CHEMICAL ENGINEERING TRANSACTIONS
VOL. 52, 2016

A publication of AIDIC
The Italian Association of Chemical Engineering
Online at www.aidic.it/cet

Guest Editors: Petar Sabev Varbanov, Peng-Yen Liew, Jun-Yow Yong, Jiří Jaromír Klemeš, Hon Loong Lam

ISBN 978-88-95608-42-6; **ISSN** 2283-9216

DOI: 10.3303/CET1652117

Understanding Chemical Engineering Student's Learning of Process Systems Engineering from Metacognitive Perspectives

Michael Angelo B. Promentilla*[a], Kathleen B. Aviso[a], Rochelle Irene G. Lucas[b]

[a]Chemical Engineering Department, De La Salle University, Manila, Philippines
[b]Br. Andrew Gonzales FSC, College of Education, De La Salle University, Manila, Philippines
michael.promentilla@dlsu.edu.ph

Process systems engineering (PSE) in the field of chemical engineering education requires a systems approach to process design and process integration which emphasizes the unity of the processes and considers the interactions between different unit operations and processes. Understanding the behavior and interaction of such systems often times require the evaluation and calculation of multiple mathematical equations which are more easily accomplished in a technology-enhanced learning environment particularly with the use of e-learning and computational tools. The integration of computer aided courses within the curriculum of the undergraduate chemical engineering degree has thus become essential in preparing students for professional practice. In addition, previous works have shown that these discipline specific computer-aided exercises can potentially assist in the development of metacognitive skills. However, the evaluation of the effectiveness of these tools in learning PSE based from metacognitive perspectives has not yet been fully assessed. Early studies on metacognition refer to it as a concept wherein an individual is aware and able to regulate his cognitive activities such as reasoning skills and perception in the learning processes. Traditional lecture delivery for example has not been considered effective for promoting higher order thinking and learning in students. This work thus explores how learning is enhanced through the use of discipline specific problem solving exercises with the aid of various computational tools and software packages. The pilot study involved creating story problems for computer-aided based course in the undergraduate chemical engineering curriculum of a certain private Philippine university. The study utilizes an evaluation instrument based on Metacognitive Activities Inventory (MCAI) to measure the metacognitive skilfulness of the students. This study also presents implications on future research directions in evaluating student's e-learning strategies.

1. Introduction

Chemical engineering students are faced with several challenges with regards to problem solving tasks required by their technical courses. It is worth noting that it is not only the knowledge of the content of the courses that matters but also the skills that will accompany them when faced with such academic tasks. As such, learners are not just expected to have mastered simply skilfulness but also the awareness to regulate metacognitive skilfulness. Metacognition is referred to as the knowledge about and regulation of one's cognitive activities in a learning process (Schraw and Dennison, 1994).It is characterized as: knowledge of cognition (KC) and regulation of cognition. Knowledge of cognition refers to the explicit awareness of the individuals about their cognition while regulation of cognition is the component that comprises the repertoire of activities used by individuals to control their cognition (Veenman et al., 2006). There were reported studies that evaluate this metacognition awareness and skillfulness during problem solving in undergraduate chemistry laboratory (Cooper et al, 2008) and in homogeneous reactor design course (Ramirez et al., 2013). However, no studies have done to understand how chemical engineering students' learning of process systems engineering is enhanced in a computer-based learning environment. This works thus attempts to understand such learning process with the aid of story problems and computational tools from the metacognitive perspectives.

2. Conceptual Framework

Figure 1 illustrates the conceptual framework which shows how meta-cognition is linked to the methodology of implementing PBL, using computer aided tools towards learning process systems engineering and the student's over-all academic achievement. The development of metacognitive skills, specifically one's Regulation of Cognition, may assist in the efficient processing of problem solving tasks within the context of process systems engineering. With the application of PBL in problem solving tasks, students' are encouraged to reflect, monitor their skills and utilize previous knowledge. With the aid of computer-assisted learning, problem solving becomes more meaningful in the students' achievement of their goal to attain success in learning.

