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Identifying Key Factors to Learning Process Systems Engineering and Process Integration through DEMATEL

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The growing relevance of improving the environmental impact of industrial processes makes it imperative to ensure that the concepts of Process Systems Engineering (PSE) and Process Integration (PI) are incorporated into the professional skills toolbox of chemical engineers. Such knowledge provides the chemical engineer with rigorous methodologies for the optimal synthesis and design of industrial processes to ensure that opportunities for resource conservation, energy savings and emissions reduction are maximized. Many of the prerequisite concepts are initially introduced in the undergraduate level as part of curriculum. Thus, any weakness in educational foundations in such concepts can result in poor Process Integration learning outcomes. This work examines the inter-relationship between core competencies developed by students in chemical engineering subjects in their ability to learn PSE/PI concepts using the method Decision Making Trial and Evaluation Laboratory (DEMATEL). DEMATEL is a powerful framework for establishing the cause and effect relationship between system factors. Results are intended to identify which competencies should be strengthened to facilitate learning of PSE/PI concepts and consequently recognize where student's prior knowledge of PSE/PI become useful for learning other chemical engineering subjects.

1. Introduction

Environmental issues continue to be a major concern for industrial processes as nations continue to aspire for sustainable development. The most recent strategy is to implement not just sustainable production but also sustainable consumption. In this regard, process integration has developed several tools for evaluating process systems and identifying strategies to optimize operations to reduce costs, reduce resource consumption or reduce waste generation. It is thus important to ensure that chemical engineers are equipped with the skill to implement process integration and to derive insights from the solutions the technique provides. It has been recognized that there is a need to develop new ways for knowledge creation and decision-making as sustainability issues become more complex in nature (Tejedor et al., 2018). Problem based learning techniques have been used to reinforce learning of Process Systems Engineering (PSE) and Process Integration (PI) among chemical engineering undergraduate students (Promentilla et al., 2017). Such strategies which relate to competency based education is recognized as the most appropriate technique for education programs that expect to develop professionals (Bensah et al., 2011) who will benefit more from performing tasks rather than just knowing. This concept is believed to have begun in the United States during the 1950s, 1960s and 1970s because of dissatisfaction in the educational systems (Hodge, 2009) and is continuously being adopted in disciplines such as nursing (Tan et al., 2018), pharmacy (Bajis et al., 2016) and engineering (Bensah et al., 2011).

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Other fundamental skills have been introduced earlier on in the curriculum of the undergraduate students of chemical engineering and it is important to see how the skills that should be developed at various stages of their education relate to each other. This can potentially identify insights to harness the learning outcomes for PSE/PI. The Decision Making Trial and Evaluation Laboratory (DEMATEL) which was developed by Gabus and Fontela (1972) provides a framework for evaluating how problem criteria relate to each other. It has been used successfully in various sustainability issues such as supplier selection for green supply chain management (Hsu et al., 2013), analysing barriers to the implementation of industrial symbiosis networks (Bacudio et al., 2016), and the evaluation of barriers to the implementation of electrical and electronic waste management (Kumar and Dixit, 2018) to name a few. It has also been implemented for mapping out competencies such as in the case of employee training and allocation to enhance a company's core competencies (Huang et al., 2016) and in the prioritization of competence training for global managers (Wu and Lee, 2007). Its strength lies on its ability to facilitate problem analysis and structuring which is essential in understanding barriers to learning in relation to building competencies. The method provides an interpretive and quick but systematic way of analysing these barriers from the perception of the students. This work utilizes the DEMATEL framework to analyse the barriers in learning PSE/PI which may lead to further understanding the competencies of chemical engineering undergraduate students in their skill development towards learning.

2. Competency based education

Competency-based education (CBE) is a pedagogical theory that promotes the development and mastery of unique and measurable skills throughout various stages of the learning process. Its main purpose is to guide learners in achieving expected competency standards that are mapped and organized utilizing specific systematic learning strategies (Hsu and Li, 2015). CBE involves the integration of knowledge, skills, values, and attitudes towards development of appropriate competencies (Gravina, 2017) with the assumption that competencies are built by performing tasks rather than just obtaining information or knowing (Dobson, 2003). Current chemical engineering curriculum has expected learning outcomes and graduates are expected to have practicable skills and competencies that they can immediately apply in the practice of their profession with very minimum retraining. Competency based training is the most appropriate approach for training chemical engineering students (Bensah et al., 2011). Ghana embarked on the development of modules to transition from subject based learning to competency based learning particularly for higher national diploma in chemical engineering (Bensah et al., 2011). Such curricular changes are currently being initiated by the ABET Engineering Criteria 2000 (EC2000) for the accreditation of engineering programs that requires the development of students' learning outcomes or competencies (Passow, 2012). As such, CBE may be the best way of teaching Chemical engineering as students are able to develop competencies required in the execution of their jobs and build confidence as they achieve the mastery of expected learning competencies (Bensah et al., 2011). Problems in the workplace are reported to have ensued when students are not equipped with competencies expected of them. Concerns such as poor communication skills, self-autonomy, appropriate attitudes and problem solving are some of the competency deficiencies observed among engineering graduates (Male et al., 2010).

