Chapter 2

Experiential Learning via Open-Ended Laboratory Initiatives

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http://dx.doi.org/10.5772/intechopen.77015

Abstract

Conceptual mapping of existing knowledge on previous subject learned with the new knowledge can be accentuated using experiential learning methodologies. Open-ended laboratory (OEL) initiative exemplifies the intended outcome of experiential learning cycle where the learners encounter new experiences via laboratory experiments, reflecting the observation made interconnecting the inconsistencies between experience and understanding. This provides a solid basis for the learners to create or modify existing abstract concept of the experiments undertaken. These experiences will be put into context where the learners actively and adaptively experimenting and integrating previous knowledge with the new knowledge and put into practice by developing appropriate experimental procedures in order to achieve the set objectives given for a particular problem statement. This chapter illustrates the concept of open-ended laboratory (problem based), describing the transition of traditional laboratory (TL) to problem-based learning experience via experiential learning methodologies. The methodologies in developing the OEL in a chemical engineering laboratory course and their implementation in a process control laboratory setup were also outlined. The transition of traditional to problem-based findings and course outcomes attainments were investigated and measured using appropriate tools. The challenges and difficulties in implementing OEL were described and analyzed with data obtained from the experiences of conducting OEL in the School of Chemical Engineering, Universiti Sains Malaysia.

Keywords: experiential learning, concepts, implementation, assessment, open-ended laboratory

1. Introduction

Chemical engineering laboratory course has always been a core module in any chemical engineering curriculum around the globe. Some universities have even started the course as early as sophomore year toward their final year to reinforce chemical engineering fundamentals and apply the knowledge and skills gained from courses to actual chemical engineering experiments. This guided and prescriptive laboratory course is no longer adequate within the context of synergies between twenty-first century learning skills and the establishment of outcome-based education.

In the advent of Industrial Revolution 4.0 and the challenges to produce learners equipped with the essential twenty-first century skills, chemical engineering laboratory course has become one of the essential tools for innovative teaching and learning processes beyond the boundaries of conventional setting. It is a platform that engages learners in multidimensions of cognitive, psychomotor, affective skills where knowledge is being applied in a practical manner thus making it the most suitable stage to increase the experiential learning of the learners.

Experiential learning provides a solid platform for stimulating the learners' intuitiveness to be more systematic, inquiry-based with specific end in mind. Thus, providing opportunities for the learners to be more engaging intellectually, creative, and taking initiative while making decision and be accountable for the outcomes attained at the end of the exercise. Conceptual mapping of existing knowledge on previous subject learned with the new knowledge can be accentuated using experiential learning methodologies. Experiential learning philosophy relies in the learning through experience where learners can reflect on their actions to gain understanding on the consequences of that action and arrange the understanding into a generalization of principles of accumulated knowledge which can be obtained via open-ended laboratory (OEL) exercise.

2. Concept of open-ended laboratory

OEL initiative exemplifies the intended outcome of experiential learning cycle where the learners encounter new experiences via designing and conducting laboratory experiments, reflecting on the made observation and interconnecting the inconsistencies between experience and understanding. These features provide a solid basis for the learners to create or modify existing abstract concept of the experiments undertaken. These experiences will be put into context where the learners actively and adaptively experimenting and integrating previous knowledge with the new knowledge and put into practice by developing appropriate experimental procedures in order to achieve the set objectives given for a particular problem statement [1].

In contrast with the OEL initiatives, the traditional laboratory (TL) approach lies in the concept of information assimilation process where information is transmitted through a symbolic medium, assimilated by the learner, and generalized before actually being applied. Therefore, most TL approach is carried out following theoretical-based lectures attended by the learners before a meaningful TL can be conceived [2]. This resulted in a laboratory procedures consisted of detailed set of instructions for the experimental set up by the instructors in closed manner with the expectation of the learners should obtain and foolproof the experimental results that would support the theory learned in the class. Though this approach would be optimal on the side of the instructors in establishing the theories learned in the classroom but it also creates a *faux accent* on the learner's sides as it skips many important steps in designing an experiment and reduced the efficacy of a laboratory experimental sessions in teaching important laboratory skills to learners, thus, placing it to only a step higher than a mere laboratory demonstration to the learners. In practice, learners not just lost the opportunity to develop skills in designing an experiment but usually mislaid the logic of the experiment as well as they put more psychomotor efforts to manipulate and following instructions when executing the experiments rather than invest time to develop higher thinking order cognitive skills involving the experimental setup.

