Integrated Mass and Energy Balance Course Project using Spreadsheet for a Chemical Engineering Degree Program

Article history
Received
1 December 2023
Received in revised form
13 December 2023
Accepted
14 December 2023
Published online
23 December 2023

Azizul Azri Mustaffa*, Jamarosliza Jamaluddin, Muhammad Afiq Zubir
Faculty of Chemical and Energy Engineering, Universiti Teknologi Malaysia, 81310 UTM Johor Bahru, Malaysia
**azizulazri@utm.my*

Abstract
In this innovation, team projects from two courses offered in different semesters are integrated. On top of that, students are trained to use a spreadsheet-based tool to solve the problem in the project. Those two courses are Mass Balance (SETK 1123) and Energy Balance (SETK 2133) offered to Chemical Engineering students in Universiti Teknologi Malaysia at their second and third semester. The main objective of the innovation is to scaffold the students' understanding of the problems given to them in the projects. At the end of the project, they should be able to clearly see the overall processes in a typical chemical industry, starting from raw materials to the targeted products, by-products, and wastes produced. In addition to that, the projects also foster digital skills by enhancing the students' skills to use the spreadsheet tools to solve Chemical Engineering problems. This is inline with their study as the students learnt about computer programming and spreadsheet tools in their first semester. From the students' reflections, it can be concluded that this innovation are able to increase the comprehension of the students on the two courses, increase the skills in using spreadsheet tools for solving problems and also inculcate critical thinking and problem solving skills.

Keywords: Chemical Engineering Education; Mass Balance; Energy Balance; Spreadsheet; Digital Skills

Introduction

Mass Balance (SETK 1123) and Energy Balance (SETK 2133) form the core curriculum offered to first- and second-year students pursuing the Bachelor in Chemical Engineering with Honours program at the Faculty of Chemical and Energy Engineering, Universiti Teknologi Malaysia (Faculty of Chemical and Energy Engineering, Universiti Teknologi Malaysia, 2022). Despite the simplicity of the calculations involved, the primary challenge arises from the complexity of problem descriptions presented to students, given their limited exposure to real industrial processes during the initial semesters. The problem-solving approach entails creating flow diagrams, labelling process streams, and solving unknown parameters through basic algebraic equations. Failure to grasp the problem can lead to inaccuracies in the flow diagram and incomplete stream labelling, hindering the student's ability to find a solution. Moreover, while industrial settings commonly employ process simulators for flow diagrams and calculations, introducing this tool early in the curriculum may overwhelm students.

Consequently, an alternative approach has been implemented: an integrated spreadsheet-based team project. This project aims to enhance students' comprehension of assigned problems, allowing them to visualize the entire process in a typical chemical industry, encompassing raw materials, end products, by-products, and generated waste. The project centres on the production rate of the main product as the starting point. Additionally, it serves as an introduction to computer tools in engineering calculations, aligning with students' prior exposure to spreadsheet and programming-based software in their first semester, as detailed in Sadikin et al., 2021. This initiative not only strengthens digital skills but also prepares students for future utilization of process simulators in their final year.

The innovation, grounded in constructivism learning theory (Dagar and Yadav, 2016), emphasizes critical thinking in problem solving with meaningful support at each step. The innovation is constructed based on the seven effective principles of constructivist pedagogy. The initial principle underscores the importance of not merely memorizing and reproducing knowledge but actively utilizing and transforming it. The second principle challenges the notion of separate phases for acquiring and using knowledge, emphasizing that knowledge is best learned through its application. The third principle highlights the practical application of knowledge, especially in problem-solving. In the context of the innovation, students are required to transform information from a problem description into a process

Mustaffa, A.A., Jamaluddin, J., Zubir, M.A. (2023), Integrated Mass and Energy Balance Course Project using Spreadsheet for a Chemical Engineering Degree Program, *ASEAN Journal of Engineering Education*, 7(2), 58-63.

flow diagram, utilizing a scaffold provided in the form of a summary mass and energy balance table, and subsequently solving for unknown information. The fourth principle focuses on stimulating students' thinking activities and enhancing their metacognitive and self-regulative skills in the study of content knowledge. This prompts students to strategize how to approach problem-solving. Working in a team, as encouraged by the fifth principle, places social interaction at the core of the learning process. The sixth principle integrates the assessment of learning within the learning process itself. Finally, the seventh principle emphasizes the active involvement of students in the assessment of their own learning.