The 2012 National Research Council taxonomy outlined three overarching domains: cognitive, intrapersonal, and interpersonal. Each domain has two or three clusters of competencies within it. The cognitive domain includes: (a) cognitive processes and strategies, which involves critical thinking, problem solving, and adaptive learning; (b) knowledge, which pertains to literacy, numeracy, and content knowledge; and (c) creativity. The intrapersonal domain on the other hand consists of: (a) work ethic/ conscientiousness, which includes perseverance and self-direction; (b) positive core self-evaluation, which includes self-esteem and psychological health; and (c) intellectual openness, which includes curiosity and continuous learning. And lastly, the interpersonal domain consists of (a) teamwork/collaboration, which includes communication, conflict resolution, and social skills and (b) leadership. These expected competencies are to be developed by the learners in order for them to cope with new concepts to be introduced as they progress in their course program.

The development of competencies in chemical engineering students particularly in PSE/PI may resemble those proposed by Pintarič and Kravanja (2016) for computer-aided chemical engineering. There are various aspects that can affect competency development for PSE/PI proficiency. For the cognitive domain in particular the different competencies are harnessed at various levels in the different courses taken by the students. Fundamental knowledge for PSE/PI is acquired through the mastery of material and energy balances, unit operations and processes and basic programming skills. Cognitive processes and strategies are then acquired during the analysis and synthesis phases of learning when students are able to integrate their basic knowledge by applying previously learned tools to solve problems. The effect of student motivation also plays an important role in acquiring the requisite skills (Azmi et al., 2017). Finally, creativity emerges when students are able to formulate their own questions and develop their own solution strategies. It is important to see how these aspects interact to identify which particular competencies should be prioritized to develop the skill for PSE/PI.

3. Decision Making Trial and Evaluation Laboratory (DEMATEL)

Decision Making Trial and Evaluation Laboratory (DEMATEL) (Gabus and Fontela, 1972) has been widely used for problem analysis and decision making. It facilitates problem structuring by identifying how the different problem criteria relate to each other. It creates a cause and effect diagram which illustrates which factors can be considered as main drivers and which ones have emerged only as effects. This diagram also uses digraph to describe the interrelationship among criteria factors. The step-by-step procedure of DEMATEL is summarized as follows:

Step 1. Determine the direct relation matrix using the value judgment elicited from stakeholders. After decomposing a complex problem into a set of factors or sub-problems, the respondents are asked to evaluate the direct influence between any two factors using a rating scale of 0, 1, 2, 3, and 4 corresponding to “no influence”, “very low influence”, “low influence”, “high influence” and “very high influence”. The average rating is then calculated and used as input for the direct relation matrix $\vec{A}$.

Step 2. Normalize the direct relation matrix. The entries to the direct relation matrix are divided by either the maximum row sum or column sum of the matrix, whichever is larger of the two. The normalized direct relation matrix ($\vec{D}$) contains elements ranging from zero to one.

Step 3. Calculate the total relation matrix ($\vec{T}$). The total relation matrix $\vec{T}$ captures both the direct and indirect relations by considering higher order interaction. It is approximated by $\vec{T} = \vec{D}\,(\vec{I} - \vec{D})^{-1}$, where $\vec{I}$ is the identity matrix.

Step 4. Plot the prominence-causal relationship diagram. From the total relation matrix $\vec{T}$, compute the row sums (R_i) and column sums (C_i). R_i measures both direct and indirect effects given by factor i to the other factors. In contrast, C_i refers to both direct and indirect effects received by factor i from the other factors. The sum ($R_i + C_i$) provides the total effects given and received by factor i. This indicates the degree of prominence of the factor in the system. On the other hand, the difference (R_i - C_i) provides the net effect of factor i in the system.

