DEVELOPING CRITICAL THINKING SKILLS THROUGH DYNAMIC SIMULATION USING AN EXPLICIT MODEL OF THINKING

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ABSTRACT

A major skill area of CDIO is Part 2.4 Personal Skills and Attitudes, which subsume skill sets relating to good thinking. This paper takes the position that critical thinking skills can be explicitly taught, much in the same way as other skills. Students need to clearly understand what good thinking actually entails, have opportunities for active and experiential application in real-world contexts, as well as receive clear and useful feedback from expert professionals.

In this paper, we firstly present our model of thinking, which has been derived from extensive review of the literature and our own research in cognitive modelling engineers as they solve real world problems. The model identifies the key types of thinking involved in such problem-solving as well as the cognitive processes involved. This provides a practical heuristic model of good thinking, which can be taught explicitly and used for purposes of assessing thinking.

Secondly, focusing on the chemical engineering context, we outline the various ways in which critical thinking skills can be effectively taught in a range of learning contexts and, in particular, dynamic simulation.

Thirdly, we present our research findings on the student learning experience in relation to the development of critical thinking skills from using dynamic simulation to solve chemical engineering problems. The research employs a rigorous qualitative methodology involving observation and in-situ and post activity questioning of student performance relating to solving problems. A broad phenomenographic approach was employed to identify the range of variation in student's cognitive approaches and heuristics when solving the problem scenarios presented. Some comparisons are also been made in terms of performance on simulated activities between student groups explicitly taught critical thinking skills and those not explicitly taught these skills.

The paper concludes with an optimistic frame on both the explicit teaching of critical thinking and the particularly useful role of dynamic simulation as an effective pedagogic tool for developing the range of critical thinking skills.

KEYWORDS

Critical thinking, dynamic simulation, chemical engineering, real-world tasks

INTRODUCTION

"Good thinking" (however defined) is a key attribute for successful learning. As Paul [1] outlined:

> Thought is the key to knowledge. Knowledge is discovered by thinking, analyzed by thinking, organized by thinking, transformed by thinking, assessed by thinking, and, most importantly, *acquired* by thinking. (vii)

Similarly, Jenson [2] suggested that:

> The best thing we can do, from the point of view of the brain and learning, is to teach our learners how to think (p.163)

However, recognition that certain internal cognitive processes – 'thinking' – make a substantive difference, beyond those of memorization, to understanding and application of acquired knowledge, does little in itself to aid systematic development of such capability in our students. Without sufficient valid definition of what constitutes such terms as 'critical thinking', 'creative thinking' – indeed, 'good thinking' – teaching faculty will find difficulty in teaching and assessing these desirable cognitive skills.

There are no shortage of models of thinking or lists of thinking skills, processes and dispositions (e.g., Marzano [3]; Swartz & Parks [4]; Perkins [5]). Similarly, there seems to be a reasonable agreement that competence in 'thinking' can be developed through appropriate pedagogic strategies. How we have learned to think will determine in large part how we think, much the same as for any kind of learned activity. As Perkins [6] points out "People can learn to think and act intelligently." (p.18) Paul [1] provides an interesting analogy between the development of mind and physical fitness. He points out that the mind, like the body, "has its own form of fitness or excellence" which is "caused by and reflected in activities done in accordance with standards (critically)" (p.103). He goes on to argue that:

> A fit mind can successfully engage in the designing, fashioning, formulating, originating, or producing of intellectual products worthy of its challenging ends .... Minds indifferent to standards and disciplined judgment tend to judge inexactly, inaccurately, inappropriately, prejudicially. (p.103-4)

However, the problem for curriculum planners and teaching faculty is to decide what exactly they are to include as *thinking* when planning courses and teaching thinking.

We introduced an explicit model of thinking that has proved useful both for planning curriculum activities to develop skill in thinking and assessing its application in real world engineering problem-solving. It does not profess to capture all aspects of this elusive cognitive capability; which is an unrealistic goal in the present context. However, we feel that it is sufficiently valid in terms of broad classification of types of thinking and the typical heuristics involved offer a useful base for the development of good thinking in students.