Regarding the utilization of spreadsheets in problem-solving, Udugama et al. (2023) conducted a study examining the preferences and requirements for digital tools in chemical engineering education. Their research involved surveying department heads at IChemE institutions and members of IChemE committees specializing in digitalization. The findings revealed various factors that could impede the adoption of specific tools, including the complexity of mathematical/programming aspects, maintenance ease, and the high initial investment costs. Respondents expressed a preference for simpler digitalization platforms like Excel (a spreadsheet tool) and scripting languages over more advanced options such as Virtual or Augmented Reality, whenever feasible.

There exists a degree of resemblance in the integration of projects or problems between the Chemical Engineering program's Introduction to Engineering and Introduction to Programming courses at Universiti Teknologi Malaysia. In a study by Malim-Busu et al. (2022), they detailed their efforts to integrate these courses utilizing the Cooperative Problem Based Learning (CPBL) framework, with a specific emphasis on incorporating real-world scenarios into the projects. This approach aims to alleviate the learning time demands on students and enhance their engagement and interest in Engineering programs.

Methodology

In this section, the methodology is detailed from two perspectives: (1) the development of innovation and (2) the implementation of innovation in learning. Concerning innovation development, the project problem description is delineated into multiple parts, as illustrated in Figure 1. The initial part covers the background of the chemical or product to be produced, offering an overview of the reasons for its production based on demand and application. The subsequent part provides a detailed description of the overall process, elucidating the functions of each individual process and their interconnections. Input data are also provided in this section. The third part furnishes detailed instructions to guide students in solving the problem, outlining the required outputs such as a concise report, a spreadsheet file containing a fully labelled process flow diagram, and detailed calculations. The final section includes a comprehensive summary table highlighting unknown values that students must determine, serving as a scaffold to ensure accurate interpretation of the problem description. An example of the project description can be found in Figure 2 and 3.

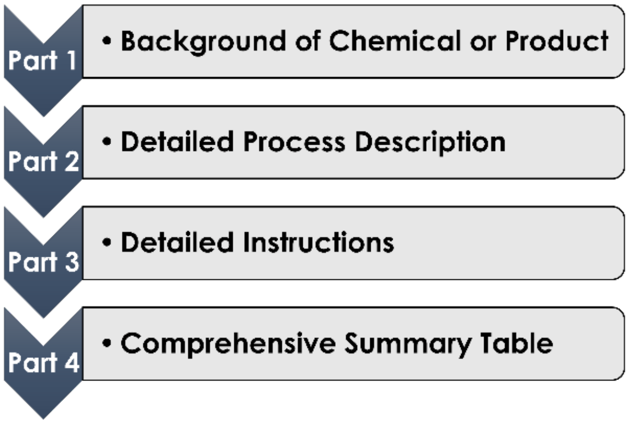

Figure 1: Elements of Innovation

ENERGY BALANCE (SETK 2133)
SEMESTER 1 SESSION 2020/2021

TEAM MINI PROJECT

Published Date: 3 Jan 2021 (in e-learning)
Submission Dateline: 23 Jan 2021 (through e-learning – Microsoft Excel files)

Topic: Production of 5000 MTA of Acetophenone from Oxidation of Ethylbenzene

A) Background:

