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University of the Philippines Diliman Chemical Engineering Plant Design Course: Addressing Student Outcomes on Engineering Design

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Highlights

- The BS Chemical Engineering program of UP Diliman offers two senior-level capstone courses on chemical engineering design.
- Achievement of course outcomes and selected student outcomes on engineering design of the two capstone courses were investigated.
- Course materials presented congruences of course deliverables with the indicated course and student outcomes.
- Student feedback for the two courses showed high percentages of responses on good learning experience and achievement of course and student outcomes.

Abstract

The BS Chemical Engineering program of the University of the Philippines Diliman offers two senior-level capstone courses on chemical engineering design. This study aims to assess the effectiveness of the courses in achieving their indicated course objectives/outcomes, as well as in addressing the selected student outcomes on engineering design. Congruences between lecture and laboratory component deliverables with the course outcomes, as well as the rubrics were summarized. Students' feedback on the extent of their learning experience and their perception on the extent of how the course and student outcomes were achieved, were also presented.

Key Words: capstone design course, engineering design, chemical engineering

1. Introduction

Capstone design courses for engineering programs bridge the gap between school and professional practice and provide students opportunity to apply lifelong learning and sound engineering judgment (Pembridge and Paretti, 2019). The experiential and project-based learning in any capstone design course integrates fundamental knowledge gained from professional and allied courses in the curriculum with the practical side of engineering design (Duston et al., 1997).

The Policies, Standards, and Guidelines (PSG) for the Bachelor of Science in Chemical Engineering (ChE) Program, as adopted by the Commission on Higher Education (CMO No. 91), have mandated that any higher education institute in the country offering a 4-year degree program on chemical engineering must offer, as a minimum, two capstone courses on chemical engineering design (Chemical Engineering Design 1 and 2). These courses must be taken as senior-level courses, with lecture and laboratory components meeting every week.

The UP Diliman Department of Chemical Engineering offers two senior-level capstone courses taken during the student's final year: ChE 141 (Chemical Process Development and Economics), taken during the first semester; and ChE 142 (Chemical Engineering Plant Design), taken during the second semester. Both courses require an end-of-semester report that discusses the market, technical, and economic feasibility of putting up a local plant to manufacture a chemical product. Each of these courses have both lecture and laboratory components.

This study aimed to assess the effectiveness of the UP Diliman BS ChE plant design courses in achieving its course objectives and selected student outcomes of the degree program. The courses, which provides one of the program's capstone projects, aim to demonstrate six of the twelve competencies upon graduation. This paper focused on two of those six student outcomes, namely, to demonstrate or possess:

1) *the ability to design a system, component, or process to meet desired needs within realistic constraints such as economic, environmental, social, political, ethical, health and safety, manufacturability, and sustainability, in accordance with standards; and*
2) *the ability to identify, formulate, and solve complex engineering problems.*

The objective of this study was to assess if the plant design courses ChE 141 and 142 were able to achieve the above student outcomes. Specifically, this study aimed to analyze the correspondence between the course outcomes and the two selected student outcomes, and to determine student's perception of the extent of their learning, and that of meeting the course objectives.

2. Methods

Laboratory activities and deliverables were checked if practical application of the lecture topics was provided. Feedback from the students regarding the extent of their learning and their perception of extent at which the course objectives were met by the courses, were obtained from the Student Evaluation of Teacher (SET) reports. Sampling population of student output and feedback were limited to students who were enrolled in the courses during the period AY 2016-2017, AY 2017-2018, and AY 2018-2019.

2.1 Determination of Lecture-Laboratory Congruence

A description of the courses, their content and the laboratory activities/deliverables were obtained from the course syllabi. These were set side-by-side on a two-column table so show correspondence. Sample evaluation forms and consultation forms were also used to indicate implementation of individual student contributions to the group outputs as well as individual reporting during consultations. Rubrics of ChE 141 and ChE 142 for checking the end-of-term report were also deemed important in assessing.