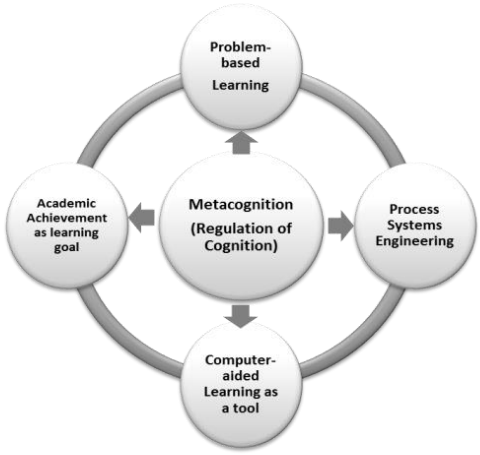


Figure 1: Conceptual framework used in this study

For students to deal with problem solving effectively, they should be aware that they need to understand how they perform such cognitive tasks. As such, problem-based learning may assist in the production of significant metacognitive development in Chemical engineering undergraduates (Downing et al., 2009). Problem-based learning (PBL) is an accepted and successful innovative method in engineering education (de Graaf and Kolmos, 2003). It is referred to as an inductive learning approach which utilizes real-life problems as the starting point of learning (Mohd-Yusof et al., 2011). PBL has its roots from medical education in the early 1960's and has long been used in the curricula of other fields of specialization (Albanese and Mitchell, 1993). At the core of PBL is the development of the desired learning skills and behaviors of students (Cline and Powers, 1997).

PBL has been extensively applied in engineering education such as in the University of Missouri, University of Monash and City University of Hong Kong to name a few. Although engineering education aims to enable students to excogitate solutions, it would be inappropriate to label most engineering educational pedagogical practices as PBL (Cline and Powers, 1997). In essence, PBL requires students to monitor and direct the process of problem solving, bringing memory of concepts and processes learned earlier to be applied in the current problem. The entire process of PBL involves processes such as setting of motivational context by real-life problem; activation of learning through peer and teacher interaction; development of knowledge of relevant materials; and application of previous knowledge to process a problem (Downing et al., 2009).

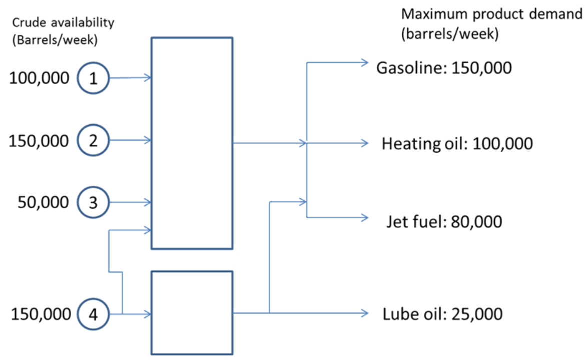
Several engineering programs have tried to introduce "good engineering" practices into their curriculum which would not just demonstrate theory based on the goals of industrial problems; but also encourage students to find out how to get the results. Although these innovations incorporated many ideas of the PBL approach, it should be noted that traditional subject-based learning, supported by applied examples, is not PBL (Cline and Powers, 1997). Apart from the traditional introduction of real-life problems in the class, the use of educational tools such as computer-based learning may aid in the development of metacognitive skills to assist students to enable them to evaluate, plan, and monitor their thinking processes during problem solving for their successful learning (Hollingworth and McLoughlin, 2001).

It has been found that e-learning tasks given to students improved opportunities to understand processes (Hollingworth and McLoughlin, 2001). Moreover, e-learning tools such as computer-based problem solving promote innovativeness. It is an engaging learning experience to students which allows them to explore concepts and problem sets in new ways and also enables them to become self-directed learners. These e-learning materials are designed to encourage the learners to reflect, reason and solve real-life problems more efficiently (Hollingworth and McLoughlin, 2001).

3. Story Problems in learning Process Systems Engineering (PSE)

Process systems engineering in the field of chemical engineering requires a systems approach to process design, operation and optimization. For example, process integration emphasizes the unity of the process and considers the interactions between different system components. Its principles have been applied in the design and development of systems at various scales, from molecular processing, product and process design (Aviso et al., 2015), inter-plant integration (Tan et al., 2015a) to enterprise wide (Tan et al., 2015b) and supply chain optimization (Yue and You, 2015). Understanding the behavior and interaction of such systems often times require the evaluation and calculation of multiple mathematical equations which are more easily accomplished in a technology-enhanced learning environment particularly with the use of e-learning and computational tools. The main challenge is to be able to develop mathematical models, which represent different aspects of chemical process industries, in order to facilitate decision-making. The integration of computer aided courses within the curriculum of the undergraduate chemical engineering degree has thus become essential in preparing students for professional practice. As such, the current study will explore the use of story problems and understand how students perceive their problem-solving skills and activities in a computer-aided learning environment. Figures 2-4 illustrate the story problems that were designed for such study.

EeZy REFINERY Problem. You were hired as part of the team of Engr. Zy 's Consulting company (EeZy Co.) to maximize the profit of a certain refinery. It has four different crude oils which are to be processed to yield four products as shown in the figure. There are maximum limits both on product demand to be sold and the crude oil availability.



