

Concept Mapping: An Interesting and Useful Learning Tool for Chemical Engineering Laboratories*

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This paper describes an ongoing study on the use of concept maps in an upper-division chemical engineering laboratory to enhance student learning. The Unit Operations Laboratory was chosen for the study since it is a comprehensive laboratory in which students are required to be familiar with various aspects of chemical engineering practice. The study was implemented in three stages. In the first stage the students were introduced to the idea and construction of concept maps. The second stage involved the construction of concept maps during a pre-lab session in which the students were orally tested about the exercise they were about to undertake. The last stage was the submission of the final reports in which the students were again required to hand in other concept maps. The students completed the lab practice in groups of three to four, and were asked to create both individual as well as collective concept maps. The present study produced three tentative findings. First, the first stage mainly produced simple concept maps that barely contained basic chemical engineering principles. These initial maps, however, developed and became more complicated as the students went on completing the lab practice and subsequently preparing the report. Secondly, it appears that each student wanted his/her contribution in the collective concept map construction to be acknowledged. Thus, the students were believed to be motivated. Thirdly, since the concept maps produced were collected and displayed in the lab for comparison with the subsequent lab sessions, the students seemed to get a feeling of continuity, something that is not normally noticeable in the traditional lab practice. These findings indicate that concept mapping has a positive effect on student learning. The paper ends with a discussion on the study with respect to its pedagogical values and applicability to other courses.

Keywords: concept mapping; chemical engineering; laboratories.

INTRODUCTION

A CONCEPT map is a schematic representation of information. It is constructed to provide a visual display of the relationships between concepts. The concepts are shown in the form of nodes or boxes and the relationships are represented by lines or arcs connecting the nodes. Words or phrases that explain the concepts are put inside the boxes, whereas the lines are labelled to indicate the characteristic of the relationships.

Concept mapping has been used extensively for a variety of purposes in the field of education. These purposes include the use of it as an instruction or teaching strategy, as an assessment tool for students' learning, and for curriculum development [1]. Concept mapping is considered beneficial both to students [2–7] and lecturers [8–11]. Concept maps require that students understand the interrelationships between concepts. Thus, concept maps may motivate student learning activities. For lecturers, on the other hand, concept maps may, among other things, help them to

'pinpoint' in which areas the students are weak, and therefore, need reinforcement. Additionally, concept maps are considered as a potential tool for lecture planning. They help arrange the material content in a logical manner. Finally, the activity of concept mapping can be useful to assess both pre- and post-subject matter knowledge of students.

This paper describes an ongoing study on the use of concept maps in an upper-division chemical engineering laboratory to enhance student learning. The Unit Operations Laboratory was chosen for the study since it is a comprehensive laboratory in which students are required to be familiar with various aspects of chemical engineering practice.

Chemical engineering courses contain many subjects that require the use of schematic representation such as flow diagrams and process flow sheets. This is evident in both lectures as well as lab exercises. It is envisaged therefore that the use of concept mapping as a learning tool will be appropriate.

Lab practice is usually of a 'cook-book' type and therefore, does not necessarily enhance critical thinking on the part of the students. This situation already concerned some educators and a number of approaches have been tried [12–13]. This paper

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presents a study to enhance critical thinking for undergraduate chemical engineering students through the use of concept mapping. Although concept mapping is assumed to lead to higher test scores [6], the present study focuses mainly on enhancing or motivating student learning.

UNIT OPERATIONS LABORATORY

Unit Operations Laboratory (UOL) is an upper-division chemical engineering lab exercise that offers two credits, and in our eight-semester undergraduate chemical engineering programme it is offered in the sixth semester. The aim of the lab exercise is to introduce the students to the chemical engineering aspects as practised in the field. Five topics are currently available in our department, and these are stripping, efflux time, HETP (Height Equivalent to a Theoretical Plate), drying, and pressure drop measurement, respectively. During lab practice students work together in groups of three to four. The experiment consists of three steps: pre-lab session, operation of the equipment, and writing of the lab reports. Each step needs to be satisfactorily completed by the group in order to earn a credit and proceed to the next step. The present work on concept mapping (being a preliminary study) was applied only for topic number 1, i.e. stripping, in which the author acted as a demonstrator. In the past, the pre-lab session was conducted as a dialogue in which a lab demonstrator would ask the students, questions of the 'second order perspective' [13], such as:

1. How do you relate this particular exercise (e.g. stripping) to the relevant UOL subject(s) you have taken before?
2. Are you familiar with the type of operation of stripping process?
3. Can you think of and elaborate a process similar to stripping?
4. How do you measure the flow rate of the compressed air used in this exercise?
5. Do you think that the flow rate will be the main variable affecting the stripping efficiency? Explain why or why not!