2.2 Feedback from the Students

Data were gathered and processed from the responses in the semestral SET results for ChE 141 and ChE 142. The SET is an online module employed by UP Diliman to collect feedback on the student's learning experience and evaluation of the handling of the courses he/she was enrolled in a semester. In this study, responses on two selected questions from the SET questionnaire were processed:

Question 1: How much have you learned from this course?

Question 2: To what extent, would you say, have the objectives of this course been attained?

Responses were categorized according to a 5-point Likert Scale: Very Much, Much, Some, Very Little, and Nothing. Results are presented separately for lecture and laboratory classes for the last three years. Histograms of responses were generated and validated with sample student outputs and their evaluation.

3. Results and discussion

3.1 UP Diliman BS ChE Program

The UP Diliman BS Chemical Engineering program uses a 5-year program until the school year 2017-2018. The new 4-year curriculum started implementation SY 2018-2019, however, the 5-year course continues to be offered until the 2015 cohort graduates in 2020. Among the nine undergraduate program goals, also known as the student outcomes, this study focuses on only the two specified in this study's objectives above.

3.2. The Plant Design Course Framework and Implementation

The plant design course in the BS Chemical Engineering program in UP Diliman spans two (2) semesters. The first semester course, ChE 141, is credited with 2 units lecture (2h/wk) and 1 unit laboratory (3h/wk), while the second semester course, ChE 142, has 1 unit lecture (1h/wk) and 2 units laboratory (6h/wk). Exams are given for the lecture part, while weekly requirements are submitted in the laboratory sessions. A written report is submitted at the end of each course. The output from the first semester course serves as the starting point of the second semester course. A hard-bound plant design report is the ultimate output of the 2-semester capstone project.

Students work on the year-long capstone project in groups of 3 or 4. A group leader is designated and tasked to ensure equitable distribution of tasks, preparation of agenda for each consultation, and timely delivery of weekly requirements indicated in the syllabi. These requirements are reported and discussed with their plant design adviser, who then rates the individual students based on the soundness and completeness of their week's deliverable. While lectures provide the knowledge and methods needed to work on weekly deliverables, it is the lab adviser who provides guidance and corrections specific to the project. Consultation meetings also provide opportunities for the group and adviser to discuss strategies for addressing concerns and problems encountered in the project during the past week.

3.3 Lecture topics and Laboratory activities

Table 1. Lecture topics and weekly deliverables for ChE 141

ChE 141 Lecture Topics	ChE 142 Laboratory Activities/Deliverables
1. Introduction to the Design Process. The Design Basis. 2. The Process Flow Diagram - general and specific requirements on content and format. 3. General design considerations on health, safety, and environmental aspects of the design. Decision on plant capacity and whether the process should be batch or continuous. 4. Heuristics for process synthesis - input-output structure 5. Heuristics for process synthesis - recycle structure 6. Heuristics for process synthesis - separation structure 7. Heuristics for process synthesis - heat exchange network 8. Process control schemes for common unit operations and whole processes 9. Fundamentals of Engineering Economics - engineering economic decisions, time value of money, taxes, capital costs and annual payments 10. Estimation of capital costs of process equipment based on preliminary sizing data. 11. Estimation of total capital and operating costs. Cash flow with consideration of taxes and depreciation. 12. Profitability analysis	1. Discussion of course requirements and class policies. Overview of market study. 2. Plant design topic selection 3. Submit market study and HSE considerations on the product. initial design basis sheet with product information. 4. Submit market study and HSE considerations on the raw material. Updated design basis sheet with raw material information. Establish plant capacity and mode of operation 5. Oral class presentation of market study and block flow diagram. Submission of design basis sheet. 6. Submit database of physico-chemical properties of raw materials, intermediate compounds and products, and pertinent reaction and thermodynamic data. 7. Submit draft process flow diagram based on the block flow diagram 8. Updated process flow diagram with selected recycle structure 9. Updated process flow diagram with selected separation system structure 10. Updated process flow diagram with heat exchanger network structure. 11. Updated process flow diagram with process control schemes. 12. Estimated total equipment and utility costs 13. Estimated total capital investment and total product cost. 14. Submit project cash flow 15. Submit results of profitability analysis and sensitivity analysis.