OEL works in tandem with the experiential learning process where learners conceived the conceptual and practical of the undertaken action with the understanding that it involves consequences in a particular circumstance and finally being able to reflectively generalizing the principle across a range of circumstances. OEL would bring the learners' learning experience nearer to the real professional life situation of practicing scientist and engineers as most engineering laboratory procedures are developed and manipulated through experience and knowledge accumulated from scientific literatures rather than handed in the form of standardized procedures as in testing laboratory works. It is important to note that neither OEL nor TL should be seen as competitive to each other but rather the two learning processes are complementary to each other. The keyword here is to strike a balance between both approaches as both are necessary for optimal learning since the emphasis between depth and breadth of laboratory skills varies greatly in both approaches. The TL has the advantages of greatly reducing the time and effort necessary to cover many new laboratory techniques, whereas OEL increases intrinsic motivation among learners as they connect the skills to real-world context and will definitely assist the knowledge retention for years to come.

Departing from TL toward OEL, one will find that there are varying degrees in the level of laboratory openness. **Table 1** shows the gross representation in level of laboratory openness. Level 0 would represent a fully laboratory demonstrations while level 5 for undertaking a full laboratory research project. Levels 1 and 2 are where the TL dominates and OEL be more dominant in Levels 3 and 4. In practice, the time for delivery at the upper level will definitely take more time than the lower level as learners require time to define the needs of open nature of elements in that level compared to time taken to understand the nature of a given elements. Al level 4, OEL elements intensify the time taken to complete tasks the learners need to develop in the laboratory procedures and dissecting the problem analysis of the experiment. A typical profile of the laboratory based on the level of openness is given in **Table 2**.

It is advisable for learners to undergo a series of progressive openness from lower levels so that the learners could acquire many useful laboratory skills that would be of help when going to the next level and finally acquire research and investigation skills that would be useful to carry out in a laboratory research project. One could see that if learners are not being

Level	Experimental theme	Problem statement	Experimental methodology	Expected results	Expected discussion
0	Given	Given	Given	Given	Given
1	Given	Given	Given	Given	Open
2	Given	Given	Given	Open	Open
3	Given	Given	Open	Open	Open
4	Given	Open	Open	Open	Open
5	Open	Open	Open	Open	Open

Table 1. Level of openness in laboratory.

Level	Typical profile
0	In laboratory demonstrations, learners are given all information pertaining to the experiment including the objectives, procedures, results, and its corresponding discussion which sometimes some of it in a form a fill in the blanks statements to emphasis the theory to the learners.
1	In traditional laboratory courses, learners are supplied with the laboratory manual containing all relevant information such as operating procedures and learners needed to digest before conducting the laboratory experiment. There are questions left for the learners for discussion or it is left open but hints of theory involved is given so that the expected results from experiment can be anticipated by the learners. Learners also supplied with the data sheets to guide them in data collection.
2	In traditional laboratory courses, learners are supplied with the laboratory manual containing many relevant information such as operating procedures and learners needed to digest before conducting the laboratory experiment. Learners need to plan and arrange the format for data collection as the data sheets to guide in data collection not given. Discussion on the experiment is left open for learners to evaluate based on the results.
3	In open-ended laboratory courses, learners are supplied with the clear objectives and problem statement of the experiment. However, the laboratory procedures to achieve the objectives are not given or coarsely given. Learners need to develop the procedures through literature or operating manual of the equipment. Learners also need to identify the various parameters and data that need to be collected. Discussion on the experiment is left open for learners to evaluate based on the results.
4	In open-ended laboratory courses, learners are supplied only with the clear objectives of the experiment. Learners to analyze the ill-defined problem with the help from literature review and come up with the problem statement. Learners develop the methodology and laboratory procedures to achieve the objectives through literature or operating manual of the equipment. Learners also need to identify the various parameters and data that need to be collected. Discussion on the experiment is left open for learners to evaluate based on the results.
5	In free laboratory research project, learners decided to carry out from an ill-defined experimental theme usually in the form of final year research project that takes at least the whole semester to complete.