Acetophenone (C_8H_8O) is an organic compound used as an ingredient in perfumes and as a chemical intermediate in the manufacture of pharmaceuticals, resins, flavouring agents, and a form of tear gas. It also has been used as a drug to induce sleep. The compound can be synthesized from benzene and acetyl chloride, but it is prepared commercially by the air oxidation of ethylbenzene. Pure acetophenone is a colourless liquid, with a melting point of 20.2 °C (68.4 °F) and a boiling point of 202.4 °C (396.3 °F). It is only slightly soluble in water but is freely soluble in ethanol (ethyl alcohol), diethyl ether, and chloroform. (Reference: Britannica.com)

B) Process Description:

In this process, acetophenone (ACP) is produced through the oxidation of ethylbenzene (EB) at 126 °C and 2 atm with water as the by product. In a year, this chemical plant operates 24 hours a day for 330 working days with a total production of 5,000 metric tonne of acetophenone. There are two side reactions, producing benzoic acid (BA), carbon dioxide (CO_2) and phenyl methyl carbinol (PMC) as the undesired side products. 15 % aqueous manganese (II) acetate (MA) is used as the catalyst for the reaction. Details of the reaction are as follows:

$$C_8H_{10}\ (l) + O_2\ (g) \rightarrow C_8H_8O\ (v) + H_2O\ (v)\ \text{(Main reaction)}$$

$$C_8H_{10}\ (l) + 0.5O_2\ (g) \rightarrow C_8H_9OH\ (v)\ \text{(Side reaction 1)}$$

$$C_8H_{10}\ (l) + 3O_2\ (g) \rightarrow C_7H_6O_2\ (v) + CO_2\ (g) + 2H_2O\ (v)\ \text{(Side reaction 2)}$$

Fresh ethylbenzene from a storage tank is added with a recycle stream containing ethylbenzene and some acetophenone and fed to the oxidation reactor. Before feeding it to the reactor, the mixed stream is heated to 126 °C and pumped to 2 atm. 30% excess compressed air is fed to the reactor through another stream. At the same time, 15% aqueous manganese acetate which act as a catalyst is fed to the oxidative reactor. The same amount of this catalyst is removed from the system through bottom stream of extraction column 1. However, the mass balance for this catalyst can be excluded from the calculation. The reactions are exothermic, thus, the reactor is equipped with cooling coils that use river water to maintain the reaction temperature at 126°C.

Figure 2: Example Background and Process Description

Another noteworthy aspect of the innovation is the use of spreadsheet software for constructing the process flow diagram, labelling streams, performing calculations, and creating a presentable file.

Table 1: Summary Mass Balance Table (with unknowns – U/N)

Stream No.	1	2	3	4	5	6	7
Stream	Input to Jet Mixer	Input to Jet Mixer	Input to Reactor	Input to Cooler	Input to Distillation Column	Distillation Bottom Stream	Distillation Top Stream
From	Storage	Storage	Jet Mixer	Reactor	Cooler	Distillation Column	Distillation Column
To	Jet Mixer	Jet Mixer	Reactor	Cooler	Distillation Column	Output	Output
Vapour Fraction	1.0	1.0	1.0	1.0	1.0	0.0	1.0
Total Mass Flowrate (kg/hr)	U/N	U/N	U/N	U/N	U/N	U/N	U/N
Total Molar Flowrate (kmol/hr)	U/N	U/N	U/N	U/N	U/N	U/N	U/N
Components Molar Flowrates (kmol/hr)							
Acetylene	U/N		U/N	U/N	U/N	U/N	U/N
Hydrogen Chloride		U/N	U/N	U/N	U/N	U/N	U/N
Vinyl Chloride				U/N	U/N	U/N	U/N
Molar Compositions							
Acetylene	1.00		0.50	U/N	U/N	U/N	U/N
Hydrogen Chloride		1.00	0.50	U/N	U/N	U/N	U/N
Vinyl Chloride				U/N	U/N	U/N	U/N
Total Mole Fraction	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Energy Data							
Temp. (°C)	25	25	-80	200	-20	-30	-10
Pressure (atm)	1	1	1	1	1	1	1
Total Enthalpy (kW)	U/N	U/N	U/N	U/N	U/N	U/N	U/N