Table 2. Lecture topics and weekly deliverables for ChE 142

ChE 142 Lecture Topics	ChE 142 Lab Activities/Deliverables
1. Introduction to the ChE plant design course 2. Piping and Instrumentation Diagrams 3. Piping Specifications 4. Detailed Design of Static Equipment 5. Equipment and Piping Layout 6. Detailed Design of Rotating Equipment 7. Instruments, Alarms, Interlocks and Safety Trips 8. Pressure Relief Systems and Relief Scenario Analysis 9. Hazard and OperabilityStudy	1. Review and resolution of open issues on the technical and economic feasibility reports of ChE 141 2. Submit revised technical and economic feasibility study reports 3. Submit draft P&IDs 4. Submit line sizing calculations, line list, and updated P&IDs with line specifications 5. Submit detailed sizing calculations of static equipment, static equipment data sheets, updated P&IDs with static equipment specifications 6. Submit detailed sizing calculations of rotating equipment, rotating equipment datasheets, updated P&IDs with rotating equipment specifications 7. Submit updated P&IDs with addition of instruments and on-off valves. 8. Submit relief scenario analysis results and updated P&IDs with addition of pressure relief valves. 9. Submit draft HAZOP study and updated P&IDs with additional instruments and valves identified during HAZOP study. 10. Submit final PFDs, P&IDs, equipment datasheets, HAZOP worksheets, equipment, line and utility lists. 11. Submit cost estimation and profitability analysis 12. Submit draft copy of design report and oral class presentation 13. Submit bound copy of plant design report

The course content of both ChE 141 and 142 and the weekly laboratory deliverables are outlined in the syllabi. Tables 1 & 2 show the topics discussed in the lectures and the weekly deliverables in the lab.

3.4 Course Outcomes and Student Outputs

Tables 3 & 4 list the course outcomes of ChE 141 and ChE 142, respectively, vis-a-vis the corresponding student outputs found in the end-of-term reports and other requirements stated in the syllabi. It is evident from these tables that the end-of-term reports demonstrate the correspondence between the student output and desired course outcomes. The course outcomes may then be considered achieved in both courses, assuming the tasks are divided equitably among the members of the group.

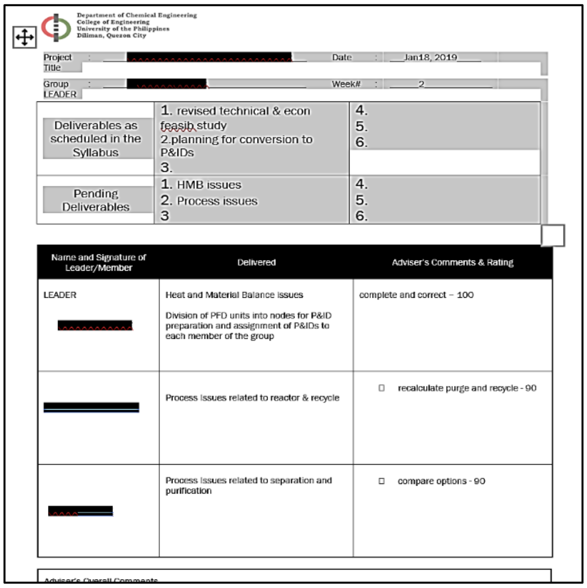
Table 3. Course outcomes of ChE 141 and corresponding student outcomes

ChE 141 Course Outcomes	ChE 141 Student Outputs
1. prepare a market study for a chemical product or commodity and its raw materials 2. translate the assessed opportunity into a design basis 3. prepare a database of physico-chemical and other relevant materials properties 4. conduct a survey of related literature on pertinent chemical processes 5. apply chemical engineering principles and heuristics in generating a process flow diagram that abides to typical industry standards 6. develop a simulation model of the process using a	1. Chapter 2 of the report discusses product and raw material specifications, supply and demand 2. Chapter 1 Introduction which discusses the problem/need/opportunity the study seeks to address, and the Design basis sheet found in the Appendix of the report 3. Physico-chemical property database in the Appendix 4. Introduction which discusses and differentiates the selected technology with the conventional processes used to produce the desired product 5. Chapter 4 (Process Synthesis and Development) which discusses the process and decisions made in the synthesis of the process flowsheet starting from the input-output structure, recycle structure, separation structure and the heat exchanger network.