Obviously, the above questions do not provide rooms for 'Yes' or 'No' answer. Instead, a narrative type of answer should be given. The answer is expected to reveal that students understand 'something'. In most cases, the demonstrator would prefer to keenly listen to the students' explanation, trying to identify further questions that might arise out of the explanation. We avoided using low order cognitive questions [13] such as: What is stripping by definition?

During operation of the equipment the following questions were frequently asked:

1. How can you be sure that the flow meter is working properly?
2. What type of tower are you going to use and

can you explain the mass transfer process inside it?

3. How do you conclude that the experimental rig is operating as expected?

During preparation of the lab reports, students might ask for help from the demonstrators and they were usually prompted with the following questions:

1. How do you describe the efficiency of the stripping you have just performed?
2. How do you estimate the error propagation?
3. You have written several conclusions out of this stripping exercise. How can you relate them to the purpose of the exercise as written in the Background?

With the introduction of concept mapping for the UOL, the author with the help of one demonstrator introduced the idea and construction of concept maps on the first day of the lab. During pre-lab the students were encouraged to create concept maps both individually and collectively. Finally, a collective concept map should be prepared along with the lab report.

IMPLEMENTATION

A careful instruction is considered necessary for the successful creation of concept maps [10]. The instruction involves exercises during which time the instructor may provide the learners/students with examples on how to create a concept map. The instructor may provide assistance in the form of comments, corrections, ideas, and so on. In our case, due to limited access to computer facilities, the concept maps were hand-written and the introduction of them was conducted in the lab. The introduction started with the author showing two diagrams depicting simple concept maps, as shown in Fig. 1.

As can be seen, Fig. 1 illustrates the hierarchical structure of a higher education institution. The diagram on the left shows a simple structure, while that on the right conveys more details. The students quickly realised, even at face value, that the two diagrams were significantly different in their comprehensiveness. It was explained to the students that both the left and the right diagrams were correct. However, the diagram on the right obviously carries more points. The students were also told that a concept map is not necessarily of hierarchical cluster form [2], and that other forms such as a network structure [1] is also common. In fact, it was explained that a concept map may take any form as long as it conveys understandable and meaningful relationship between concepts.

After the introduction the students were told to create a concept map similar to those depicted in Fig. 1 but related to the content material, i.e. stripping, and were given the following basic concepts: unit operations, stripping, mass transfer,

