Case study based teaching of process economics in the context of Chemical Engineering

SELECT SESSION (delete all but one session)

C3: Integration of teaching and research in the engineering training process

CONTEXT

A key area in the Chemical Engineering curriculum is process economics which forms the backbone of process design. Teaching and delivery of this unit may be difficult due to the diverse economics concept not familiar amongst engineering students. Another challenge in teaching process economics is that while the theory may be relatively straightforward, the application of the theory to real world situation is quite challenging. Students may also find the topic relatively 'dry' as parts of the topic may be quite empirical.

PURPOSE

Is there a way to enhance the delivery and teaching of process economics in the context of Chemical Engineering?

APPROACH

In this work, a case base approach to learning the theories of process economics was introduced. A large case study based on the economic evaluation of the construction of a dairy milk powder processing facility was introduced into the unit. The same case study will stretch over 5 weeks of lecture from which the students will cover the following concepts: market evaluation, capital cost estimation, operating cost estimation and profitability assessments. This is in contrast to teaching the theory and introducing smaller examples for each theory. This approach also encapsulates the research experience of the author of this paper and is relevant to providing a wider training to students for the dairy industry in Victoria.

RESULTS

This approach provided a more interesting approach to learning process economics with more focus on the application, rather than starting from a theoretical perspective. In learning process economics, the students also had a good exposure to the dairy industry which is one of the primary industry in Victoria. The class also benefits from the research experience of the first author, incorporating research experience into teaching.

CONCLUSIONS

The strategies described in this communication can be tailored for other examples specific to the expertise or experience of the lecturer. An important element to the implementation of this pedagogy to teaching engineering economics is to identify suitable large case studies which can be stretch across the whole delivery of the engineering economic course.

REFERENCES (OPTIONAL)

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KEYWORDS

Process Economics, Chemical Engineering, Case Base Approach, Dairy Processing

Introduction

A key area in the Chemical Engineering curriculum is process economics, which forms the backbone of process design. Teaching and delivery of this unit may be difficult due to the diverse economics concept not familiar amongst engineering students. Another challenge in teaching process economics is that while the theory may be relatively straightforward, the application of the theory to real world situation is quite challenging. Students may also find the topic relatively 'dry' as parts of the topic may be quite empirical. In order to improve the delivery of this type of unit to engineering students, a more applied approach is introduced in this communication.

Another challenge which may be faced when delivering a unit of this nature is that some students in the class may be coming from a double degree Commerce/Engineering background. In essence, these students would have covered and have learnt the basic economics theory in their commerce courses. Teaching such a unit starting from the theoretical approach will not be interesting for these students. Increasing the scope of the content or making the course more difficult to cater for the commerce students may also make the unit too difficult for engineering only students. Therefore one alternative is to have more applications form of teaching incorporated into the unit which will cater to both streams of students.

This communication describes and provides ideas on how this form of teaching can be introduced based on the revamping of a unit delivered in Monash University in 2017. The author will also share the experience, especially the finer details important in this form of application based delivery of the unit by the introduction of a large case study based discussion approach in lectures, completely replacing the traditional dictative type of lectures.

Challenges in the previous delivery approach

In order to better appreciate the case study based approach introduced in this communication, it will be important firstly describe the scope of the engineering economics materials covered listed below chronologically. This is important for the reader to better appreciate the strategies highlighted later on and to interpret for application to their own units:

1. Market Identification and forecasting
    a. What is a market – Supply/Demand
    b. Classification of markets: high/low demand, commodity, specialty etc.
    c. Different forecasting tools for demand volume
    d. Different forecasting tools for pricing
2. Capital cost estimation
    a. Stages of engineering economics evaluations
    b. Location selection
    c. Sources of capital or funding
    d. Tools to predict capital costs
        i. Equipment by equipment estimation
        ii. Whole plant estimation
        iii. Battery limits in capital cost estimation
        iv. Effect of location and inflation