AN EXPLICIT MODEL OF THINKING

As indicated above, accurate conceptualization of internal cognitive processes (e.g., thinking) is problematic and hence likely to be unreliable, especially across subject domains. However, research suggests that while there is variation in how humans experience phenomena in the world - based on prior experience and selective perception, etc - our common human apparatus and need orientation typically results in shared ways of experiencing the world. Indeed, without this commonality, the inter-subjectivity of everyday life would be even more problematic than it is already. For example, Marton [7] points out that:

> …we have repeatedly found that phenomena, aspects of reality, are experienced (or conceptualized) in a relatively limited number of qualitatively different ways. (p.181)

What this means is that while psychologists may solve problems is some qualitatively differently ways from chemical engineers, both at the individual and collective level, there is much of similarity in the types of cognitive activity involved. For example, they will need to analyse situations (cases), make comparison and contrast with similar cases, build up inferences and interpretations from ongoing perceptions and data accumulation, generate possible solutions and decide action based on chosen criteria. Around this swirl of cognitive activity, there will be an overall monitoring of what is going on – typically referred to as metacognition. The explicit model of thinking used in the context of this paper depicts six main types of thinking as shown in Figure 1.

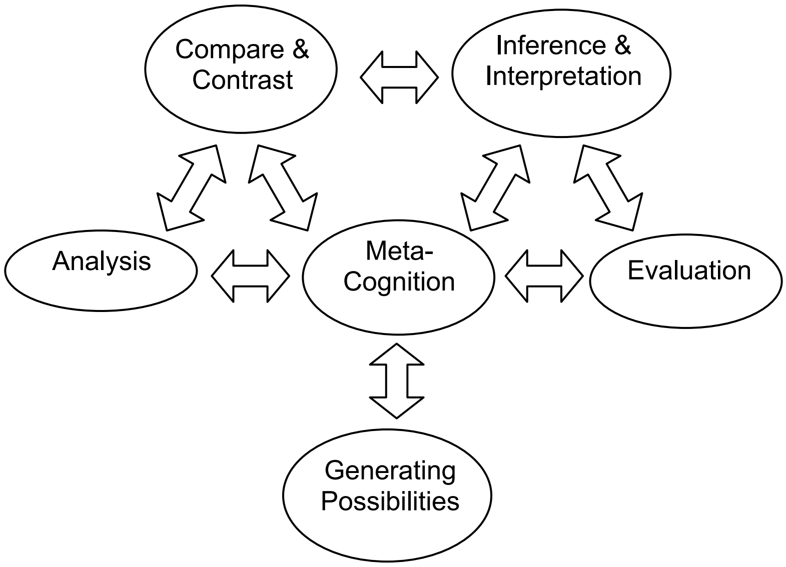

Figure 1: A Model of Types of Thinking

Table 1 summarizes the key heuristics that underlie these broad classification frames on different types of thinking.

Table 1
Summary of Key Heuristics of Types of Thinking

Generating Possibilities • Generate many possibilities • Generate different types of possibilities • Generate novel possibilities
Compare & Contrast • Identify what is similar between things - objects/options/ideas, etc • Identify what is different between things • Identify and consider what is important about both the similarities and differences • Identify a range of situations when the different features are applicable

Analysis • Identify relationship of the parts to a whole in system /structure/model • Identify functions of each part • Identify consequences to the whole, if a part was missing • Identify what collections of parts form important sub-systems of the whole • Identify if and how certain parts have a synergetic effect
Inference & Interpretation • Identify intentions and assumptions in data • Separate fact from opinion in data • Identify key points, connections, and contradictions in data • Make meaning of the data/information available • Establish a best picture to make predictions
Evaluation • Decide on what is to be evaluated • Identify appropriate criteria from which evaluation can be made • Prioritize the importance of the criteria • Apply the criteria and make decision
Meta-Cognition • Aware that we can think in an organized manner • Actively thinking about the ways in which we are thinking • Monitoring and evaluating how effective we are thinking • Seeking to make more effective use of the different ways of thinking and any supporting learning/ thinking strategies /tools

In this model, analysis, compare & contrast, inference & interpretation and evaluation are typically employed during critical thinking; whereas generating possibilities, as the term implies, is predominantly in creative thinking. Metacognition is the overall monitoring of the other types of thinking with a view to enhancing overall effectiveness. In practice, these types of thinking run as overlapping and intertwined programmes, moving from foreground to background as the focus of a problem changes and certain questions arise . Certainly, when creativity is sought, generating possibilities is at the minds forefront, but other types of thinking will weave in and out of consciousness and, probably run continuously in the sub-conscious mind.