In other words, if the net effect is positive, factor i is a causal factor, otherwise, it is an effect factor. These values are then plotted in the Cartesian plane where the sum and difference are in the x and y coordinates.

Step 5. Set the threshold value to form a digraph in the cause and effect diagram. The threshold value, e.g., the average of the entries in the total relation matrix, is used to define the significant relation and filter out some negligible effects. These significant relationships are shown in digraph form of the prominence-causal relationship diagram.

4. Case study

This case study explores the application of DEMATEL in systematically understanding the barriers of learning from the point of view of the students. The case of chemical engineering undergraduate students in a private university in the Philippines is taken as an example. The program specifications set by the Philippine Commission on Higher Education require 229 credit units for the completion of the Bachelor of Science in Chemical Engineering degree (BS ChE). The BS ChE degree is accomplished for a total duration of 4 years and 4 months. Within this period, the concept and tools of PSE/PI are reinforced in the course on “Computer Applications in Chemical Engineering” which is taken during the first academic term of the 4th year. This course is designed to give an introduction to various PSE/PI tools (i.e. mathematical programming, P-graph, simulation software and spreadsheet calculations). The students are expected to have completed their foundation courses by this time. Foundation courses include engineering mathematics, chemical engineering calculations and unit operations and processes to name a few. The survey was administered at the end of the trimester to obtain feedback about their learning experience in the course.

Different barriers encountered by chemical engineering students in understanding PSE/PI were identified. The following are the seven barriers considered for learning PSE/PI. These barriers were identified based on the required competencies and skills for the student to understand PSE/PI:

1) Lack of material and energy balance skills (C1)
2) Lack of knowledge in Unit Operations and Processes (C2)
3) Difficulty in applying appropriate mathematical skills (C3)
4) Difficulty in interpreting results from computational tools applied (C4)
5) Difficulty in constructing the problem structure (C5)
6) Difficulty in selecting appropriate optimization tool (C6)
7) Lack of computer programming skill (C7)

The direct relation matrix ($\vec{A}$) calculated based from the survey data is shown in Table 1 which shows the direct effect of the row factors to the column factors. For example, the students perceived that their lack of material and energy balance skills (C1) has very high impact (3.57) on their difficulties in formulating or constructing the problem (C5). On the other hand, their lack of material and energy balance skills (C1) has low impact (1.86) or relation to their lack of programming skills (C7). The normalized direction matrix ($\vec{D}$) is shown in Table 2. This is then used to obtain the total direction matrix ($\vec{T}$) as shown in Table 3. The degree of prominence ($R_i + C_i$) is shown in Figure 1 while the net cause/effect ($R_i - C_i$) are illustrated in Figure 2. Similarly, the relationship between the degree of prominence and net cause/effect is plotted as shown in Figure 3. As shown in Figure 1, the most prominent barrier in learning process integration is the difficulty in interpreting results from the tools applied (C4). On the other hand, Figure 2 shows that difficulty in applying appropriate mathematical skills (C3) is the main key driver of the barriers in learning PSE/PI. Thus, in understanding and developing the competency skills of the students in particular for PSE/PI, a strong foundation of mathematical skills is a must, and students should be taught more on how to interpret the results from applying these tools for PSE/PI. These competencies should be strengthened to facilitate learning of PSE/PI concepts.

According to Figure 3, C3 is the lone causal factor and all other factors considered are classified as effects.

Table 1: Direct Relation Matrix ($\vec{A}$)

	C1	C2	C3	C4	C5	C6	C7
C1	0.00	3.36	3.50	2.93	3.57	2.50	1.86
C2	3.07	0.00	2.93	3.29	3.43	2.79	2.00
C3	3.43	3.07	0.00	3.50	3.29	2.86	2.29
C4	2.71	2.71	3.43	0.00	3.00	2.64	2.29
C5	2.93	2.86	3.07	2.79	0.00	2.86	2.36
C6	2.07	2.14	3.07	2.71	3.00	0.00	2.86
C7	1.71	1.64	2.07	2.21	2.50	3.14	0.00

Table 2: Normalized direct relation matrix ($\vec{D}$)

	C1	C2	C3	C4	C5	C6	C7
C1	0.00	0.18	0.19	0.16	0.19	0.13	0.10
C2	0.16	0.00	0.16	0.17	0.18	0.15	0.11
C3	0.18	0.16	0.00	0.19	0.17	0.15	0.12
C4	0.14	0.14	0.18	0.00	0.16	0.14	0.12
C5	0.16	0.15	0.16	0.15	0.00	0.15	0.13
C6	0.11	0.11	0.16	0.14	0.16	0.00	0.15
C7	0.09	0.09	0.11	0.12	0.13	0.17	0.00

