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Comparing Learning Strategies in Understanding Process Integration, Optimization and Sustainability

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Process Integration provides an excellent engineering toolbox for optimising industrial systems to achieve sustainability gains. However, effective large-scale use of such tools depends on effective education of new generations of engineers with the correct training and mind-set. Learning strategies refer to the different combinations of activities the learners utilise in their process of learning. Chemical engineering students often face the challenges in processing key concepts integral in the understanding of Process Integration, optimisation and sustainability. A preliminary survey of students from the undergraduate program from the Philippines identifies learning strategies they employ in better understanding Process Integration, optimisation and sustainability. These strategies help learners in analysing concepts, monitoring the learning process, linking concepts with one another, inferring meanings from context, and managing their behaviour towards learning. Educational best practices are suggested based on insights drawn from the responses.

1. Introduction

The growing concern for the environment necessitates exposure of students to sustainability concepts. They need to be equipped with skills for understanding the complexity of environmental problems so that they can develop strategies and solutions to address these issues. Chemical engineering, which initially focused on the large-scale production of products, has now evolved to integrate the need for production systems to work more efficiently and more sustainably. Conceptual frameworks like Process Integration (PI) and tools such as Mathematical Programming (MP) have become essential components of chemical engineering curriculum. Students thus face the challenges of understanding of complex concepts in their courses. Understanding how they process information can potentially provide insights for improving the delivery of course content. For example, based on student interviews, application of learner-centred approaches can facilitate effective learning of programming skills (Azmi et al., 2017). Promentilla et al. (2017) proposed the use of metacognitive perspective to understanding how students learn Process Systems Engineering (PSE), while the study by Aviso et al. (2018) attempted to identify the key factors to learning PSE using the Decision-Making and Trial Evaluation Laboratory (DEMATEL) framework. An investigation of Problem-Based Learning (PBL) in chemical engineering was also presented by Promentilla et al. (2017).

Students employ multiple learning strategies to deal with their learning tasks. This work intends to provide a more comprehensive assessment of these different learning strategies using the established Motivation Strategies for Learning Questionnaire (MSLQ) (Pintrich et al., 1991), with particular attention to concepts of PI, MP and sustainability in chemical engineering education. Learning strategies are defined as the variations in the activities (i.e., “strategies”) employed by students to deal with new concepts. Learning strategies are influenced by the task to be done, are dynamic by nature, and can be manipulated over a period of time (Hartley, 1998). Studies on factors influencing students’ academic achievement focus on students’ use of learning

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strategies (Pintrich et al., 1993), suggesting that highly self-regulated students who employ several learning styles perform well (Pintrich et al., 1991).

Learning strategies have been further classified as cognitive and metacognitive strategies. Cognitive strategies refer to processes, which are done on the content to be learned (Benson, 2013). They allow learners to reorganise new skills and knowledge in various ways through social interactions (Schmid, 2017). Metacognitive strategies, on the other hand, manage the learning process by focusing on how cognitive strategies are integrated (Benson, 2013). They involve principal processes in planning for learning, and assessing whether the learning outcomes have been achieved (O'Malley and Chamot, 1990). Furthermore, these strategies help the learners to control their cognition by coordinating the entire learning process (Oxford, 1990).

Secondly, resource management strategies are important components of self-regulated learning, which are directly correlated on academic achievement, which is significantly influenced by time and study management environment, as well as effort regulation (Stegers-Jager et al., 2012). Examples of learning resource management strategies are: management of learning time, management of study environment, effort management, and seeking assistance from peers (Pintrich et al., 1991). Understanding student perspectives when facing challenging subject matter can aid in improving pedagogical strategies.

The rest of the paper is organised as follows. The next section provides a discussion of the related literature and methodology used for analysing the learning strategies of chemical engineering students; it is then followed by the case study. Next, results and discussion are provided. Finally, the implications for educational practice, conclusions, and directions for future work are given.

2. Related literature

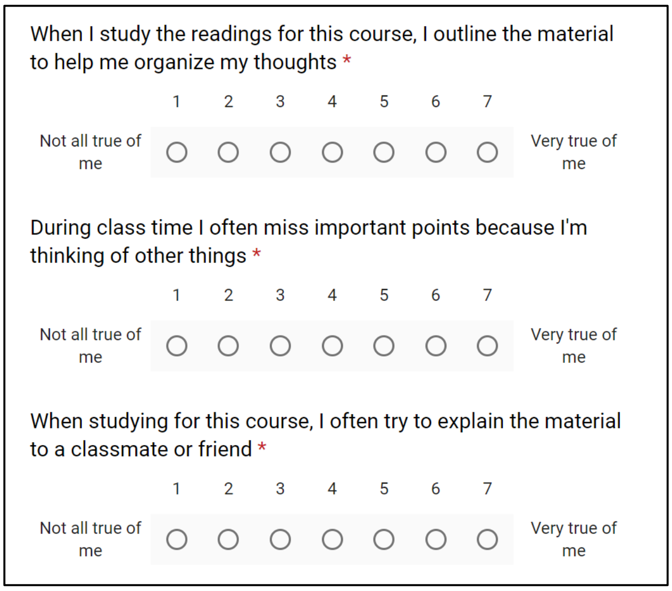
The efficacy of learning strategies determines students' academic performance. Studies further support how learning strategies promote autonomy and self-regulation among learners. For example, these effects have been observed in students learning pharmacy (Sera and McPherson, 2019), sociology (Pelton, 2014), and medicine (Ainscough et al., 2018). Metacognitive learning strategies were shown to lead to marked improvement in academic achievement of college students (Gargallo et al., 2016). Aizpura et al. (2018) showed that strategies encouraging social interaction and collaboration among peers aid in the development of cognitive skills such as creative thinking and problem solving.