Furthermore, in the process of problem-solving, there will be the influence of personal beliefs, emotions and psychological state. The reality may indeed resemble that suggested by Apter [8]:

> ... everyday life, as it is experienced, is a tangled web of changing desires, perceptions, feelings, and emotions that filter in and out of awareness in a perceptual swirl. (p.33)

Similarly, Marcus [9], from a cognitive neuroscience perspective, fully highlights the challenge of achieving good critical thinking when he asserts that:

> Our beliefs are contaminated by the tricks of memory, by emotion, and by the vagaries of a perceptual system that really ought to be fully separate – not to mention a logic and inference system that is as yet, in the early twenty-first century, far from fully hatched. (p.67)

Good thinking, from the standpoint of this paper, is the ability to navigate this "perpetual swirl", and be able to employ the various heuristics of these types of thinking in a fluid, efficient and highly synergistic manner. This is perhaps the reason that good thinking is quite rare in many situations, and why we really need to teach it to our students.

It is in this context that writers in the field see critical thinking not just in terms of cognitive processes and technical standards but also in terms of the development of intellectual traits and standards. For example, Paul et al [10] identify the following traits as central to acquiring a high level of expertise in critical thinking:

- Intellectual humility – sensitivity to owns own biases and the limitations of knowing
- Intellectual courage – prepared to question own beliefs and those of others, even if unpopular with dominant perspectives and people
- Intellectual empathy – awareness of need to actively entertain different views from one's own
- Intellectual integrity – holding oneself to the same intellectual standards of others (no double standards)
- Intellectual perseverance – working through intellectual complexities despite frustration
- Confidence in reason – recognizing that humankind's interests are best served by giving free play to reason
- Intellectual autonomy – thinking for oneself in relation to standards of rationality and not uncritically accepting the judgements of others
- Fair-mindedness – conscious of the need to treat all viewpoints alike and be influenced by vested interests

Such dispositions are certainly desirable, but the extent to which some are more integral to deep seated personality traits is open to question, as is their successful development in a pedagogic context. However, they remain a regulatory ideal and as educationalists we do our best to encourage productive outcomes for our students. Carroll [11] summarizes the goal of critical thinking quite succinctly in terms of:

> ... guarantee, as far as possible, that one's beliefs and actions are justifiable and can withstand the test of rational analysis.

CRITICAL THINKING IN CONTEXT OF CHEMICAL ENGINEERING

A particular challenge facing educators in chemical engineering is the inter-relatedness of various process variables. A typical chemical plant is made up of a number of unit operations in which various process parameters such as pressure, flow rate, composition, level, etc are being monitored and controlled. Often changes in one variable will have significant impact on other variables throughout the plant. Engineers and operators therefore need to have a thorough understanding of the inter-relatedness of the various variables to perform their tasks in a safe and efficient manner. This requires critical thinking in terms of being able to do effective and quick analysis, make appropriate inferences and interpretations as well as evaluate likely outcomes.

The development of critical thinking can be facilitated through a variety of active learning strategies that systematically cue such types of thinking. The good use of questions is particularly effective and efficient. Asking students to specifically analyse relationships, make comparisons and contrast, decide options, etc, focuses the mind on these types of thinking. Similarly, activities that require sustained engagement of such types of thinking, especially when dispositions that serve to enhance critical thinking such as open-mindedness and perseverance are also encouraged. A particularly good approach is the use of dynamic simulation for a number of reasons, these include:

- providing a more authentic and motivating learning context for real world chemical processes than other school-based methods
- enabling a wide range of activities and complexity levels to be introduced strategically to progressively cue the full range of critical thinking skills and their underpinning cognitive heuristics, for example:
  - comparing and contrasting the differences in various process variables (temperature, level, pressure, flow rate, composition) in a chemical process plant resulting from a disturbance in stable operating condition or due to equipment malfunction
  - perceiving connections of the various observed phenomena, making accurate inferences and deriving plausible explanations of what had happened in the plant
  - inferring the best picture of what is happening in the plant, predict likely outcomes and evaluate consequences for possible actions taken
- facilitating the use of rapid and strategic feedback on student learning in which gaps in both thinking skills and knowledge domains can be rapidly ascertained and addressed in situ.