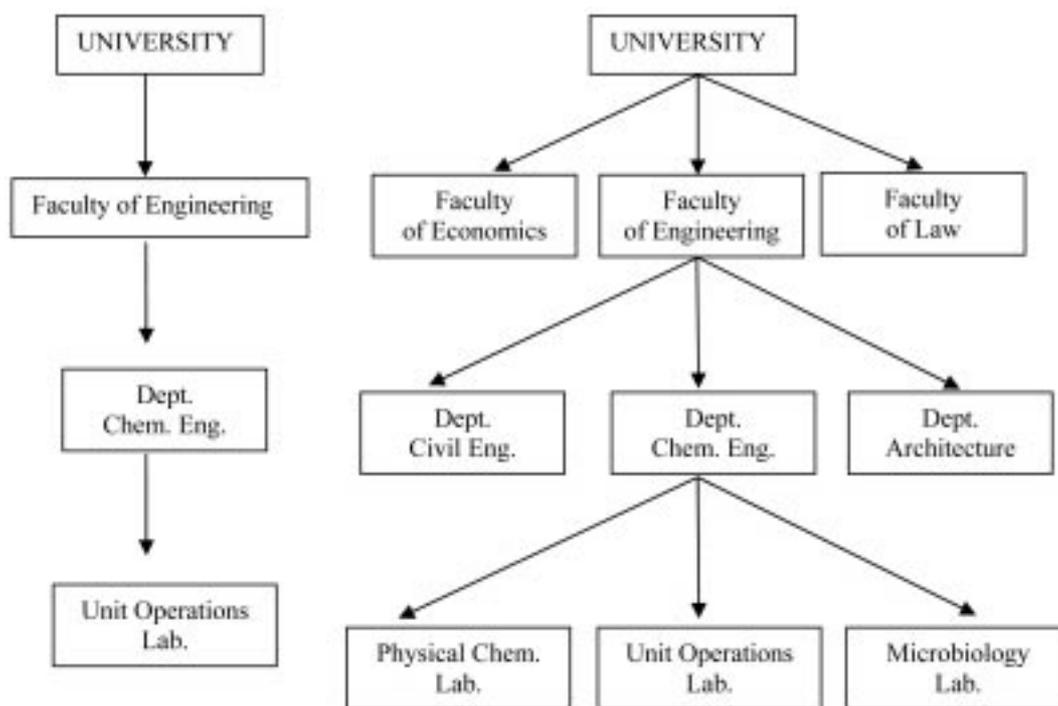


Fig. 1. Two comparable introductory concept maps.

gas phase, liquid phase, gas–liquid equilibrium. Furthermore, the questions as written in the previous section (see Unit Operations Laboratory) were also used for the creation of the concept maps. Additionally, the students were also asked to select several concepts related to stripping. Prior to drawing the concept maps, it was emphasised that this is an open-ended work with no single solution, and that the students could ask for help from either the demonstrator or the peer groups. Each group should at least hand in one collective concept map. Submission of many individual concept maps alongside the collective ones might indicate that the students were motivated to learn actively. These maps were kept separately as individual contributions and treated accordingly.

It was encouraged that each member of a group should feel free to contribute as many revisions to the collective concept maps as possible. Since individual contributions should be acknowledged, it was also informed that each contribution/revision to the collective concept maps should be labelled with the name of the contributing students. Each collective concept map was drawn on a piece of paper and was then glued to a cardboard or other hard backing provided in the lab. These maps were then hung on the wall of the lab and left displayed there so that from time to time the students from the group who owned the concept maps might modify or revise them.

Ferry *et al.* [10] have used volunteers in their research on the use of concept maps. Their method was also simulated in this work. It was announced that the students were expected to participate voluntarily in an interview that would be conducted in conjunction with this introduction

of concept mapping. The interview was intended to examine how the students felt about this new idea of concept mapping.

ANALYSIS OF THE STUDENT-GENERATED CONCEPT MAPS

To date, analysis of concept maps is mainly carried out in an arbitrary manner. Some researchers have used scoring criteria to assess the quality of a concept map, while some other researchers have applied the ‘density’ criteria, i.e. the frequency of the connecting lines that were used in a concept map [1]. The scoring system requires that values should be allocated on each component of a concept map. Obviously, the allocation of such values can be a subjective process with regard to both the domain of study and the expertise of the instructors. Similarly, counting the frequency with which components or propositions in a concept map may arise may also be inappropriate for evaluation purposes. Higher frequency does not automatically represent the intrinsic relationships between components [1]. Since the present study emphasises on the use of concept maps as a motivation tool for learning, the analysis was carried out to examine the ‘extent’ of knowledge that the students have in relation to the topic under consideration, i.e. unit operations. Thus no values were assigned to the components of the concept maps submitted by the students. In fact, the analysis was carried out with two purposes. First, the results of the analysis would be used to encourage student learning. Secondly, the analysis would be part of the author’s intention