Similarly, findings in a chemical engineering education research reveal that the use of flipped classroom enhances students' learning and develops their critical skills. The inclusion of cooperative learning assists in students' communication skills, which facilitated teamwork, and problem-solving skills (Munier et al., 2018). It was also found that chemical engineering students using a design software developed mathematical skills to apply their previously acquired knowledge (Lim, 2017). Moreover, programming skills were developed by chemical engineering students who utilized advanced tools, which helped them in the integration of other problem-solving skills (dos Santos et al., 2018).

3. Methodology

The MSLQ developed by Pintrich et al. (1991) is utilised as the framework for assessing strategies used by learners. The instrument has two categories: (1) learning strategies and (2) information processing and on motivation. The category covering strategies include two sub-categories: cognitive and metacognitive, and resource management. There are four cognitive and metacognitive strategies: (a) rehearsal (measures strategies to learn by repetition), (b) organization (taking into account the ways of managing mathematical learning), (c) elaboration (measures how incoming information is related to existing materials in the record of the subject), (d) critical thinking, and (e) metacognitive self-regulation. The second category on resource management strategies include: (a) time and study environment (b) effort regulation, (c) peer learning, and (d) help-seeking.

The questionnaire consists of 50 questions, which had to be evaluated using a Likert scale of 1 to 7 where a student is expected to respond as to whether he or she agreed to the statement provided. A score of 1 represents that the statement is not at all true for the student, while a score of 7 represents that the statement is very true for the student. A score between 1 and 7 indicates the degree of disagreement or agreement of the student to the statement provided. The 50 questions are meant to evaluate various aspects of cognitive and metacognitive strategies as well as resource management strategies. In addition, 4 open-ended questions were also listed. A sample of the questions, which required the 7-point Likert scale, is shown in Figure 1. The questionnaire was administered using Google forms.


When I study the readings for this course, I outline the material to help me organize my thoughts *

	1	2	3	4	5	6	7	
Not all true of me	○	○	○	○	○	○	○	Very true of me

During class time I often miss important points because I'm thinking of other things *

	1	2	3	4	5	6	7	
Not all true of me	○	○	○	○	○	○	○	Very true of me

When studying for this course, I often try to explain the material to a classmate or friend *

	1	2	3	4	5	6	7	
Not all true of me	○	○	○	○	○	○	○	Very true of me

Figure 1: Sample questions for 7-point Likert scale

In addition, four open-ended questions were administered as follows:

- Q1: In your experience, what is the most challenging aspect of learning mathematical programming?
- Q2: How do you envision using mathematical programming to improve the sustainability of industrial systems?
- Q3: What is the difference between Process Integration and Optimization?
- Q4: How can the implementation of process integration/optimisation improve the sustainability of an industrial system?

4. Case Study

The delivery of the chemical engineering curriculum may differ from one continent to another, between countries and perhaps even between universities and institutions. The case study considers undergraduate and graduate students of the Chemical Engineering program from a private institution in the Philippines. In the Philippines, the Commission on Higher Education is in charge of developing the Policies, Standards and Guidelines for a Bachelor's degree in Chemical Engineering (BS ChE). At the moment, a BS ChE degree requires a minimum of 170 credit units to be delivered for a minimum of 4-years. Of this, 120 credits are categorised under technical courses which include Mathematics and Physical Sciences (20 units), Basic Engineering Sciences (7 units), Allied Courses (22 units) and Professional Courses (71 units). As a guideline, 3 credit units of lecture course are equivalent to 3 contact hours each week while each unit of laboratory course also corresponds to 3 hours each week. Universities and institutions in the country can include additional courses as long as the minimum requirement is met. Sustainability principles are introduced as early as the second academic year of the students in the subject Environmental Engineering and further supplemented by other professional courses such as Industrial Waste Management and Control and Elective Courses. However, process integration and optimisation principles are introduced much later particularly in the fourth academic year of students in the subjects on Computer Applications in Chemical Engineering and Process and Plant Design where mathematical programming is introduced as an essential tool for identifying the optimal structure of process systems. For some students, the integration of sustainability concepts with process integration and optimisation are more developed when integrated into their thesis projects. For the graduate level, a dedicated course on Optimization Methods for Chemical Engineering is offered on a regular basis.
The summary of the results obtained from the questionnaire is shown in Table 1. A total of 17 respondents from both the undergraduate and graduate level were considered. It has been found that students by and large use all of their cognitive and metacognitive, and resource management strategies in their understanding of Process Integration, Optimization and Sustainability. Furthermore, some of the notable responses for the open-ended questions are summarised in Table 2. Most of the responses obtained, which related to Q1 indicated that the main difficulty in mathematical programming is in translating real-world problems into the corresponding mathematical model. Responses in Q2 and Q3, on the other hand, revealed that students were able to find a

connection between mathematical programming, optimisation and its relevance towards achieving environmental sustainability.