3. Operating cost
    a. Variable costs (raw material, utilities, cleaning etc.)
    b. Fixed costs (manpower, overheads, administration, sales, research etc.)
    c. Working capital
4. Profitability evaluation
    a. Cash flow estimation
        i. Taxes
        ii. Depreciation
        iii. Inflation
        iv. Non-cumulative/cumulative cash flow estimation
    b. Net present value estimation
    c. Project payback period
    d. Economic risk assessment

Before the revamping, these topics were typically covered via 12 hours of lecture over 4 weeks. The syllabus for the engineering economics listed above constitute one-third of a larger unit which also focuses on process safety and environmental management. The current scope of the engineering economics materials covered were mainly focused on the forecasting in the context of building a manufacturing facility. It does not put emphasis on other aspects of engineering such as production management and product development etc. which will also require engineering economic analysis (Walter 2008).

These materials were mainly covered by firstly going through the theory and then followed by short examples or application for each theoretical section covered. The examples were mainly not related to each other. Such an approach may effectively cover the theoretical aspects adequately, however, it may not give the students opportunity to link up these ideas. It is also noteworthy that theoretical aspects of these topics are rather empirical. Therefore, there is minimal value to teach these concepts theoretically (it would have been very boring too to teach!). The assessments for the engineering economic section involves:

1. Group Assignment on market evaluation
2. Group Assignment on cost and profitability estimation
3. Written exam with part of the exam covering engineering economics

Single large case study replacing lecture approach

The delivery of these units were then revamped by introducing a large engineering case study from which these concepts were introduced. This also ties in closely with the intended outcome of the unit as students are expected to know how to apply these concepts in evaluating the economics of engineering projects. Switching from a traditional theoretical approach to engineering economics to a case study approach has been reported and described by several reports in the literature (Manohar 2012, Russ and Nance 2004, Brunnhoeffer III 2017). Most of these papers suggest the use of different case studies in the weekly delivery of the unit followed by discussion of the cases in or out of lectures or as additional group projects outside of lecture. One report suggested the implementation of a game, in the opinion of the author analogous to case studies albeit a significantly more interactive approach, as an additional component complementing traditional lectures (Dahm 2002). There was also a report in the literature in which slightly larger case studies were

introduced stretching across half of the teaching semester (Barsanti 2011). In these reports, apart from the approach by Barsanti (2011), regardless of the different forms in which case study was introduced, students had to firstly learn the theory in class before attempting the case studies. The current report differs from those described in the literature and aimed at using case study discussions as the main teaching medium without the need to students to firstly learned the theory: the theory only formalized and introduced only after the case study discussion. In addition, only one significantly large cases study, which stretches across the whole delivery period of the engineering economics section of the unit. The main hypotheses were: Will a "case study discussion first" approach be more effective in teaching engineering economics? Will a large case study help students link the different materials better?

In order to assess these hypotheses, the other aspects of the engineering economics part of the unit was deliberately maintained the same the previous year. Please refer to the section above for more details. The main difference was that the traditional lectures have now been converted into the discussion of the large case study. This is completely flipping the delivery approach in contrast to some approaches report in the literature where case studies were added as an additional component to complement traditional lectures (Manohar 2012). For this, the discussions of the case studies were not assessed and there is no marks attributed to the large case study introduced.

Drawing from the experience and familiarity of the author, a case study in the evaluation of the construction and operation of a skim milk powder manufacturing facility was introduced. Students also get to concurrently learn in greater detail of the economics, operation and technical aspects of the dairy industry which is a major industry in Victoria. The new structure below was then introduced. The headings provided are key sections of the lecture (or questions) delivered to the students over 4 weeks.