commercial simulator	6. Chapter 5 (The Process) which shows and describes the process flow diagram, and the heat and material balances.
7. integrate health, safety and environmental considerations in the process design	7. Chapter 3 (General Design Considerations) which discusses HSE considerations on products, raw materials and the process
8. estimate total capital investment, total product cost, gross and net profit, and cash flow	8. Chapter 6 (Cost estimation) which shows cost estimation of static and rotating equipment and estimation of other capital and operating costs
9. quantify the effect of interest, taxes, and other economic parameters that affect profit	9. Chapter 7 (Profitability Analysis) discusses the generation of the cash flow diagram where taxes, interest rates, and value of money have been taken into consideration
10. apply economic evaluation principles and methods in making investment decisions.	10. Chapter 7 (Profitability Analysis) where the net present value, return on investment and payback period are presented. Sensitivity and Scenario analyses are also discussed to address risks posed by assumptions and rough estimations.

Table 4. Course outcomes of ChE 142 and corresponding student outcomes

ChE 142 Course Outcomes	ChE 142 Student Outputs
1. review of a market & feasibility and process design development study	1. Chapter 2 and 3 of the hard-bound plant design report
2. preparation of piping and instrumentation diagram (P&ID)	2. P&ID diagrams of every unit node in Chapter 3 and Appendix of the hard-bound plant design report
3. detailed sizing of static and rotating equipment with due consideration of standards and heuristics	3. Equipment lists in Chapter 4 and equipment data sheets and equipment design calculations in the Appendix of the hard-bound plant design report
4. preparation of plant equipment and piping layout	4. Equipment and piping layout in Chapter 4 and Appendix of the hard-bound plant design report
5. preliminary assignment of alarms, safety trips and interlocks	5. P&ID diagrams and Chapter 7 (Safety Studies) of the plant design report
6. preparation of a hazard and operability study (HAZOP)	6. Chapter 7 (Safety Studies) and HAZOP worksheets in the Appendix
7. giving oral technical presentations	7. Oral presentations required as indicated in the syllabus
8. writing a plant design report	8. Hard-bound plant design report as specified in the syllabus, copies of which are available at the Engineering Library and at the UPD ChE Department



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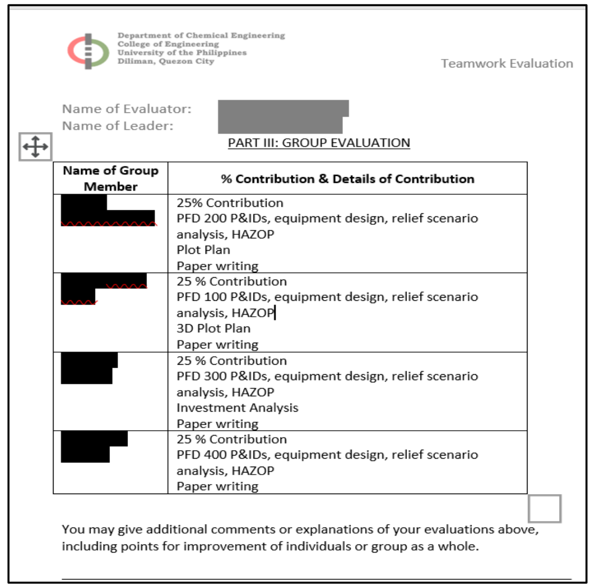
Project Title: [redacted] Date: Jan18, 2019
Group LEADER: [redacted] Week#: 2

Deliverables as scheduled in the Syllabus	1. revised technical & econ feasib study 2.planning for conversion to P&IDs 3.	4. 5. 6.
Pending Deliverables	1. HMB issues 2. Process issues 3	4. 5. 6.