Given the tabulated profits, costs, and yields, what would you propose to the client to maximize their profit? Propose three feasible solutions.

		Crude Type					
		1	2	3	4		Product value
					Jet Fuel	Lube	($/bbl)
Yield (bbl product per bbl crude)	Gasoline	0.70	0.40	0.30	0.30	0.35	50.00
	Heating oil	0.20	0.30	0.35	0.30	0.15	35.00
	Jet Fuel	0.05	0.20	0.30	0.25	0.15	20.00
	Lube oil	0.00	0.00	0.00	0.00	0.25	65.00
	Others (losses)	0.05	0.10	0.05	0.15	0.10	0.00
Crude cost ($/bbl)		20.00	20.00	20.00	30.00	30.00	
Operating cost ($/bbl)		10.00	15.00	15.00	5.00	5.00	

Figure 2: Story Problem 1 to demonstrate the application of Excel for optimization problem

4. Case Study

The case study considered here is the implementation of computer aided courses and activities within the undergraduate curriculum in De La Salle University (DLSU), a private, non-profit university in the Philippines. The Commission on Higher Education of the Philippines requires a total of 229 credit units in technical courses for the Bachelor's degree in Chemical Engineering. At DLSU, the BS Chemical Engineering degree is conducted using a trimestral system with a total duration of 13 terms. The introduction of computer-aided tools into the curriculum is done through a 1 unit laboratory course entitled "Computer Applications in Chemical Engineering" (LBYCHEJ) which is taken for 3 hours a week for a total of 13 weeks. This course is taken by students during their 10th term in the program (4th year). However, other computer aided activities are conducted within various Chemical engineering courses. A study on the implementation of P-graph for LBYCHEJ and DESCHE2 for example, was recently done by Lam et al. (2016). LBYCHEJ in particular, introduces various software tools for solving typical chemical engineering problems. These tools include spreadsheet programs such as Excel and What's Best! (LINDO systems, 2016), the modelling software UNISIM (Honeywell International Inc, 2013), a generic optimization modelling software, LINGO (LINDO systems, 2016), and the P-graph studio (P-graph community, 2015) which is a dedicated software used for problems related to or are similar to process network synthesis. The lessons in LBYCHEJ are implemented through a discussion of basic principles in chemical engineering and basic functions of the software which are necessary for solving the assigned problem. Story problems such as those shown in Figures 2 to 4 are utilized in order to facilitate the thought process of students.

Man of STEEL PRODUCT Design Problem. As one of their best design engineers, EeZy Co. gave you the task to design a new steel product of one of their clients with the following strict quality requirements:

Content	At least	Not more than
Carbon	3.50%	4.00%
Chrome	0.25%	0.35%
Manganese	1.20%	1.50%
Silicon	2.50%	3.00%

The following materials are available for mixing up a batch:

	Cost/kg	%Carbon	%Chrome	%Mn	%Si	Amount available
Pig Iron 1	0.06	5.00	0.00	1.00	3.00	Unlimited
Pig Iron 2	0.14	0.00	15.00	5.00	20.00	Unlimited
Ferro-silicon1	0.15	0.00	0.00	0.00	46.00	Unlimited
Ferro-silicon 2	0.11	0.00	0.00	0.00	40.00	Unlimited
Alloy 1	0.22	0.00	0.00	65.00	20.00	Unlimited
Alloy 2	0.25	0.00	18.00	10.00	32.00	Unlimited
Alloy 3	0.23	0.00	10.00	35.00	23.00	Unlimited
Carbide	0.17	15.00	0.00	0.00	30.00	Unlimited
Steel 1	0.06	0.50	0.00	1.00	0.00	500 kg
Steel 2	0.05	0.10	0.00	0.35	0.00	500 kg
Steel 3	0.04	0.1	0.00	0.35	0	500 kg

Dr. Knowitall in the company claims that the least cost mix will not use more than nine of the element raw materials. What do you think about his claim? What amount of each of the eleven materials should be blended together to produce a one ton batch so as to minimize the cost but satisfy the quality requirements as well? What would be the effect on the production of these steel product if all the alloy materials become scarce?