Table 3: Total relation matrix ($\vec{T}$)

	C1	C2	C3	C4	C5	C6	C7
C1	0.38	0.54	0.13	0.55	0.61	0.53	0.43
C2	0.51	0.37	0.09	0.55	0.59	0.52	0.43
C3	0.54	0.53	-0.05	0.57	0.60	0.54	0.45
C4	0.56	0.56	0.25	0.47	0.64	0.58	0.49
C5	0.50	0.50	0.11	0.52	0.43	0.52	0.44
C6	0.44	0.44	0.11	0.49	0.54	0.36	0.44
C7	0.37	0.37	0.07	0.42	0.46	0.46	0.26

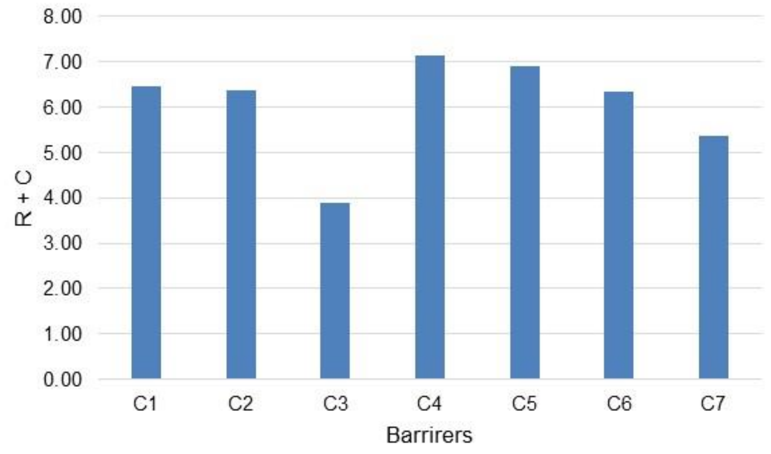

Figure 1: Prominence graph

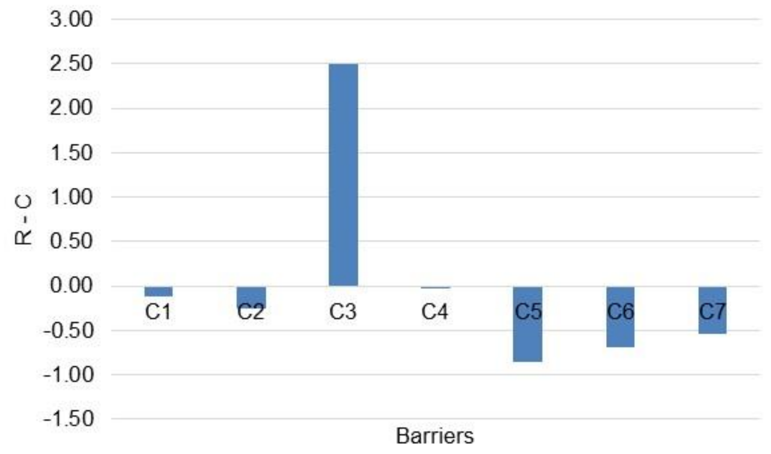

Figure 2: Net Cause/Effect Graph

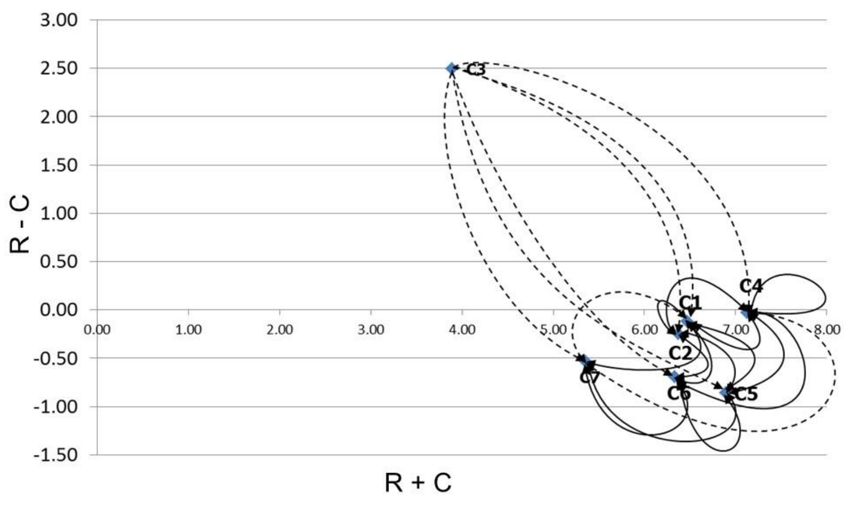

Figure 3: Overall DEMATEL prominence-causal relationship diagram

5. Conclusions

In this work, the DEMATEL framework was utilized to map out how the different barriers to learning PSE/PI relate to each other. These barriers result from the weakness in building competency and based on the results, the mastery of mathematical skills is an essential factor in learning PSE/PI. However, it was the difficulty in learning the engineering interpretation of results of computations which was identified as the main barrier. The latter aspect may be regarded as the main educational bottleneck. This implies that the students lack the ability to synthesize and analyse which are essential skills that must be learnt to progress towards creativity and innovativeness. An evaluation of the current curriculum design and learning outcomes is recommended to identify potential gaps in competency development. Future work can look at barriers in other domains of competency such as the interpersonal and intrapersonal competencies.

References

Azmi N.A., Yusof K. M., Phang F.A., 2017, How to motivate chemical engineering undergraduates to learn programming? Chemical Engineering Transactions, 56, 1303–1308.

Bacudio L.R., Benjamin M.F.D., Eusebio R.C.P., Holaysan S.A.K., Promentilla M.A.B., Yu K.D.S., Aviso K.B., 2016, Analyzing barriers to implementing industrial symbiosis networks using DEMATEL, Sustainable Production and Consumption, 7, 57-65.

Bajis D., Chaar B., Penm J., Moles R, 2016, Competency-based pharmacy education in the Eastern Mediterranean Region—A scoping review, Currents in Pharmacy Teaching and Learning, 8, 401-428.

Bensah E.C., Ahiekpor J.C., Boateng C.D., 2011, Migrating from subject-based to competency-based training in Higher National Diploma Chemical Engineering: The case of Kumasi Polytechnic, Education for Chemical Engineers, 6, e71–e82.