Name and Signature of Leader/Member	Delivered	Adviser's Comments & Rating
LEADER [redacted]	Heat and Material Balance issues Division of PFD units into nodes for P&ID preparation and assignment of P&IDs to each member of the group	complete and correct – 100
[redacted]	Process issues related to reactor & recycle	recalculate purge and recycle - 90
[redacted]	Process issues related to separation and purification	compare options - 90

Adviser's Overall Comments

Figure 1. Sample consultation form



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Teamwork Evaluation

Name of Evaluator:
Name of Leader:

PART III: GROUP EVALUATION

Name of Group Member	% Contribution & Details of Contribution
[redacted]	25% Contribution PFD 200 P&IDs, equipment design, relief scenario analysis, HAZOP Plot Plan Paper writing
[redacted]	25 % Contribution PFD 100 P&IDs, equipment design, relief scenario analysis, HAZOP 3D Plot Plan Paper writing
[redacted]	25 % Contribution PFD 300 P&IDs, equipment design, relief scenario analysis, HAZOP Investment Analysis Paper writing
[redacted]	25 % Contribution PFD 400 P&IDs, equipment design, relief scenario analysis, HAZOP Paper writing

You may give additional comments or explanations of your evaluations above, including points for improvement of individuals or group as a whole.

Figure 2. Sample peer evaluation form

To validate that course outcomes are indeed achieved, other tools were used, such as the individual evaluations by the adviser during consultations, as well as the peer evaluation at the end of the semester. A sample consultation form and Part III of the Peer Evaluation Form are shown in Figures 1 and 2. The peer evaluation form is accomplished and submitted individually and includes a self-evaluation (Part I), an assessment of their leader and other groupmate(s) (Part II), and a matrix of contributions of each group member (Part III). Shown in Figure 2 is a sample of a duly filled out peer evaluation Part III. Peer and self-evaluation assess one's ability to be an effective team player. Leaders are evaluated based on their project management skills.

The final manuscripts submitted per semester are evaluated by the adviser using a set of rubrics for every report section. For brevity, a condensation of the evaluation rubrics relevant to the student outcomes of interest in this study are shown in Table 5 for ChE 141 and Table 6 for ChE 142. A portion of a sample rubric table is also shown in Table 7. Specifically, the rubrics for "exemplary" are shown. Generally, a report component (section or chapter) is deemed "exemplary" if the content is correct, consistent with technical standards, well-supported by calculations and explanations, and a well-composed write-up. Any deviation from the foregoing, depending on the extent of deviation would result in any of the following ratings: "accomplished", "developing", or "missing/unacceptable". An output is considered "accomplished" if the section provides adequate information and discussion to support the findings or results therein. Spot checking of plant design reports by the authors at the UPD Department of Chemical Engineering confirms congruence of the student output with the course requirements which in turn are congruent with the course outcomes.

Table 5. Condensed rubrics used for the evaluation of salient components of ChE 141 reports.

Project Report Component	Exemplary
Market Study	Gives comprehensive product and raw material specifications. Provides market data and a sharp market analysis including competitiveness analysis, trends, opportunities and threats. No errors.
Plant location	Clearly explains the choice of plant location using each of the applicable plant location considerations including but not limited to meteorological, socio-cultural, logistical, and economic considerations. No errors. Clearly and efficiently shows the plant location relative to main thoroughfares, ports, airports, bodies of water, nearby communities.
General Design Considerations	Gives comprehensive yet concise discussion of Health, Safety, and Environmental considerations about the products, raw materials, intermediates, other materials, and the

	process. Discusses ways to mitigate the risks. No errors.
Process Synthesis	Describes in detail the development of the process flowsheet from the input-output structure, thru the recycle and separation structures, up to the heat exchanger network analysis. Discusses in detail the selection of reaction process variables based on thermodynamic and kinetic considerations. Clearly and efficiently shows how each structure is arrived at, particularly the selection and decision criteria used per development phase.
The Process	A well-written and well-organized write-up. Provides well-constructed and fully coded BFDs and PFDs using standard symbols, complete with stream summary tables, heat and material balance tables that are correct and well-formatted for ease of comprehension. Provides a complete equipment and utility list.
Economic Analysis	Provides a complete cost estimation of all static and rotating equipment. Justifications for assumptions and analysis of results are provided. Profitability analysis is complete, correct, well-presented and discusses the significance of various factors that affect the profitability. Provides a sensitivity and scenario analysis to provide quantification of the uncertainties in the analysis.