Figure 3: Example Summary Mass and Energy Balance Table

Regarding assessment, four criteria are considered: (1) clarity of the process flow diagram and completely labelled streams (3 marks), (2) interconnections of input values and other data in the diagram (2 marks), (3) a brief report on the steps taken to solve the problem (2 marks), and (4) final answers, including the filled summary table and other questions from the instructions (3 marks). This project constitutes 10% of the total course marks for each course. The rubrics are shown in Table 1.

Table 1: Assessment Rubrics for Both Projects

Criteria	Description	Marks
Document: Spreadsheet		
Process Flow Diagram (PFD)	• Contains all the block that represent the equipment. • Contains the overall stream summary and its value. • Contains the stream summary for each equipment and its value. • Labels at each stream are complete. • The PFD are drawn neatly.	3
Data Interconnection	• The stream summary connected with mass and energy balance for each equipment. • Calculations between different equipment are interconnected • All calculations are made using the spreadsheets' function	2
Document: Word/PDF		
Report	• Contains the steps used to develop the spreadsheet file. • Prepared in maximum of 2 pages	2
Answer	• The answers are accurate (unknowns and based on questions given)	3
Total Marks		**10**

Moving on to the implementation of the innovation in learning, as depicted in Figure 2, both courses cover mass and energy balance calculations for non-reactive systems, reactive systems, and multiphase systems (Mustaffa, 2022 and 2023). However, this integrated project specifically addresses the first two topics. The project is introduced after covering these topics in classes, around week ten of the syllabus. Students, organized into cooperative teams early in the semester, receive the project descriptions through the e-learning portal (elearning.utm.my). They are given one day to review the problem description before attending a briefing session conducted by the project coordinator. The coordinator, assigned for the entire student batch, clarifies any questions during the briefing. Students typically have three weeks to complete the project, with questions only allowed in the first two weeks to discourage last-minute work.

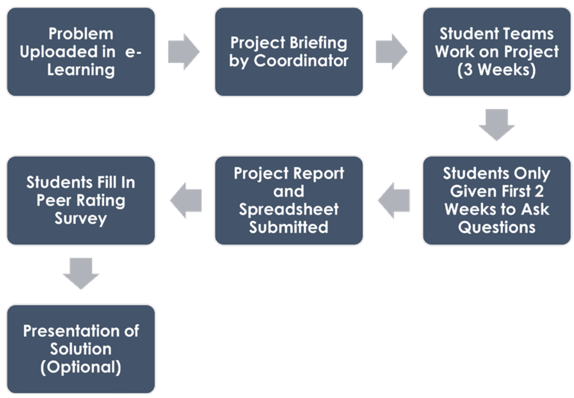

Figure 2: Implementation of Innovation

Additionally, at the project's conclusion, students complete a peer rating survey to evaluate their teammates' performance. While team working skills are not directly assessed, the peer rating helps prevent free riders, and each team member's marks are influenced by their efforts, following the auto-rating factor method (Brown, 1995). The peer rating survey consists of six criteria which include contribution and attitude, cooperation, focus and commitment, team role fulfilment, communication, and work accuracy where each member evaluates their team members including themselves. Table 2 show the peer rating tool where the rating of member is averaged to obtain the individual average (IA). IA of each member is then averaged to obtain the overall average (OA). The auto-rating factor (AF) is obtained by dividing IA with OA. The maximum value is capped at 1.05 while the lower limit is not set. The AF obtained will be multiplied with the project mark.