1. Market Identification and forecasting
    a. What are the markets which can be derived from raw milk? (Supply/Demand, classification of markets)
    b. What is the outlook of skim milk and full milk powder demand over the next 10 years? (Market volume forecasting)
    c. What is the market value of skim milk and full milk powder over the next 10 years? (Price forecasting)
2. Capital cost estimation
    a. Who will be the stakeholders and decision makers in the skim milk plant project? (stages of engineering economic evaluation)
    b. Should we build the skim milk powder plant in northern, eastern or western Victoria? (location selection)
    c. Should we release bonds, inject capital, search for angle investors, or go IPO to get capital for the project? (sources of capital)
    d. Let us estimate the cost of the project based on some similar large projects implemented in New Zealand (whole plant estimation + inflation)
    e. Let us double check the rough estimation with a equipment-by-equipment cost estimation (equipment-by-equipment estimation + inflation)
    f. How about we build this plant in China? (effect of location)
3. Operating cost

a. How much milk do we need for the skim milk powder plant? (raw material costs)
b. What is the energy requirement in a skim milk powder plant? (utilities)
c. What is clean-in-place (CIP) strategies in a plant and waste management strategies? (utilities and waste management costs)
d. How many operators and additional personnel are required to operate the plant? (manpower and overhead– fixed costs)
e. What happens if we need to ramp up or down the production capacity dues to seasonal variations? (Working capital)

4. Profitability evaluation
    a. How much tax do we have to pay based on our estimated skim milk powder plant operation? (taxes, depreciation, non-cumulative cash flow)
    b. When will we get back our investment on the skim milk powder plant? (cumulative cash flow and payback period)
    c. Should we be investing our capital in other investment tools or opportunities? (Net present value estimation)
    d. How will the fluctuation in milk price or demand affect the outlook of the project? (economic risk evaluation)
    e. What is inflation and how it affects the engineering economic evaluation. (inflation)

It can be seen that the new structure is actually a series of discussions revolving around a large example in which the student will repeatedly go through. The theory covered under each discussion is listed in brackets next to the topic of the discussion. These topics are delivered as discussions and the students are only informed of the theory after the discussion. While these questions for discussion may change depending on the case study used, it is the intention of the authors to illustrate the approach and to give an example to the reader on how these topics can be flipped. The rationale for this pedagogical approach, the challenges in which it was intend to overcome for each particular topic, is given in Table 1. For brievity, the technical content of these individual section and not included and interested readers are directed to the reference cited here (Brennan 1998).

Referring to Table 1, for components of the syllabus in which the theory was relatively too empirical, students may find it difficult to selection correlations and empirical constants suitable for specific economic estimations. By flipping the delivery of the content, students can firstly examine a real (and real numbers) before making comparison with the empirical theory. This was intended to help students make better judgement of the empirical tools available in engineering economics. While Part 4a,b are not empirical in nature, students may find these fundamental theory complex this would be the first time they are exposed to economic term and concepts; they may not have the ‘sense of money’. Therefore, similarly, the rationale was to start introducing these concepts by examining real numbers (from the case study) which they would have generated by themselves over the past few weeks of the course. Theory for Part 2a,b,c are relatively very general and in the opinion of the author, there is little value in teaching them in detail. The value in theory introduced in Part 2,a,b,c lies in better understanding the constraints when applying them and these are best introduced in the form of a real case study.

Additional observations

For single degree engineering students, there was significantly more questions asked during lectures in Part 4 when compared to the other parts of the course. This is especially in grappling with how depreciation affects tax calculation. In fact, additional lecture time was allocated explaining depreciation from the perspective of 'book keeping practice' and it actual tangible meaning. Interestingly, throughout the semester, there was feedback from double degree engineering/commerce students that the application approach actually helped them understand better the depreciation-tax concepts, which they had learned in the commerce units (verbal feedback from two students after the lectures).

From the questions raised in class, when delivering of the net present value concept, there was significant confusion amongst the student on the difference between calculating the total net present value and the internal rate of return of a project. Details on these concepts can be obtained from any engineering economics textbook (Brennan 1998). The strategy devised in the delivery of this unit is to explain that both concept utilizes the same theoretical framework in calculating net present value. The only different is that total net present value evaluation utilizes a fixed rate of return as a basis for comparison whereas the internal rate of return evaluation utilizes a zero total net present value as a basis for evaluation. In the opinion of the author, this set of explanation seemed to provide a logical approach to link these two concepts.