Table 6. Condensed rubrics used for the evaluation of salient components of the ChE 142 reports.

Project Report Component	Exemplary
Introduction	States the design problem, its background and significance; the objectives of the study, its scope and limitations.
Preliminary studies	This is basically a condensed discussion with any updates of the market study, plant location, general design considerations, and process synthesis that w.
The Process	The same rubric as in ChE 141
Static and Rotating Equipment	Shows the design basis, design criteria, design calculations, and justification of any assumptions. Provides complete and detailed equipment data sheets with equipment specifications, performance curves, material of construction.
Safety Studies	Discusses a summary of the findings of the relief scenario analysis and the hazard operability study and the P&ID updates because of these findings. Provides the detailed worksheets of the relief scenario analysis and HAZOP in the Appendices.
Flow and Plot Plan	Provides the complete and fully coded piping and instrumentation diagrams and plot plans. Provides equipment layout which indicates adequate space for access and maintenance, pipe trays, piping layouts indicating horizontal and vertical runs. Uses the total pipe lengths in the sizing of pumps and compressors.
Economic Analysis	The same rubric as in ChE 141. should be updated as more detailed equipment designs are provided.

Table 7. A sample rubric for ChE 141.

Market Study		Missing/Unacceptable	Developing	Accomplished	Exemplary
	Product and Raw Material Specifications, Supply, and Demand	No market description.	Gives inadequate data or gives adequate data, but does not give a good analysis.	Gives adequate specifications and market data; describes the market, and gives a good analysis of the data. Few errors.	Gives comprehensive product and raw material specifications. Provides market data and a sharp market analysis, trends, opportunities and threats. No errors.
	Plant location	No mention of plant location considerations.	Mentions plant location considerations but does not identify particular location of the plant or fails to justify proposed location of the plant.	Adequately explains choice of plant location by citing each of the plant location considerations applicable. Few errors.	Clearly explains the choice of plant location using each of the applicable plant location considerations including but not limited to meteorological, socio-cultural, logistical, political, and economic considerations. No errors. Clearly and efficiently shows the plant location relative to main thoroughfares, ports, airports, bodies of water, nearby communities.
	Scale and Mode of Operation	No mention of scale and mode of operation	Mentions the scale and mode of operation but does not offer basis for these.	Adequately explains the basis for the scale and mode of operation chosen. Few errors.	Clearly and concisely explains the basis for the scale and mode of operation chosen. No errors.
General Design Considerations		**Missing/Unacceptable**	**Developing**	**Accomplished**	**Exemplary**
	Health, Safety & Environmental Considerations on Products, Raw Materials, Other Chemicals and Process	Very little or No discussion	Gives inadequate discussion of HSE Considerations for the products, but discussion did not include all relevant aspects.	Gives adequate discussion of HSE Considerations for the products. Few errors	Gives comprehensive yet concise discussion of HSE Considerations about the products, raw materials, intermediates, other materials, and the process. Discusses ways to mitigate the risks. No errors.

3.5 ChE 141 SET Feedback
3.5.1 Evaluation of Learning Experience

Figure 3 shows the percentage of responses to Question 1 per point in the Likert scale for the lecture and laboratory components of ChE 141 in the past 3 years. Based on the collected responses, majority of the respondents indicated that they received a substantial amount of learning from the lecture and laboratory classes of ChE 141. The percentage of responses for the positive points in the scale for the evaluation of the laboratory classes are higher than the ones for the lecture classes. Since weekly consultations for the laboratory classes are more hands-on in nature, students are expected to respond better to them; hence, the percentage of responses towards greater learning is higher.

3.5.2 Achievement of Course Outcomes

The responses to Question 2 indicate the degree of how much of the course outcomes were obtained by the end of the semester. Figure 4 shows the percentage of responses for Question 2 per point in the Likert scale for the lecture and laboratory components of ChE 141 in the past three years.