Dynamic Simulation in Context

In a nutshell, simulation is the construction and use of a computer-based representation, or model, of some part of the real world as a substitute vehicle for experimentation and behavior prediction. The central components of the simulation process are building the model (modeling) and running the model (i.e. the experiment). Broadly speaking, two types of simulation can be discerned, namely “static” (or steady state) simulation and dynamic simulation. By steady state simulation we mean that the modeled process is solved only for a specific set of operating conditions. This is like a snapshot of the process or operation. Any change in the operating conditions, requires re-solving the model. After converging, the model should predict where the process will settle. On the other hand, dynamic modeling will provide us with information about the process or operation over time. All variables are being “solved” at each time step and at any specific time we can monitor the operating conditions. Compared to the steady state “snapshot” equivalent, the dynamic modeling is more of a movie than a single picture.

Luyben [12] described the key factors driving the increased popularity of dynamic simulation in the chemical processing industry, such as “increased plant complexity”, “increasing product yield” and “suppressing of environmentally unfriendly by-products”. In the past, dynamic simulation used to be the privileges of large corporations and universities with generous research funding. Typical uses included review of new design and control strategy, modeling transient behaviour, operation and troubleshooting. With technological advances that resulted in declining manufacturing cost and increasing computing power, dynamic simulation tools are now becoming affordable to educational institutions in general. The usage in the universities is primarily for fundamental research at the molecular level, as well as to facilitate understanding of basic chemical engineering fundamentals. Various authors had provided detailed discussions on the use of computer simulations in the context of chemical engineering education [13], [14], [15]. In our context, we are interested in using dynamic simulation as a pedagogic aid to facilitate learning of critical thinking skills.

Suffice to say, in dynamic simulation, natural and chemical phenomena are expressed with algebraic and differential equations based on engineering principles. The mathematical models created are used for analysing how process behaviour varies with time. For the typical case of a process industry, we describe/model the plant subunits and their regulatory control. The relevant equations are solved repeatedly in the time domain and the values of temperature, pressure, flow and composition as well as the valve openings and the process control system output are calculated at every point of interest. Thus, the interactions between the process subunits can become obvious. We want our students to be able to practice critical thinking using the model explained in the previous section to troubleshoot chemical process plant problems.

METHODOLOGY

We have employed the same integrated CDIO approach currently practiced over the past 3 years of CDIO adoption (Sale and Cheah [16]; Cheah [17]; Cheah and Sale [18]); that is through systematically integrating the development of critical thinking into a suitable core chemical engineering module, instead of teaching it separately in a standalone module. Hatcher [19], in summarizing the research, concluded that an integrated approach to teaching critical thinking give better results than standalone courses.

Also, consistent with our past practices in integrating CDIO skills into our curriculum, we adopted the learning activity design using the student-centered framework "Triangle of Course Design" by Felder and Brent [20] as shown in Figure 2.

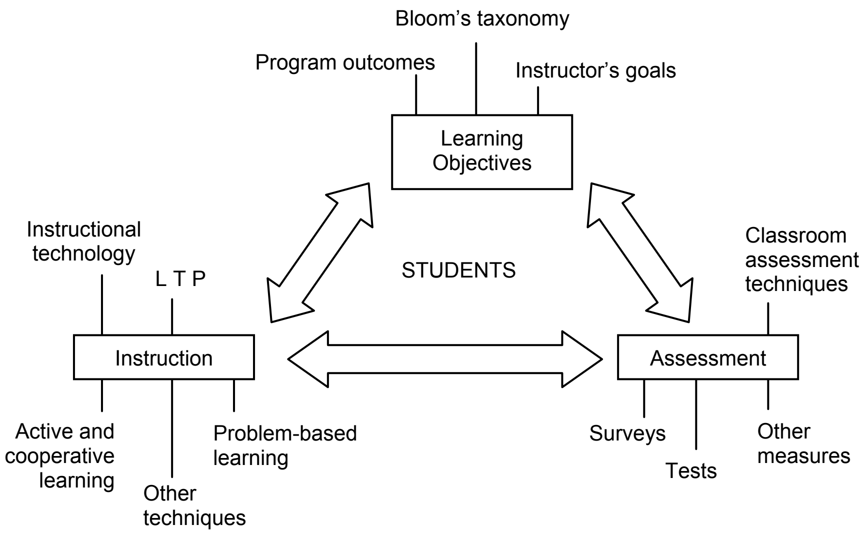

Figure 2: Triangle of Course Design

This seeks to ensure that the learning outcomes are effectively and efficiently developed and assessed through the instructional strategies and assessment systems employed. The advantage of using dynamic simulation has been identified. In the more generic sense, it is aptly summarized by Gurmen et al [21] who noted that:

> Interactive computing can greatly facilitate the learning of troubleshooting skills because of the rapid feedback, the alternate pathways the student may progress and the multiple solutions they can generate. Complementary to the traditional classes, interactive computer modules enable the students to create various what-if scenarios and to concentrate on critical thinking.