Table 1 Rationale of the introduction of the new pedagogical approach

Section of the syllabus based on the previous delivery approach	Challenges in the previous approach	How the new approach aims to overcome the challenges
1 a, b, c, d	Theory too empirical	Examine real cases and numbers first to better appreciate the empirical theory
2 a, b, c	Concepts too general	Examine the constraints in the concepts via a case study and significantly minimise the theory part of the delivery
2 d	Theory too empirical	Examine real cases and numbers first to better appreciate the empirical theory
3 a, b, c	Theory too empirical	Examine real cases and numbers first to better appreciate the empirical theory
4 a, b	Theory may be complex for some students	Students to firstly work with monetary values generated by themselves (better familiarity) before the introduction of the theory

Student evaluation and on-going work

There was no formal and specific survey or class feedback undertaken to evaluate this change in the teaching pedagogy. The overall evaluation for the unit following Monash University's general unit evaluation system was, however, slightly lower when compared to the previous year (Table 2). It is noteworthy that the engineering economic part of the unit constitutes only one-third of the whole unit and it was unclear if the evaluation score directly reflects the the changes undertaken for the engineering economic part of the unit. Anonymous qualitative feedback from the students also did not specifically addressed the use of the new pedagogy. The actual detailed feedback was not included here for confidentiality. In general, the were comments that the delivery of the engineering economic part of the course helped in understanding of the tricky financial concepts. Surprisingly, most of the comments for improving pertains to the huge number of slides used to guide the discussion during the lecture session; comments which is not related to the pedagogy used. It is noteworthy that the use of the large number of slides were meant to 'flip card' animate the presentation. Students did not like this mainly due to the difficulty in printing the slides. More specific quantitative survey will be undertaken in the upcoming semester.

In addition to addressing the comment from the student survey, from the additional observations above on the difficulty faced by students in Part 4 of the materials covered, there is now on-going work to put more emphasis on this area in the upcoming semester. This will be balanced by reducing the time allocated to the teaching of economic factors and the mathematics involved in the unit. This also follows the pedagogical change discussed by Ristroph (2009) highlighting for stronger emphasis on areas such as tax (which is affected by the computation of depreciation) and inflation.

Table 2 Student evaluation of the whole unit (0 – lowest, 5 – highest)

Evaluation questions	2016 (previous approach)	2017 (pedagogical change)
The Learning Outcomes for this unit were clear to me	4.18	3.98
The instructions for Assessment tasks were clear to me	4.05	3.93
The Assessment in this unit allowed me to demonstrate the learning outcomes	4.10	4.07
The Feedback helped me achieve the Learning Outcomes for the unit	4.06	3.57
The Resources helped me achieve the Learning Outcomes for the unit	4.04	3.75
The Activities helped me achieve the Learning Outcomes for the unit	4.11	3.91
I attempted to engage in this unit to the best of my ability	4.22	4.07
Overall, I was satisfied with the unit	3.99	3.70

Conclusion

The strategies described in this communication can be tailored for other examples specific to the expertise or experience of the lecturer. The principle is to use a large example in which the student can repeatedly discuss throughout the semester. Another main strategy introduced here is to run the lectures as a form of discussion and only introduce the concept as an 'artifact' from the discussion. This strategy will make the largely empirical or qualitative nature of most of the engineering economic concepts more interesting. When implementing this approach, readers are advised examine the two 'lecture schedules' provided above as a guide on who to modify the theoretical content of the lectures in to suitable discussion topics for the large case study. It is noteworthy that the pedagogical approached introduced here uses the large case study to replace lectures and not an additional components or assessment to lectures. Lastly, feedback from single degree engineering students indicate that the most enjoyable outcome from a unit of this nature is that it exposes them to economic concepts, which they have not considered before. It is the opinion of the author that this should be the main aim of engineering economic units, which is to focus on providing exposure to students to a breadth of economic concepts, rather than focusing on the 'nitty-gritty' details of economics. Such philosophy, if adopted, should also be reflected in the type of assessments developed for the unit.

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