All three years show greater percentages on responses from the positive points in the scale than the negative points. Majority of the respondents indicate that all, or almost all, of the course outcomes were achieved by the end of the semester.

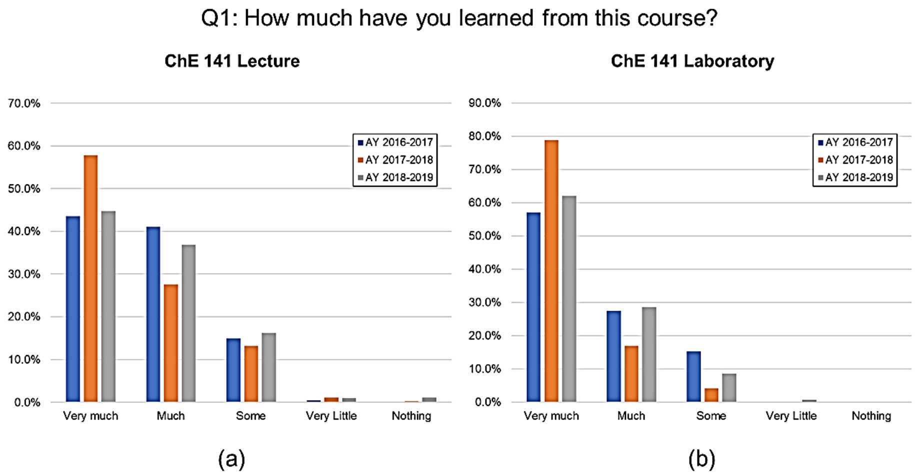

Figure 3. Percentage of responses to Question 1 for the evaluation of (a) ChE 141 lecture, and (b) ChE 141 laboratory, for the past 3 years.

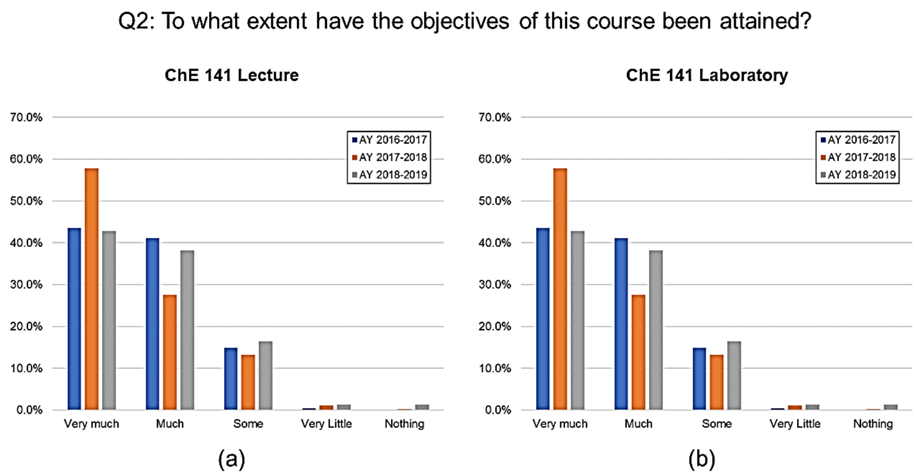

Figure 4. Percentage of responses to Question 2 for the evaluation of (a) ChE 141 lecture, and (b) ChE 141 laboratory, for the past 3 years.

3.6 ChE 142 SET Feedback

3.6.1 Evaluation of Learning Experience

Figure 5 shows the percentage of responses to Question 1 per point in the Likert scale for the lecture and laboratory components of ChE 142 in the past three years.

The combined responses of the respondents for the positive points on the scale (Very Much and Much) indicate that they have learned much from the lecture and laboratory components of ChE 142. The higher percentage of responses for most positive point in the scale (Very Much) of the laboratory component over the lecture one indicates a greater learning experience for respondents for their laboratory classes.