Figure 3: Story Problem 2 to demonstrate the application of Excel and LINGO for optimization problem

Geopolymer-based prefabricated blocks Problem. EeZy Co. expands its business to building geopolymer-based prefabricated blocks. The company operates 3 plants, called Plant A, B and C in different locations which have different manufacturing capacities (the number of blocks built at the end of each production week). Because of their sizes, all the blocks built at each plant must be transported to a warehouse for storage at the end of production week. The company owns three warehouses in different locations, which also have different storage capacities. The total cost associated with storing one prefab block (e.g., transportation cost, space rental fee, etc.) at each warehouse is known and given in the table below:

Cost of storing prefab blocks at a warehouse				
	Warehouse 1	**Warehouse 2**	**Warehouse 3**	Plant Capacity
Plant A	**20**	**30**	**55**	40
Plant B	**20**	**40**	**45**	30
Plant C	**40**	**20**	**15**	45
Max Storage Capacity	50	40	35	

As the chemical engineer working for Eezy Co., you were asked to minimize the total cost of storing all the prefab blocks manufactured at the end of a production week at the 3 warehouses. If Plant C and Warehouse 3 has 20% reduction of capacity due to typhoon in the area, how would the optimal cost of storage will differ from the baseline?

Figure 4: Story Problem 3 to demonstrate the application of LINGO and P-graph for optimization problem

A 27 item questionnaire designed by Cooper et al. (2008) was utilized in the attempt of measuring the metacognitive skills of the students. The questionnaire was administered twice during the term, the first prior to the discussion and application of software tools while the second instance was done at the end of the term. The questions can be answered using a 5 point Likert scale as illustrated in Figure 5, to indicate how much they agree to the statements given. Note that the last eight items are negatively coded items to probe the negative aspect of metacognition. Hence, responses from these negatively-coded items were transformed (e.g., a 1, “strongly disagree” becomes a 5, and so forth) before computing the metacognitive activities inventory (MCAI) score . The MCAI scores of each student were obtained by calculating the percentage of the student’s score against the maximum attainable score. The higher the MCAI score is, the higher the level of self-reported metacognitive skilfulness is.

1. I read the statement of a problem carefully to fully understand it and determine what the goal is.
1. strongly disagree 2. disagree 3. undecided 4. agree 5. strongly agree
2. When I do assigned problems, I try to learn more about the concepts so that I can apply this knowledge to test problems.
1. strongly disagree 2. disagree 3. undecided 4. agree 5. strongly agree
……
26. I spend little time on problems I am not sure I can solve.
1. strongly disagree 2. disagree 3. undecided 4. agree 5. strongly agree
27. When practicing, if a problem takes several attempts and I cannot get it right, I get someone to do it for me and I try to memorize the procedure.
1. strongly disagree 2. disagree 3. undecided 4. agree 5. strongly agree

Figure 5: Sample questionnaire survey to measure metacognitive skillfullness (MAI score).

There were a total of 15 students in the class, 10 of them answered the pre-test properly while 11 were able to answer the post-test. However, only a total of 6 responses were obtained for the paired t-test since some respondents in the post-test were not the same as those who responded in the pre-test. From the pre-test results, MCAI score of the students ranged from 73.3 to 84.4. Results from the paired t-test (p-value = 0.32) show that there is not enough evidence to reject the hypothesis that the post-test scores are higher than the pre-test scores at a level of significance of 0.05. Thus, further study is needed to evaluate whether the current class activities and designed interventions can improve the metacognition skills of the students.
The activities used in the course included the use of story problems which were designed to simulate real life scenarios wherein actual decisions need to be made. For example, one story problem required the students to identify the optimal mix of crude oil types which must be processed in order to meet the desired product demand of goods (see Figure 2). The objective is to achieve the maximum profit and the students were asked to make use of Excel to solve the problem. Students were initially asked to perform the activity without any additional input from the instructor. Thus, in addition to the survey answered by the students, they were also asked to explain how they solved the given problem. Some students who were already familiar with the Excel Solver utilized the Excel add-in in order to arrive at the solution. Other students resorted to using Excel functions which were already known to them and several approaches were considered. Students decided to fix certain parameters in the problem in order to arrive at a solution. Such parameters include fixing the amount used for a particular crude oil type or maximizing the demand of one product type. During the discussions it was also evident that students found it easy to conduct what-if scenarios within the context of the story problem simply by varying their assumptions on the parameters. Conducting these what-if scenarios has also helped the students in assessing how the model solution behaves whenever a change is introduced into the system.