The research methodology involved a range of qualitative and quantitative methods in order to explore the ways in which students actually went about their thinking when actively involved in solving problems presented in the simulation activities.

The qualitative methods included observation and questioning of students while in the process of problems-solving, as well as focused group interviews of selected students. We also involved several students serving as “co-participants”, a term used by Lincoln [22] (p.78) to describe students who had some personal interest and commitment in taking part in research activities. The student co-participants provide their reflective comments via a designated blog. A typical scenario involves students working in groups on troubleshooting chemical plant processes/systems using dynamic simulation in the presence of the observing researcher. During the simulation activities the researcher would ask students questions relating to their perception of the problems presented and how they were going to respond to them. The students were also interviewed on completion of the simulation exercises. Other data was obtained from a questionnaire survey administered at the end of each semester of study to all students.

The Learning Activity

We used the dynamic simulation package that is available commercially from EnVision Systems Inc (http://www.envisionsys.com/), which is used for the training of process technicians and operators. The “model” that we used is the depropanizer unit as shown in Figure 3.

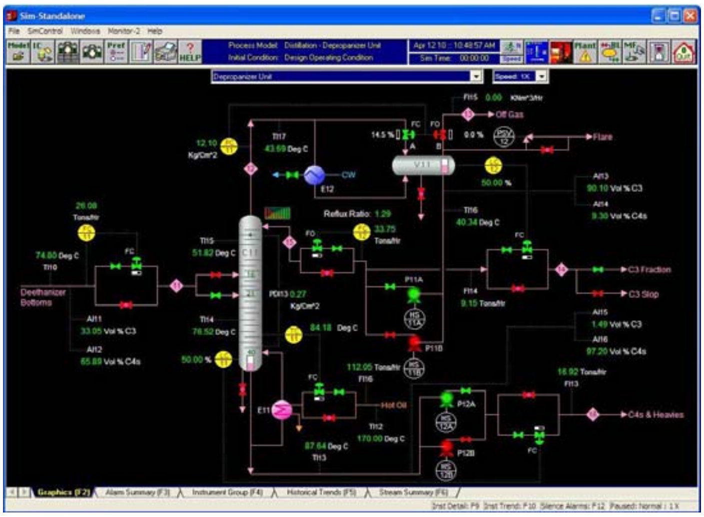

Figure 3. Dynamic simulation model for Depropanizer unit

To promote critical thinking, we have designed a range of activities that involves the skills of analysis, comparison and contrast, evaluation and making inferences and interpretations. For example, in one activity from one of the Year 3 core modules, students have to troubleshoot a process upset in the depropanizer unit, which is a typical real-world task faced by a chemical engineer, as shown in the task scenario shown in Table 2.

For assessment, students were given a range of problem-solving scenarios, for example:

> <u>Scenario 1: Explanation of Changes in Plant Operation</u>
>
> From the print-out(s) of the *relevant trends* of the appropriate process parameters, explain how the decrease in reflux rate affects the distillation operation. You need to make explicit connections between the process variables identified. You are restricted to use a maximum of 2 pages of print-outs; so decide carefully what to be printed.

Scenario 2: Submission of Incident Report

Write an incident report (A4 size, 12-point font, single-spacing, not more than 2-pages long) and submit to the chief engineer. Your report should clearly identify the malfunction by drawing conclusion(s) from analysis of the changes in relevant process variables, plant alerts and alarms observed, etc. You should also outline the corrective measures taken to restore the plant to its design operating conditions.

Table 2
Task scenario for activity using dynamic simulation

Task Scenario

Armed with a Diploma in Chemical Engineering from *Kilat Polytechnic*, you recently joined *SuperSafe Chemicals* as an engineering technologist, and were assigned to the Engineering Department. The company's main business is the separation of C3 and other 'light ends' from C4 and other heavier hydrocarbons using distillation.