This process is applied to both courses, with the Energy Balance course involving additional tasks related to calculating enthalpies and energy requirements for some process equipment. Importantly, previous Mass Balance course calculations may not be applicable in the Energy Balance course if team compositions differ. Teams must reevaluate and adjust their process flow diagrams and calculations unless the previous work is identical, allowing them to select one teammate's work and continue.

Table 2: Peer Rating Tool

		Ratings				Average
Criteria 1	Student 1	1.0	3.0	3.0	2.0	2.3
	Student 2	2.0	3.0	3.0	2.0	2.5
	Student 3	3.0	3.0	3.0	3.0	3.0
	Student 4	4.0	3.0	3.0	4.0	3.5
Criteria 2	Student 1	2.0	3.0	3.0	4.0	3.0
	Student 2	3.0	4.0	4.0	3.0	3.5
	Student 3	4.0	5.0	5.0	4.0	4.5
	Student 4	5.0	4.0	4.0	3.0	4.0
Criteria 3	Student 1	5.0	4.0	4.0	5.0	4.5
	Student 2	4.0	5.0	5.0	5.0	4.8
	Student 3	3.0	5.0	5.0	4.0	4.3
	Student 4	2.0	4.0	4.0	4.0	3.5
Criteria 4	Student 1	2.0	3.0	3.0	3.0	2.8
	Student 2	3.0	3.0	3.0	4.0	3.3
	Student 3	3.0	4.0	4.0	3.0	3.5
	Student 4	4.0	3.0	3.0	4.0	3.5
Criteria 5	Student 1	4.0	3.0	3.0	4.0	3.5
	Student 2	4.0	4.0	4.0	5.0	4.3
	Student 3	4.0	5.0	5.0	4.0	4.5
	Student 4	4.0	4.0	4.0	3.0	3.8
Criteria 6	Student 1	5.0	5.0	5.0	4.0	4.8
	Student 2	5.0	5.0	5.0	3.0	4.5
	Student 3	5.0	5.0	5.0	4.0	4.8
	Student 4	5.0	5.0	5.0	4.0	4.8
	Member	IA	OA	AF		
	Student 1	3.46	3.79	0.91		
	Student 2	3.79	3.79	1.00		
	Student 3	4.08	3.79	1.08		
	Student 4	3.83	3.79	1.01		

Results and Discussion

The example output of the process flow diagram (PFD) and calculations in the spreadsheet tools is highlighted in Figure 3. The diagram is drawn neatly with labels in each stream containing the stream condition and composition. The data between different streams must be interconnected also between individual equipment in different sheets. It means that, there is one sheet for the overall diagram and separate sheets for individual equipment. This is clearly highlighted in the instructions given to the students in the project description and during the briefing.

The main findings from the implementation of this innovation are extracted from the learning reflection prepared by the students. Some representative reflections are presented in Table 3. Some students (see reflection 9) appreciate the integration made between the two courses where it is easier for them as they are already familiar with the problem. Plus, they can also relate the previous lesson with the new lesson that they learnt. The next obvious findings would be the digital skills obtained (see reflections 1, 2, 4, 5, 6, 7).

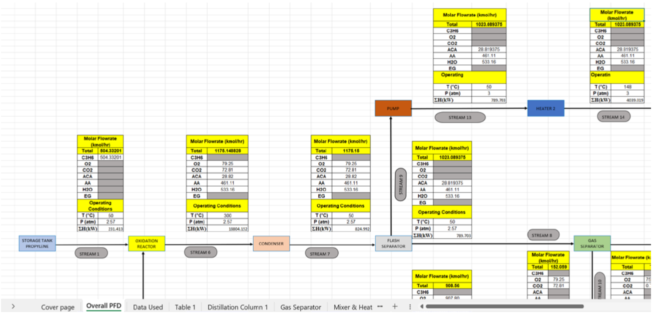

Figure 3: Example of PFD and Calculations in a Spreadsheet Tool.

