap; check valves are available and easy to install, and there is provision for a by-pass line. The final choice might be to install a check valve, a by-pass line and to keep a level above the inlet to the pump.

At this point a discussion is in order to reflect on the problem. Students began to appreciate the steps involved in solving the problem:

- identifying the situation;
- defining the problem;
- widening perception;
- looking from different angles;
- looking for possibilities and alternatives and screening them;
- analysing;
- looking for analogies;
- not being arrogant;
- not jumping to conclusions to quickly.

In problem solving, it is important to alternate between creative thinking and critical thinking, not to stop at the obvious solution but to look for others.

## CONCLUSIONS

In the UOL, there is a requirement to improve thinking skills as a vital part of the curriculum, because our graduates need to have the right attitude to succeed, to be able to solve practical problems, and to cope with real world situations when they move to industry. This helps to bridge the gap between the expectations of industry and the education our graduates receive. This task is not easy; it requires a great deal of effort, time, and follow-up later.

A programme is followed that includes as many techniques and tools as time and capabilities allow. The instructor does not need to follow every step, nor does he need to look for every tool or thinking technique. They must make sure that the process of thinking flows naturally and that it is not overtaken by the content. The instructors' background is important because he can widen the scope of thinking to include several types of problems and situations.

With progress, the level of students' proficiency is raised and their ability to control their emotions and fears, to direct their attention, and to isolate the relevant information is expected to improve.

They become more self-confident and can perform well with minimum effort and time.

Underestimation of the programme's disadvantages should be avoided or at least, minimised as far as possible. For example, working in a team might have the disadvantage that the group can suppress or weaken the students' thinking. A lack of awareness on this issue could create a disadvantage within a team with respect to thinking instead of being an advantage.

Overall, students enjoy this programme and find the UOL a very interesting and attractive place to work. They have the opportunity to think effectively, to reinforce and emphasise what they have learned elsewhere, and to link with everyday life. They quickly realise that troubleshooting involves more than just finding a problem and fixing it, it also involves prevention of defects.

To transfer this experience to other fields, there is a need for clear concepts on thinking skills, related to the mechanism of the mind, recognising needs, and setting goals. For example, some departments choose to limit their focus on certain skills such as experimentation and communication, while others stress troubleshooting, startup and shutdown, safety, and maintenance. Adaptation of programmes to student needs is possible and practical. Thinking skills serve to work in any other context and if invested in properly it provides fruitful results.

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