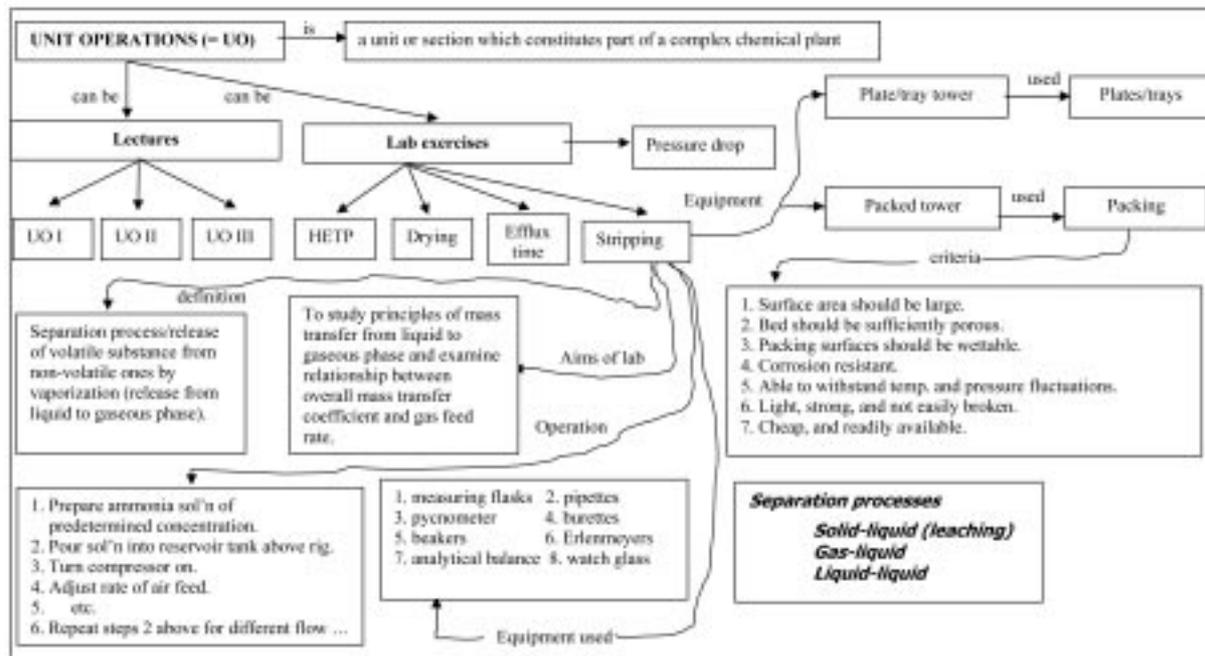


Fig. 2. Example of a student-generated concept map created after pre-lab (redrawn on computer for ease of representation).

to experiment with concept mapping in the domain of chemical engineering.

Figure 2 displays a concept map created by one of the groups right after the pre lab session when the concept map idea was introduced for the first time. For clearer representation, the hand-written concept map submitted by the students was redrawn on computer and shown as such in Fig. 2. The figure is typical of many individual concept maps created during this period. It seems that the group has made a serious effort in constructing it. The boxes, the connecting lines, as well as the words and phrases within the boxes are well presented. In addition, the direction of the arrows showing the interrelationships between concepts is all correct. The words and phrases explaining the concepts, however, are mostly copied from either the lab manual or the previous lab reports (the author as one of the demonstrators is well aware of such a situation). This clearly indicates the typical 'cook-book' type of lab activities, in which earlier reports etc. are simply passed on from one batch of students to the next. During the introduction of concept mapping, stripping as one type of separation processes was also discussed. It was anticipated that separation processes would appear and be explained in the concept map. However, as can be seen in the lower right hand corner of Fig. 2, the box containing the idea of separation processes was shown but left unconnected. It was not developed as expected. This is further evidence of the 'cook-book' tendency in lab activities.

It is also interesting to note that the concepts offered previously during pre lab session (unit operations, stripping, mass transfer, gas phase, etc.) were not used by the students. It could be

that concept mapping was still something so new, as if coming out of the blue, that the students did not have enough courage to venture into this area. The concept maps submitted were collected and analysed, and were later given back to the groups with comments for improvements.

Figures 3 and 4 respectively, demonstrate how the concept map on stripping as previously shown in Fig. 2 has been developed. Once again, for clearer viewing the hand-written concept maps were redrawn using a computer. Actually, the original hand-written version of Figures 3 and 4 was constructed on one large piece of paper. As can be seen, the concept of separation processes has been developed into several examples. References for the examples indicate that in developing the concept the students could have been motivated to work as a team. The possible increase in the understanding of the theory of stripping can be seen as well, that is, by the inclusion of such concepts labelled: Things to consider, Examples of Unit Operations, and Types of Packing. Labeling the concepts with both references and the name of the contributing students seems to be the most motivating part of this concept mapping activity. First, the students felt the need to show to the demonstrators that they were actively involved, that is by adding both the references and their names to the concept maps. Secondly, it could also be possible that they put down their names in the maps to make an impression on other fellow students.

It was observed that more discussion occurred between the students in a group during this activity, thus it is believed that concept mapping could encourage team building and critical thinking skills. Based on Figs 3 and 4, it is assumed that