The company puts you through a series of training programs. Part of the training program is to assess your ability to operate a distillation column. The company uses a dynamic simulation program for this part of the training. The company has arranged for you to attend a training session conducted by the chief engineer, Mr. Tong Bay Khoo. The chief engineer has included two scenarios in this training session:

Scenario 1

You are asked to decrease the reflux flow rate for the Depropanizer unit, observe the change in process parameters, analysing the trends, and explain your observations. You will also be asked to explain some start-up and shutdown procedures.

Scenario 2

The chief engineer has activated an unknown malfunction scenario. You are expected to troubleshoot and identify the unknown malfunction. An incident report should then be submitted to the chief engineer.

The research comprised two interrelated phases. In Phase 1, the initial part of the research, students had not been explicitly taught using a model of thinking as depicted above. The main focus of the research questions were more generally related to the learning experience of students in using dynamic simulation, for example:

- Does dynamic simulation result in a more interesting/motivating learning experience than other methods employed?
- Is the learning more effective and meaningful (e.g., results in better understand)?
- Is thinking evoked in the solving of problems and how is it conceptualized by students?

For this part of the research, from October 2009 until February, 2010, some 40 students were observed and interviewed during the full range of simulation exercises presented.

In Phase 2, from April 2010 to February 2011, we introduced the explicit teaching of good thinking to selected group of students; and carried out further observations and interview. We made comparisons between groups not inducted into the model of thinking with those who have; as well as review the actual performance of students on tasks that require thinking – and any comparisons with those who have not been inducted.

For this part of the research, we divided one class of approximately 20 students into 5 groups, each group with 4 – 5 members. The grouping was formed by the faculty in charge of the module, deliberately mixing up students of different academic capability, so that no one group had a congregation of top students, which if left to their own free will, will form their own groups. Two of the five groups are then selected as the "Treatment" Groups, where they are explicitly taught the use of the thinking model. The other three groups serve as the "Control" Groups.

Every alternate week, one group of students will carry out the activity in the presence of a faculty, who will take notes of their discussions. During the laboratory session, the treatment groups were specifically encouraged by the faculty to utilize the various types of thinking. Student co-participants are distributed in both "Treatment" and "Control" Groups, and write in their blogs regularly on their experience of CDIO skills introduced into lessons. A focus group discussion is conducted at the end of the semester, comprising both co-participants and other students.

Findings and Analysis

The salient findings from Phase 1 are summarized below:

All students responded positively to use of simulation as a means of providing a more interesting and meaningful learning experience than other methods used in their teaching programme. However, the experience was enhanced or mitigated based on a number of factors. The key factors that enhanced learning related to the nature and variation of problems set. Generally, more challenging and varied problems were preferred, providing they were achievable based on prior learning and within the times frames allowed. More routine problems and time waiting for changes in the simulator state were the main negative aspects of the learning experience for the majority of the students interviewed. In terms of learning students felt that the use of dynamic simulation helped to build understanding of the working and relationship of the various chemical processing systems and their subunits.

The findings clearly supported a view that simulation can be an effective tool for promoting thinking. This was apparent from the student response and observations by the researcher. However, all the students, though with some variation, were unable to offer a descriptive and/or illustrative model (albeit an implicit one) of what good thinking or critical thinking entailed. Typical responses were as follows:

> "Use knowledge to solve problems"
> "Thinking out of the box"
> "Conscious mind, a good amount of reasoning"

These initial findings indicated to us that explicitly teaching of critical thinking skills, using a suitable model as a guiding framework, may well support student learning in terms of the development of good thinking.

Key findings from Phase 2 are summarized below:

Results from the student feedback indicated that overall students are able to use some of the types of thinking. For example, 71.4% students responded (out of 49 respondents) either "Agree" or "Strongly Agree" that they were able to "think critically when solving problems during the practicals, as well as the questions posed during debrief". However, those explicitly taught the use of the thinking model are able to do so in a more systematic and confident manner, as discerned from the replies given in focus group discussion and blogs. For example, it is noticeable from the blogs that students who were explicitly taught the thinking model are better able to articulate their thinking processes during their group discussions, using "the language of thinking", such as "compare and contrast", "infer and interpret", etc. This is further confirmed by the faculty who observe the conduct of the dynamic simulation exercises.