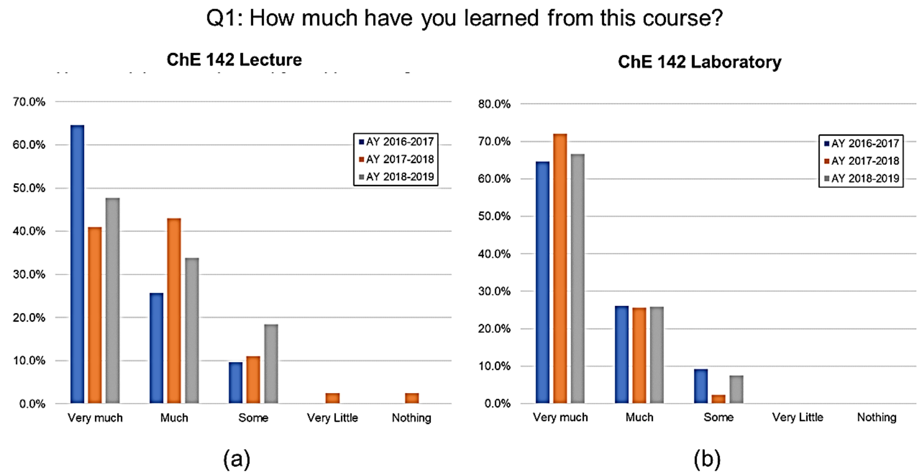

Figure 5. Percentage of responses to Question 1 for the evaluation of (a) ChE 142 lecture, and (b) ChE 142 laboratory, for the past 3 years.

3.6.2 Achievement of Course Outcomes

The responses to Question 2 indicate the degree of how much of the course outcomes were obtained by the end of the semester. Figure 6 shows the percentage of responses for Question 2 per point in the Likert scale for the lecture and laboratory components of ChE 142 in the past three years:

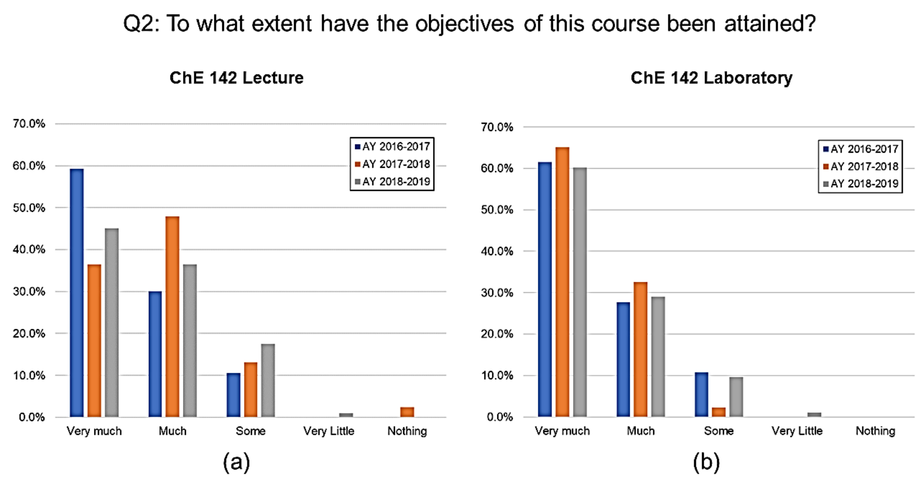

Figure 6. Percentage of responses to Question 2 for the evaluation of (a) ChE 142 lecture, and (b) ChE 142 laboratory, for the past 3 years.

All three years show greater percentages on responses from the positive points in the scale than the negative points, for both lecture and laboratory component. Majority of the respondents indicate that all, or almost all, of the course outcomes were achieved by the end of the semester for both components.

4. Conclusions

This study has shown that the senior-level chemical engineering capstone courses offered by the University of the Philippines Diliman in the past three years achieved the indicated course objectives/outcomes and addressed the selected student outcomes on engineering design through: (1) lecture-laboratory congruence in course requirements, and (2) student feedback.

5. Acknowledgement
The authors wish to thank Ms. Audrey Marie Yumul for patiently downloading the SET reports for this study. Gratitude is also extended to all the lecture and laboratory instructors of ChE 141 and ChE 142 who have designed, developed, taught, and perfected the two courses since their inception.

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