5. Conclusion and Implications

This exploratory study recognizes that metacognition plays an important role in developing problem solving skills while learning the concepts of process systems engineering. Designing story problems that will promote metacognitive awareness and skilfulness could be a valuable teaching technique to improve student’s performance. Moreover, the Metacognitive Activities Inventory (MCAI) could be used as a tool to understand the problem solving skills as perceived by these chemical engineering students and to provide a measure on one’s regulation of cognition. Because of the inconclusive results obtained in this initial survey, further research is needed by collecting more data over a longer period of time and using a larger number of chemical engineering students so that the metacognition awareness and skilfulness of students’ ability can be examined across different contexts and different learning environments. In addition, it would be interesting to map out how the different courses contribute towards the metacognitive awareness of the students. Metacognition components should also be examined separately through multi-method approach including observations, interviews, and ‘thinking aloud’ techniques in order to complement the results obtained from the survey. Open ended questions for example can potentially provide feedback from students on how computer aided activities impact their learning. Thus, this could provide insights on how to design interventions including computer-aided learning tools that can develop metacognition which leads to improved learning outcomes for students. Future works should study deeper the self-regulated learning of undergraduate chemical engineering students in an e-learning environment. E-learning can be used as a powerful tool to foster students' will and skill for learning about complex topics in process systems engineering. Note that according to Zimmerman (1986), students are considered self-regulated learners when they are metacognitively, motivationally, and behaviourally active participants in their own learning process. It is thus important to understand how self-regulated learning strategies can be supported properly in such e-learning environments.

Reference

Albenese M.A., Mitchell S.M., 1993, Problem-based Learning: A Review of Literature on its Outcomes and Implication Issues, Academic Medicine, 68, 52-81.

Aviso K.B., Sy C.L., Ubando A.T., Tan R.R., 2015, Target-Oriented Robust Optimization of Polygeneration Systems, Chemical Engineering Transactions, 45, 199 – 204, DOI: 10.3303/CET1545034.

Cline M., Powers G., 1997, Problem Based Learning via Open Ended Projects in Carnegie Mellon University's Chemical Engineering Undergraduate Laboratory. In J. Heywood, Ed., 2005, Engineering Education: Research and Development in Curriculum and Instruction, John Wiley and Sons, Inc.Hoboken, New Jersey.

Cooper M., Sandi-Urena M., Stevens R., 2008, Reliable Multi Method Assessment of Metacognition Use in Chemistry Problem Solving, Chemical Education Research and Practice, 9, 18-24.

de Graaf E., Kolmos A., 2003, Characteristics of Problem-based Learning, International Journal of Engineering Education, 19,5, 657-662.

Downing K., Kwong T., Chan S.W., Lam T.F., Downing W.K., 2009, Problem-based Learning and the Development of Metacognition, Higher Education, 57, 609-621.

Hollingworth R., McLoughlin, C., 2001, Developing Science Students' Metacognitive Problem Solving Skills Online, Australian Journal of Educational Technology, 17,1, 50-63.

Honeywell International Inc., 2014, <www.honeywellprocess.com/en-US/explore/products/advanced-applications/unisim/Pages/unisim-design-suite.aspx> access on 09.04.2016

Lam H.L., Tan R.R., Aviso K.B., 2016, Implementation of P-Graph Modules in Undergraduate Chemical Engineering Degree Programs: Experiences in Malaysia and the Philippines, Journal of Cleaner Production, article in press, doi: 10.1016/j.jclepro.2016.03.110.

LINDO Systems, 2016, <www.lindo.com>, accessed on 09.04.2016

P-graph Community, 2015, www.p-graph.com, accessed on 07.04.2016.

Ramirez-Corona R. N., Zaira R., Lopez-Malo A., Palou E., 2013, Assessing Metacognitive Awareness During Problem-solving in a Kinetics and Homogeneous Reactor Design Course. Proceedings of the Conference on the 120th American Society for Engineering (ASEE), 1-14, USA, Atlanta.

Tan R.R., Ng R.T.L., Andiappan V., Wan Y.K., Ng D.K.S., 2015a, An Optimization-Based Cooperative Game Approach for Allocation of Costs and Benefits in Interplant Process Integration, Chemical Engineering Transactions, 45, 403 – 408, DOI: 10.3303/CET1545068

Tan R. R., Aviso K.B., Cayamanda C. D., Chiu A.S.F., Promentilla M.A.B., Ubando A.T., Yu K.D.S., 2015b. A fuzzy linear programming enterprise input–output model for optimal crisis operations in industrial complexes. International Journal of Production Economics, doi:10.1016/j.ijpe.2015.10.012.

Veenman M., Van Hout-Wolters B., Afferbach P., 2006, Metacognition and Learning: Conceptual and Methodological Considerations, Metacognition Learning, 1, 3-14.

Yue D., You F., 2015, Bilevel Optimization for Design and Operations of Non-cooperative Biofuel Supply Chains. Chemical Engineering Transactions, 43, 1309 – 1314.

Zimmerman B., 1986. Becoming a self-regulated learner: Which are the key subprocesses? Contemporary Educational Psychology, 11(4), 307-313.