Table 2. Typical profile based on level of openness of the laboratory.

exposed to OEL and only used to participate in TL, it is going to be a steep learning curve for the side of learners to be able to do a full laboratory research project in a later stage. In this perspective, OEL act as the scaffolding for the full research project.

The delivery of OEL has many models which the instructors would have to see as which models would give the best fit to the learning processes organization as different learning institutions have different strength and capability. The factors to weigh, in addition to selecting the level of laboratory openness, would be the degree of independence given to the learners in OEL for decision-making. As OEL would be more open than TL, the questions arise on the role of instructors in assisting learners in determining the scope of the problem statements, selected experimental procedures, selected parameters, and data collection. OEL initiatives would take a longer period of time not just by the learners but also by the instructors as the role of laboratory instructors are now redefined to include supervision.

3. Open-ended laboratory in undergraduate program in the School of Chemical Engineering, Universiti Sains Malaysia

A case study of OEL practiced in the School of Chemical Engineering, Universiti Sains Malaysia is presented in this section. OEL initiative has been introduced to the laboratory courses offered by the School since academic session 2013/2014 and has been the standard practice until now. The implementation of OEL has been adapted from the OEL approach reported in [3, 4]. The laboratory courses involved three courses: EKC291, EKC394, and EKC493 that would be taken by students at their second, third to fourth year, respectively. Each laboratory course is a two credit hours course which means about 4 h of laboratory session per teaching week. The level of laboratory openness in OEL approach is made increasing with the students' incremental years of study. The laboratory courses are a mix between OEL and TL approaches. The students were divided into groups of three/four, and each team is given one OEL project during the semester, while another eight laboratory works are meant for TL. Prior to the introduction of OEL in the laboratory courses, students would have been required to conduct about 12 experiments in TL approach. The School believes that 1 OEL + 8 TL format in three laboratory courses would be best compromise to both develop generic laboratory skills by the students and give students opportunity to delve into a wide variety of experimental topics.

The OEL were running for 4 weeks with one supervisor to craft the question or the problem statement, monitor and marking the group and individual performance of the student. Each group was given 3 h duration of in-lab sessions and 2 h duration of out-lab sessions in each week. The distributions of in-lab and out-lab sessions were shown in **Tables 3–6**. In-lab and out-lab sessions were spread between week 1 and week 4 where the student can have a mixture of session in each week. In-lab session means the students can carry the laboratory work during laboratory session where it normally starts in week 3 after the students have familiarized with the experimental rig and came up with the appropriate standard operating procedure (SOP) of the experiment, while an out-lab session is the discussion handled outside or during the laboratory session which do not involved directly with the laboratory experiment.

In addition, students were briefed on the safety on the laboratory prior to the OEL Lab in the first week. This safety briefing is carried out by the school safety officer. In week 1, the supervisor will hand in in-lab and out-lab activity to the student as shown in **Table 3** and the

In-lab session (3 h)	Out-lab session (2 h)
• Understanding the problem with facilitator's guidance • Brainstorming, giving ideas to solve problem • Identifying available resources and tools • Identifying what you know and what you need to know in solving the problem • Facilitator marks individual in-lab activities	• Get more resources to help understand the problem • Divide work among group members • Report findings to group • Agree on a solution

Table 3. In-lab and out-lab activity for week 1.

In-lab session (3 h)	Out-lab session (2 h)
• Present solution to facilitator • Facilitator comments on solution, making sure the group is on the right track • Group begins to design experiment • Group confirms the experiment layout • Facilitator monitors and marks individual in-lab activities	• Group conducts some simulation work to reconfirm design (if necessary) • Group verifies availability of equipment and tools to conduct experiment • Group prepares schematic or flow diagrams for experiment

Table 4. In-lab and out-lab activity for week 2.

In-lab session (3 h)	Out-lab session (2 h)
• Group begins to conduct experiment • Facilitator monitors and marks individual in-lab activities • Group obtain results from experimental work	• Group starts preparing comprehensive report • Planning for presentation session

Table 5. In-lab and out-lab activity for week 3.

In-lab session (3 h)	Out-lab session (2 h)
• Report writing • (Facilitator monitors and marks individual in-lab activities)	• Continuation of report writing and submission not later than Thursday of the week.