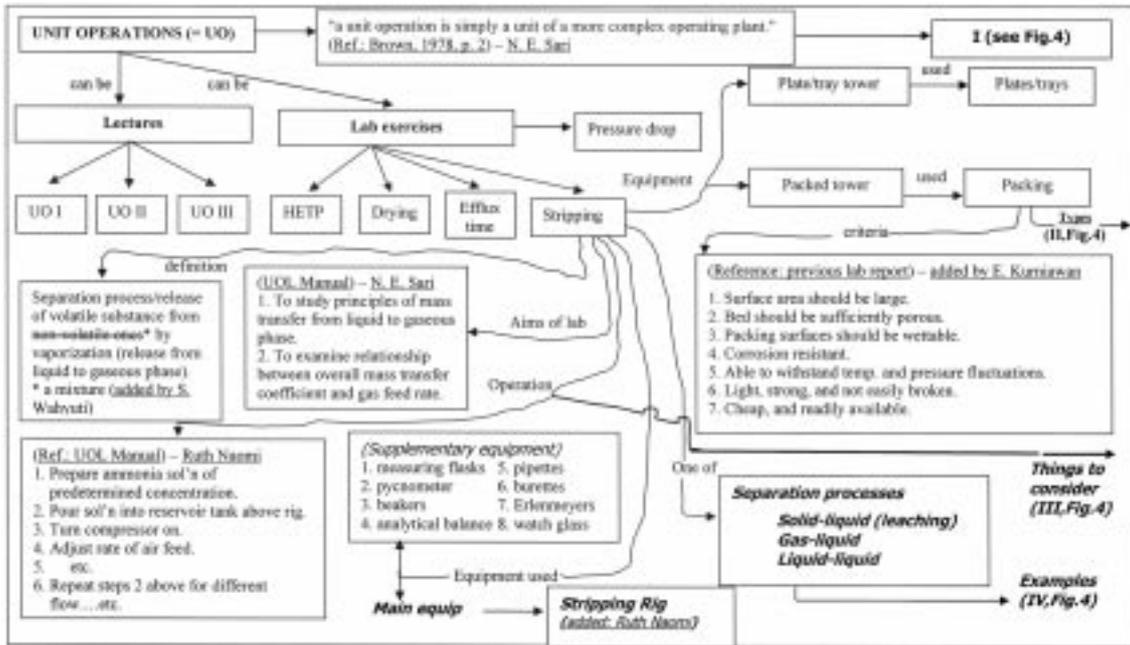


Fig. 3. Development of Fig. 2 (carried out throughout the lab practice).

the present work is also useful in discouraging rote memorization where students only memorized what they had learned.

SAMPLES OF JOURNAL ENTRIES FROM STUDENTS

An interview for the volunteer students was conducted by the author and the results of it were made into a journal. Following are some of the journal entries.

1. *I feel more confidence since I realize that I won't be penalized with a zero mark, whatever my answer was.*

This student valued the concept mapping application as a method by which his effort would certainly be acknowledged. He actually compared the present method of pre-lab session, i.e. using concept maps, with the previous one when students were asked questions. Unable to answer the questions correctly could result in the lab exercise being postponed. In his case, it seems that the

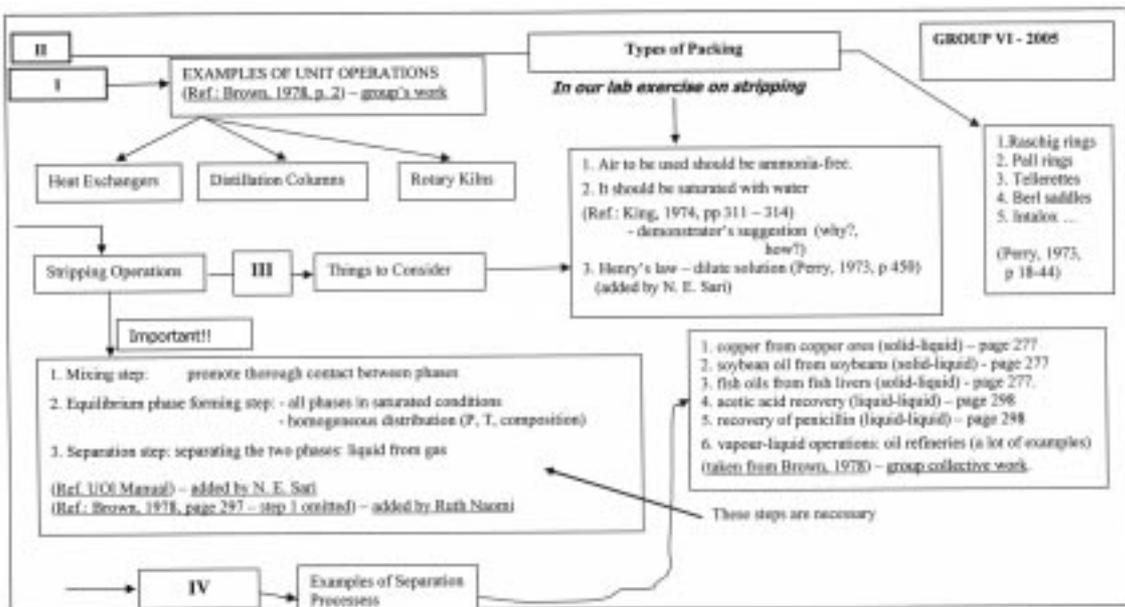


Fig. 4. Development of Fig. 2 (carried out throughout the lab practice and beyond).

application of concept maps made him feel more comfortable.