Even though digital skills are not part of the learning outcomes, it is an important skill for a chemical engineer and need to be embedded in a least one course per semester. In addition, from the project, the students can develop critical thinking and problem-solving skills (refer reflections 3, 5, 8) as the project itself aim to promote higher order thinking skills. Finally, since the comprehensive project are conducted in cooperative teams, indirectly team working skills are also enhanced (see reflection 7). The implementation of the peer rating really helps to strengthen this.

Table 3: Feedback from Students on the Integrated Project

No.	Student Feedback
1	*"For mini project, we were instructed to do all the calculations in Microsoft Excel which* ***led me to learn how to use MMULT and MINVERSE functions for simultaneous equations*** *through YouTube which was quite contemporary to me. I enjoyed throughout the whole process with my teammates. We divided the tasks, and everything went smoothly."*
2	*"I learned to* ***use Excel while doing the mini project*** *as I think it's going to be beneficial by learning it earlier."*
3	*"On next week, we obtained mini project assignment which we assigned to use Microsoft Excel to draw process flow diagram of overall and each equipment and show calculation using it.* ***We exposed to difficult and higher thinking question****, but we succeed to overcome and finish this project. We learned a lot from this mini project specially to use Microsoft Excel."*
4	*"The mini project was also an eye-opening experience for me. The length of the problem*

	statements was tremendous, however after breaking it into PFD it was readable and solvable through the efforts of our team. ***I love it when we were asked to solve the problem by using Excel as this really reflect on how it should be done on real work environment****."*
5	"During completing this mini project, **I learnt more effective skills using Microsoft Excel and I can understand more on the chapter on multiple process units.**"
6	*"While for the mini project, the first impression on so many process units are very difficult but with the discussion with other members it becomes easier when each part of it is being solved. Through his project, I found that* ***Microsoft Excel plays an important role in industry*** *because by changing one of the values the following variable will also change which I think is* ***very convenient for later if I want to create a system****."*
7	*"By doing the mini project given, I can* ***develop the soft skill which is teamwork*** *as this mini project is group work. Without any help or other opinions, it is difficult to finish this project alone. We need to do all the calculations in Excel so that I* ***can enhance my knowledge about using Microsoft Excel****. Besides, we can use the knowledge that we learned for the few first topics to solve the solution."*
8	*"From this mini project, I learnt that we will* ***not always find a perfect solution as stated in the textbooks to solve the real world's problem****. Therefore,* ***ability of critical thinking is significant*** *for us to find out an alternative solution to solve the problems."*
9	*"The mini project was* ***similar to the one conducted in our mass balance class****. But this time, we had to include energy balance calculations in our solution. It was pretty* ***easy as we already had experience doing it during our mass balance class last semester****. My team and I did a really good job, and I are proud of the teamwork, fellowship, and friendship that we have managed to attain".*

Throughout the implementation of the integrated project for around 8 years, three lecturers have administered the project. Table 4 presented the reflection of the lecturers on the integrated project.

Table 4: Lecturers' Reflection

Lecturer	Reflection
1	*"I have been administering this integrated project for more than 5 years. Along the years, I have seen that the same method was used during the* ***final year plant design project*** *during the preliminary manual mass and energy balance part. The transition from merely pen and paper is enormous as students now are able to utilize digital tools to solve problems. My future plan is to copyright all the project descriptions that we have developed so that other institutions can also use the innovation."*
2	*"In the integrated project of mass and energy balance where students used a spreadsheet-based tool for calculations in chemical engineering, the tool effectively* ***simplified complex calculations****. This helped students understand key concepts and prepared them for more challenging courses like plant design project. Some students demonstrated excellent collaboration, similar to a real engineering environment, while others faced challenges in task distribution, indicating a need for more structured teamwork guidance. Overall, this project was a great way for students to learn and for me to see what we can do better next time."*
3	*"Integrating the mass and energy balance project allows students to understand the relationship between these two courses. These two courses are very important for chemical engineering students since they serve as a foundation for the upcoming senior year courses. In the future, the project can be further improved by integrating* ***elements of sustainability****."*

From the reflections, we can see that there are many benefits of the innovation but more importantly what more that can be further improved.