Table 6. In-lab and out-lab activity for week 4.

examples of the scenario/problem statement in **Figures 1** and **2**. The tasks can be given out as a role-playing case study or as in a problem scenario case study.

The supervisor will act as the facilitator to guide the student in understanding the given problem, propose the SOP and run the experiment accordingly to get the expected experimental outcomes. In week 2, the students need to propose the solution and the SOP to the supervisor where the supervisor will then evaluate and assess the proposed solution and ensure that the propose solution and SOP able to guide the team to get the expected outcome of the problem as shown in **Table 4**. In weeks 3 and 4 (see **Tables 5** and **6**), the team will

> Memo: Technical Manager to Technical Team
>
> Subject: Cooling Tower performance
>
> I received a complaint from Operation Department about the performance of our cooling tower where the additional heat exchanger in the cooling water circuit makes the existing cooling tower seem not be able to cool down the cooling water return (CWR) to the design values. In the complaint, it is reported that the additional heat exchanger in the system increased the heat load of the cooling tower.
>
> Therefore, I would like your team to investigate the claim by the Operation team and please rectify the problem, if the complaint in the report is true. Please check the performance of the existing tower using the min temperature of the CW inlet at ambient temperature then after additional heat exchanger in the CW circuit the cooling water inlet temperature may increase up to max of ΔT to 15 C. The criteria you may need to have a look are:
>
> 1. Air velocity through the tower
>
> 2. Driving force
>
> 3. Performance/efficiency

Figure 1. Sample of role-playing memos as task given in OEL.

> Problem Scenario:
>
> The School has bought 3 control valves with different characteristics from supplier A to replace the old control valves in the existing engineering laboratory. The School's management place an order for the valves based on the specification information given in the catalogue.
>
> Using the existing rig in the Laboratory, the laboratory manager asked your team to check whether the delivered control valves are actually following the design specifications given in the catalogue or in reality differ from the original specifications. The technical instructor requires your team to outline the procedures to determine the control valve characteristic in the report. (Please refer to specifications given in the catalogue, in particular, the inherent characteristic of the control valve).
>
> After the study, the engineering laboratory technician as the person in charge would like to seek your opinion about the suitability of the control valves because the person in charge are not sure which control valve would be better for low flow with quick response application. The person in charge would like to know about the controllability of the valves in the region of high flow as well, as he/she intended to install one of the control valve in a boiler system which needs a fast response to reduce the pressure in the steam header.
>
> Since the flow is unstable at times, the pressure tend to oscillate quite heavily, therefore the laboratory manager would like you to determine whether this scenario has a significant effect to the control valve performance. Please outline the procedures or state the justifications in the report when deciding the correct control valves and report all important parameters in the performance study.

Figure 2. Sample of problem scenario given as task in OEL.

conduct the experiment and monitored by the supervisor and also laboratory technicians, analyze the result, preparing the comprehensive report, and also the viva voce session.

4. Assessment methods for open-ended laboratory

The assessment method covers not only the comprehensive report submitted but also other components of assessments as shown in **Table 7**. Many assessments methods employed by

Details	Marks
Peer and self-assessment	10
Supervisor evaluation on student participation (quizzes, assessment rubrics, etc.)	15
Comprehensive report	50
Seminar presentation/viva 45 min	20
Attendance	5

Table 7. Assessment method in OEL.

Bil	Item
1	Title page
2	Abstract/summary
3	Table of content
4	Introduction
5	Application in industry
6	Objectives
7	Methodology-procedure and experimental setup
8	Result and discussion
9	Conclusions
10	Acknowledgment
11	Abbreviation/nomenclatures
12	References (at least 10 from technical articles/books)
13	Appendices
14	25–30 pages max (excluding title page and appendices)

Table 8. Format of comprehensive report for OEL.

http://dx.doi.org/10.5772/intechopen.77015

the School were adapted from references [5–7]. Based on the assessment, the students' teamwork, psychomotor/lab handling skill, and presentation skill were taken into account. In each assessment, for example, the comprehensive report, the rubrics are given based on the rating for each attribute. The contents of the comprehensive report are shown in **Table 8**.