2. *I feel great to learn that other students, they are the forthcoming batch of students, would recognize my work. I think my contribution to the drawing will be part of a big continuous project in this lab.*

It appears that the application of concept mapping has been able to motivate this student. He feels the need to work properly, realising that future students would recognise his work.

3. *The references are useful for other subjects as well. Other students may benefit too.*

4. *Can be used for other lectures.*

5. *I'll try the concept mapping for other subjects. For my own use.*

Comments numbers 3, 4 and 5 (from three students) indicate that the idea of concept mapping could be applicable to other subjects.

6. *It's not that easy. You need to understand the relationship among concepts. Well, connecting pieces of information forces you to think hard.*

Many students had this comment (not necessarily in the same sentences). Such a comment is particularly valuable for the author. It helps him understand the need to explore the advantages of concept mapping further with respect to teaching and learning.

7. *Could be useful if introduced early. The beginning of uni studies.*

This student considered the concept mapping as a useful tool that should be made known to students earlier. The idea of concept mapping was related to effective learning.

8. *I used something like this in high school. I feel comfortable using it.*

One of the volunteers did mention about her previous experience using concept mapping. It seems to be a positive experience.

EVALUATION OF THE STUDY

Students' response to this concept mapping project within the context of laboratory exercises is generally positive. They pointed out that such a project could improve their critical thinking skills. Most of the students admitted that their learning skills are still below that required for the scientific environment. This is especially noticeable when the author asked the students to write yet another concept mapping for any other courses taught in the chemical engineering programme. The concept maps, they stated, were something new to them although on several occasions they had been asked or had constructed something like an organizer or a concept map. During the interview conducted by the author some students acknowledged how

inadequate their understanding on unit operations (e.g. stripping) was, until they faced with creating a concept map. They explicitly mentioned that a seminar on concept mapping could be useful.

The project does reinforce the materials received in lectures. The students were made aware that the project was typically an open-ended type with no specific solution. The time spent (apart from those spent in the lab and in writing the reports), however, was often underestimated by the students, which made some of them feel under pressure towards the end of the project.

The teaching staff response indicates that such a project on concept mapping applied to lab exercises is beneficial to students. They are concerned however, on the marking system since evaluation of concept mapping tends to be subjective in nature. Instead of a seminar on concept mapping, our department is inclined to 'insert' the concept mapping idea in certain subjects including the lab exercises. This is because the chemical engineering curriculum already consists of several concept-like components as described previously.

This preliminary study on the application of concept mapping indicates that lab exercise can be a practical avenue for the enhancement of student learning. It is concluded that concept mapping can be used as a motivation tool for learning activities in the chemical engineering studies.

CONCLUDING REMARKS

This paper has offered lecturers and demonstrators ideas on how to use concept mapping to encourage student learning especially in the area of chemical engineering laboratories. As concept mapping is visually displayed, it helps students/learners understand the concepts and their inter-relationships relatively easily. For the teaching staff, on the other hand, analysing the concept maps may help them to decide which area(s) the students have not fully understood. In addition, concept mapping recalls past content knowledge and/or experience that is useful for other subjects as well. Furthermore, concept mapping helps arrange logical flow of ideas in a visual manner.

It was felt that the application of concept mapping to UOL was successful in enhancing student learning. This could be caused by the familiarity of the students with assignments similar to concept mapping such as the construction of flow diagrams or process flow sheets. Apart from this, it was also observed that the students were motivated, which could be shown by their enthusiasm in revising the initial concept maps and the way they labelled the concepts.

Based on the seemingly positive results of this preliminary study on concept mapping, it was planned to pursue other goals. These goals include application of concept mapping to:

1. Assess students' understanding of the subject matter knowledge.
2. Outline and sequence problem solutions in a logical manner.
3. Effectively improve the structure of the teaching materials with regard to instructional design or lecture planning.

It was also agreed to conduct an informal one hour

session occasionally at lunch hour during the semester, during which time the idea and application of concept mapping could be discussed among students and teaching staff.

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