Conclusion

This spreadsheet-based project introduces a novel approach to mass and energy balance calculations, offering students the opportunity to synthesize content from two foundational courses and gain insight into processes typical in chemical industries. The project, spanning Mass Balance (SETK 1123) and Energy Balance (SETK 2133) courses, integrates knowledge sequentially, allowing students to apply prior understanding to new concepts. The innovation lies in the coordination between classes and the shift from manual calculations to spreadsheet tools like Microsoft Excel, enhancing digital skills crucial in the 4th industrial revolution. The creative aspect involves students using their cumulative knowledge and given information to construct process flow diagrams and perform comprehensive calculations, fostering higher-order thinking skills. Ultimately, this project equips students with practical skills essential for designing chemical plants in their final year.

Acknowledgement

We would like to acknowledge (Prof.) Dr. Kamarul 'Asri Ibrahim, the former course coordinator of the Mass and Energy Balance courses who have provided the idea for this innovation and all lecturers of the courses who have helped us in administering the mini project to the students.

References

Faculty of Chemical and Energy Engineering, Universiti Teknologi Malaysia. (2022). Undergraduate Guidebook Academic Session 2022/2023. Retrieved from https://fkt.utm.my/wp-content/uploads/2022/11/GUIDEBOOK-UG-SKT-1-2022-2023-071122.pdf

Sadikin, A. N. B., Mustaffa, A. A. B., Hasbullah, H. B., Zakaria, Z. Y. B., Abd Hamid, M. K. B., Che Man, S. H. B., Hassim, M. H. B., Ab Aziz, M. A. B., & Mohd Yusof, K. B. (2021). Qualitative Development of Students' Digital Skills by Integrating a Spreadsheet Software in First Year Introduction to Engineering and Seminar Course. International Journal of Emerging Technologies in Learning (iJET), 16(18), pp. 213–227. https://doi.org/10.3991/ijet.v16i18.24325.

Dagar, V., Yadav A. (2016). Constructivism: A Paradigm for Teaching and Learning. Arts Social Sciences Journal, 7:4 DOI: 10.4172/2151-6200.1000200

Udugama, I. A., Atkins, M., Bayer, C., Carson, J., Dikicioglu, D., Gernaey, K. V., Glassy, J., Taylor, M. & Young, B. R. (2023). Digital tools in chemical engineering education: The needs and the desires. Education for Chemical Engineers, 44, 63-70.

Malim-Busu, T. Z., Rosli, A., Mohd-Yusof, K., Yunus, N. A., Lim, J. S., & Hamid, M. Y. S. (2022, October). Integrating Introductory Courses for First Year Engineering Students: Systematic Strategy Using a Complex Problem. In 2022 IEEE Frontiers in Education Conference (FIE) (pp. 1-6). IEEE.

Mustaffa, A. A. (2022). Course Information: Mass Balance (SETK 1123). Semester 2 Session 2022/2023. Faculty of Chemical and Energy Engineering, Universiti Teknologi Malaysia

Mustaffa, A. A. (2023). Course Information: Energy Balance (SETK 2133). Semester 1 Session 2023/2024. Faculty of Chemical and Energy Engineering, Universiti Teknologi Malaysia

Ventura-Medina, E., Tanner J., Young B. (2022). Teaching: Educating Chemical Engineers on Digitalisation. The Chemical Engineer. Retrieved from https://www.thechemicalengineer.com/features/teaching-educating-chemical-engineers-on-digitalisation/

Brown, R. W. (1995). Autorating: Getting Individual Marks from Team Marks and Enhancing Teamwork. Frontiers in Education Conference Proceedings. Pittsburgh, IEEE/ASEE, November 1995.