5. Reflections in open-ended laboratory initiatives

In OEL, the students will utilize their fundamental knowledge of chemical engineering that they had learned in Years 1 and 2 and apply in Year 3 in Chemical Engineering Laboratory III. The students need to set what are the objectives of that particular experiment and also what is the goal that they want to obtain or achieve in that particular given problem. In addition, they need to discuss and propose to their supervisor the design steps on the experiment, how to set up the procedures for the experiment and the most important thing is they need to present it to the supervisor to attain his agreement on the proposed procedures. In this activity, the students will cogitate and use their higher order thinking skill to design and propose the procedures to the supervisor. Thus, the data that need to be collected also need to be determined by the students. Some experiment like in TL, there a lot of data need to be taken into account; however in OEL, only data that related to the design of experiment or goal need to be collected. Skill of presenting the result like using graph or flowchart or how to organize the data are very important in this stage as well as skill to analyze the data using any statistical tool, if needed. The results and the goals of the experiment need to be justified whether it is achieved or the result deviated from the theory. In this stage, the student uses their own ability to propose the solution and set the goal for the experiment. However, if the student were not able to obtain or achieve the goals, the student can apply different strategies or methods, subject to supervisor's approval in the attempt to get the expected result. This activity indicates that the students have the capability to analyze the result properly and propose a new solution that may solve the problem hence obtaining the goal of the experiment.

The feedbacks on OEL from the student were carried out as part of the question asked in the exit survey by the exiting students. The response obtained from the students are shown in **Figure 3** and summarized in **Table 9**. The students were asked the question how effective OEL in strengthening students' laboratory skills with 5-point Likert scale-type response with least effective, less effective, average, very effective, and highly effective. It is shown that the students' tendency is favorable toward OEL and has been improving from the first year of OEL's inception to the laboratory courses in 2014. This can be seen from mean rating scale of 3.50 out of 5.00 in 2014 and increasing to 4.00 and 4.08 in 2015 and 2016, respectively, before settling at rating scale of 3.75 in 2017 (see **Table 9**). The accepted minimum response as a performance indicator to indicate support on the OEL initiative was set at response at scale 4 (very effective) and above. Response started in 2014 with highly divided at 48:52 (yes:no) ratio and later improved in the subsequent years presumably by better supervision and guidance by the laboratory instructors on the students groups as the laboratory instructors gained more experience. In the qualitative response section in exit survey, most students generally comment that

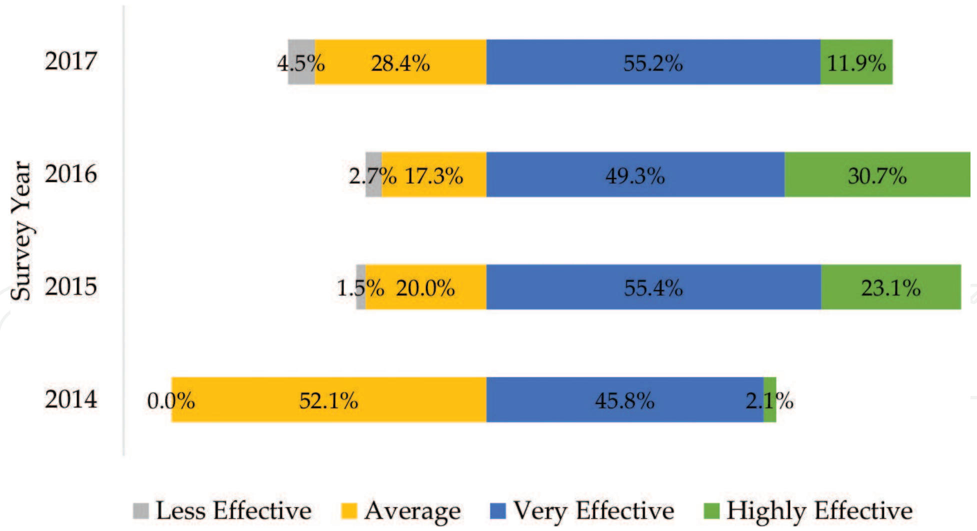

Figure 3. Exit survey response of students on how effective OEL in strengthening students' laboratory problem-solving skills.