During subsequent debrief sessions the faculty also noted that these students are able to offer a more coherent explanations of their observations and actions in arriving at the correct conclusions to accurately identify the unknown malfunction. This is also reflected in the Incident Report, where students who were explicitly taught the thinking model are able to produce better quality accounts, in terms of systematically detailing way their approach of restoring the plant back to its normal operating conditions.

In our focus group interview, students who were not taught the thinking model agreed that having a framework on thinking may help them in the learning process. We noted that these students are able to articulate some elements of thinking during debrief but most are unable to explain what metacognition is.

MOVING AHEAD

The research to date has been informative and encouraging. We have established the potential use of dynamic simulation as a useful learning tool, both in terms of encouraging critical thinking and enhancing motivation, when used from a sound pedagogic perspective.

We have introduced the model of thinking into the DCHE curriculum by explicitly teaching it in a core Year-2 module entitled *Plant Safety and Loss Prevention*. We also recognize that merely encouraging students to practice critical thinking in a single module is not sufficient to internalize the full range of cognitive heuristic necessary to facilitate a high level of understanding and competent application. It is essential that other lecturers use the same model of thinking in their modules to reinforce these skills and facilitate transfer. As noted by Marzano [3]:

> ... we can improve students' ability to perform the various processes by increasing their awareness of the component skills and by increasing their skill proficiency through conscious practice. (p.65)

It is necessary, therefore, to encourage widespread use of the critical thinking model in other core chemical engineering modules. The challenge remains for faculty to design more learning activities that explicitly encourages skill in critical thinking. Hargreaves and Grenfell [23] for example, had asserted that most faculty still held the assumption that "students will learn from the implicit values buried deep within our teaching philosophies." To address this situation, induction workshops have been conducted for faculty by the authors to provide guidance in using the model and how the use of dynamic simulation can facilitate the acquisition of critical thinking skills.

Also, faculty need to be encoraged to be more reflective in their practice in order to be situationally aware of their thinking, making it explicit where necessary for students, and guiding them as they solve problems. It is certainly the case that direct modeling of meta-cognitive thinking by faculty is useful in making explicit to students the mental operations involved and how they contribute to the effectiveness of the overall thinking process. As noted by Mimbs [24]:

> Teachers need to model critical thinking skills to their students and explicitly teach them to think critically. Teachers can be transformed in their teaching and students can be transformed in their learning through continued, consistent use and application of critical thinking skills.

This is supported by Mandernach et al [25] who noted that the "key to the success of a discussion in fostering students' higher-order thinking strategies is the instructor's interactivity in leading the discussion. Instructors who actively engage their students via a more critical exploration of course concepts are more successful in promoting students' critical thinking than those instructors who take a more passive role in their teaching."

SUMMARY AND CONCLUSIONS

Introducing an explicit model of thinking as part of the instructional approach seems highly promising based on the qualitative data obtained from the various sources documents in the paper. However, it has yet to be verified in more quantitative performance outcomes over time. This will require further and more substantive research in future.

In conclusion it certainly make pedagogic sense to help students to clearly understand what good thinking actually entails (the cognitive heuristics involved), provide them with opportunities for active and experiential application in real world contexts, as well as provide clear and useful feedback on an ongoing basis. The summary frame in this context is well captured by Sheppard et al [26] when they argue that:

> ... teachers have to make their own intellectual processes (their performances) visible. This means that the teacher-expert has to make visible to learners the otherwise invisible processes of thinking that underlie complex cognitive operations at the heart of engineering thinking. Teachers have to articulate and demonstrate rather than assume the thought processes they want students to learn.
>
> ... Then student's efforts to replicate these thought processes need to be made visible so that the teacher can see where the learner is on and off track, in order to provide appropriate coaching and feedback. (p.188)

By designing more learning activities that allows the practice of critical thinking would certainly help to create the much needed opportunities for future research into this very important area of professional concern.

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Dennis Sale is presently Senior Education Advisor at Singapore Polytechnic. He has worked across all sectors of the British educational system and provided a wide range of consultancies in both public and private sector organizations in the UK and several Asian countries. His specialist areas include *Creative Teaching* and *Curriculum Development*. He has invented highly effective and practical models in these areas, conducted numerous workshops in all educational contexts and many countries, presented papers at international conferences and published in a variety of journals and books.

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