Gabus A., Fontela E., 1972, World problems, an invitation to further thought within the framework of DEMATEL. Battelle Geneva Research Center, Geneva, Switzerland.

Gravina E.W., 2017, Competency-Based Education and its effect on Nursing Education: A literature review, Teaching and Learning in Nursing, 12, 117–121.

Hodge S., 2007, The origins of competency-based training, Australian journal of adult learning, 47, 179.

Huang K.W., Huang J.H., Tzeng G.H., 2016, New hybrid multiple attribute decision-making model for improving competence sets: Enhancing a company's core competitiveness, Sustainability, 8, 175.

Hsu W.C., Li C.H., 2015, A competency-based guided-learning algorithm applied on adaptively guiding e-learning, Interactive Learning Environments, 23, 106 –125,

Kumar A., Dixit G., 2018, Evaluating critical barriers to implementation of WEEE management using DEMATEL approach, Resources, Conservation and Recycling, 131, 101–121.

Male S.A., Bush M.B., Chapman E.S., 2010, Perception of competency deficiencies of engineering graduates, Australasian Journal of Engineering Education,16, 55-67.

National Research Council, 2012, Education for life and work: Developing transferable knowledge and skills in the 21st Century, The National Academic Press, Washington DC, USA.

Passow H.J., 2012, Which ABET competencies do Engineering graduates find most important in their work? Journal of Engineering Education, 101, 95-118.

Pintarič Z.N., Kravanja Z., 2016, Towards outcomes-based education of computer-aided chemical engineering, Computer Aided Chemical Engineering, 38, 2367–2372.

Promentilla M.A.B., Lucas R.I.G., Aviso K.B., Tan R.R., 2017, Problem-based learning of process systems engineering and process integration concepts with metacognitive strategies: The case of P-graphs for polygeneration systems, Applied Thermal Engineering, 127, 1317–1325.

Tan K., Chan C. M., Subramaniam P., 2018, The effectiveness of outcome based education on the competencies of nursing students: A systematic review, Nurse education today, 64, 180-189.

Tejedor G., Segalàs J., Rosas-Casals M., 2018, Transdisciplinarity in higher education for sustainability: how discourses are approached in engineering education, Journal of Cleaner Production, 175, 29–37.

Wu W.W., Lee Y.T., 2007, Developing global managers' competencies using the fuzzy DEMATEL method, Expert systems with applications, 32, 499–507.