Year	Sample size, n	Mean, μ	Standard deviation, σ	Mode and median
2014	48	3.50	±0.30	3 (Average)
2015	65	4.00	±0.50	4 (Very effective)
2016	75	4.08	±0.59	4 (Very effective)
2017	67	3.75	±0.53	4 (Very effective)

Table 9. Analysis of exit survey response on effectiveness of OEL in strengthening laboratory problem-solving skills.

the OEL did make the students to be more creative in solving the given problem, excite their HOTS and also increased their attainment toward lifelong learning. Other skills like teamwork and presentation skill were also seen to improve and in turn would provide the necessary skills for the students' survival in the ever-challenging working environment in industry.

Reflecting through the OEL initiatives as compared to TL approach has shifted the norm of laboratory practices among the students. Given ample time to design their experimental work, the students learn the importance of coming to the laboratory prepared and developed the logic of experimental work. This initiative promotes intrinsic motivation of the students and creates a mind shift from passive laboratory user to an active participant. Knowing responsibly the hardwork required in OEL, prepares the students a real-life research project environment where delicate balance of compromise between the theoretical experimental setup that can be carried out in laboratory to the constraints of time, cost, and safety. Students are also compelled to learn independently from literature and sought guidance from their supervisor and found to be involved in peer to peer learning as they tried to solve the problems.

Supervisors of the OEL project need to invest time to supervise the OEL groups as our experience shows that while few of the OEL groups tend to seek shortcuts and find the easiest way to complete the project, the reality is many of the OEL groups tend to choose the most exciting path. However, due to the constraints in resources and time, many of the chosen exciting paths taken by the OEL groups are not practical. It was the experience of the supervisors that can help the students to take into considerations the practical aspects of the project to enable them to complete the OEL project within the time frame. Creative students will find the given autonomy, and fewer restrictions on the implementation of OEL project will increase their intrinsic motivations as they themselves (to certain extent) define the direction of the OEL project. The creativity in solving OEL project usually would translate well into the good assessment grades by the OEL supervisor as students make an impression by giving fresh ideas and unorthodox approaches.

Nonetheless, not all students would be pleased on the introduction of OEL initiatives, as a handful of students were found to be frustrated, as the results of OEL do not necessarily be one correct answer. Students also feel that the increased interaction with the laboratory teammates and the technicians as well as the progress of the OEL project sometimes depends on factors beyond individual control that can contribute to their frustration. The OEL initiative also found to create many logistic and laboratory safety issues. In TL, each piece of equipment had one specific role with particular standard operating procedures, whereas in OEL, students are required to use different raw materials and operating parameters in order to meet the needs of their problems and thus, creates additional load to the laboratory technician to monitor the experimental work by the students. The laboratory technicians also need to upgrade their know-how and knowledge, especially the safe operating limit of equipment and limit of its flexibility in adapting to new experiments.

It is important for the course or program owner to note that the considerations for selecting and embedding OEL in laboratory courses depend on the learning outcomes. It is the laboratory course's intended learning outcomes that dictate the pedagogy and assessment for laboratory courses. This is the crux of constructive alignment in the philosophy of outcome-based education. Adopting TL approach would be sufficient if the intended learning outcomes in the laboratory course simply concentrate on students' ability to skillfully conduct experiments on certain topics; however if the intended learning outcomes of the laboratory course would be the ability of the students to design an experiment on a given topic and at higher level the program intended outcome aspires to increase the experiential learning of the students then the TL approach would be less adequate and it warrants a better delivery method to achieve the intended learning and program outcomes such as OEL.

6. Conclusions

Analysis for the reflection activity showed that there are mixtures on the students' perception on OEL. Some of the students see the OEL initiatives did help them to have a deeper understanding on the fundamental concept of chemical engineering like mass transfer and heat transfer. On the other hand, there are a handful of students who perceive this OEL as a burden to them like creating their own experimental procedures. A higher percentage of the students agreed that OEL activities provide them better laboratory skills than TL. OEL initiatives nevertheless increase the experiential learning of the students as they equip and prepare them better in their research-based final-year project (FYP) and facing the real environment in industry.

Acknowledgements

The authors would like to acknowledge Dr. Derek Chan and Dr. Khairiah as a coordinator of Chemical Engineering Laboratory II (EKC 394) and Dr. Vel Murugan for Chemical Engineering Laboratory III (EKC 493) for fruitful discussion on OEL implementation in the School of Chemical Engineering USM.

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