Table 1: Summary of results from the questionnaire

Learning Strategies	Sub-categories	Mean	Standard Deviation
Cognitive and metacognitive strategies	Rehearsal	5.10	1.67
	Elaboration	5.52	1.29
	Organisation	5.30	1.36
	Critical Thinking	5.24	1.22
	Meta-cognitive self-regulation	5.53	1.26
Resource Management Strategies	Time and study environment	5.55	1.31
	Effort regulation	5.80	1.01
	Peer learning	5.40	1.35
	Help-seeking	5.17	1.60

Table 2: Selected responses for open-ended questions

Questions	Responses
Q1	• Translating the problem into mathematical models • Starting out and not being familiar with the different software applications and types of models • Understanding how codes are interpreted within the software and understanding how coding strategies can be applied for given tasks
Q2	• Mathematical programming can be used in modelling a system that involves sustainability and looks at its possible pathways. • Through mathematical programming, equations can be set up to test and improve systems • Optimisation of recycling/reuse processes
Q3	• Integration is making use of by-products and producing more useful products. It can also be a way on how to use heat from a certain process and integrate this into the entire process. Optimisation, on the other hand is determining the optimised result that is limited by a set of constraints.
Q4	• Knowing the optimal interconnection of unit processes within a system would not only minimise cost related to the overall design but could also ensure that the system would be able to meet industrial demands. This is important and useful because demands may change overtime and without optimising a system one would be unable to tell whether the current interconnection of processes is the best possible design to accommodate future changes. Implementing process integration/optimisation could improve the sustainability of industrial systems in that their design could be built to accommodate future demands by evaluating which processes or units are more flexible, economical and accessible.

The results suggest that these students made use of the following cognitive and metacognitive learning strategies: (1) rehearsal strategies are utilised for the activation of information in the working memory that influences the encoding process; (2) elaboration helps the learners store information to the long-term memory and integrate new information with prior knowledge; (3) organisation assists the students to choose the appropriate information to construct connections with what has been learned; (4) critical thinking is the degree in which the learners apply previous knowledge to new learning and make critical evaluations; and (5) metacognitive self-regulation refers to the cognizance and control of cognition that focuses on self-regulation. Cognitive and metacognitive strategies predict success in academic performance by helping students in monitoring their behaviour in line with their learning process (Pintrich et al., 1991).
The data yield interesting findings as some respondents of the questionnaire are undergraduate students in their final year level. These learners may have utilised all the learning strategies available to them and have opted to optimise them in the process of their learning. These learners may have more self-autonomy and regulation as they have developed awareness that learning strategies are indeed helpful in their academic achievement and success.

As regards the utilisation of resource management strategies, more than the students' ability to self-regulate and monitor, they are also able to manage their time, study environments and promote collaboration with their peers. Such supporting strategies facilitate academic achievement and success (Pintrich et al., 1991). This would suggest that the presence of infrastructure in the university that promotes spaces for learning might have better facilitated the learning process of these students. Moreover, given the maturity of these learners, they are more capable of collaborative learning that helps them in coping with their studies. They are more engaged with their learning process as they seek assistance from their peers through social interactions, which make learning more meaningful.

The points shared in the open-ended questions gave a very positive insight as regards to how mature students utilise these strategies in their own process of learning difficult and complex concepts and techniques. Through the use of these strategies, they were able to have a better understanding and appreciation of these engineering concepts and processes, which are essential in their further understanding of higher and more complex concepts that they will encounter in their courses.

5. Implications for Curriculum Design and Pedagogy

These results suggest ways to improve pedagogical strategies for more efficient delivery of subject matter. Learning process integration and optimisation seem to occur at the level of, first, acquiring tools (e.g., knowledge of concepts such as objective functions, constraints, solution algorithms, etc.), and subsequently applying these tools to new problems (i.e., model-building). As in the case of programming skills (Azmi et al., 2017), learner-centred strategies that focus on providing collaborative environments may be the most effective approach. In particular, extensive use of trial and error with a large number of sample problems can create opportunities for learning, wherein students eventually gain deeper understanding of key concepts via insights that occur during problem solving.

In heterogeneous classes where students have different paces in learning, each student might be utilising their learning strategies differently in the processing of complex concepts. Courses should have provision for pedagogical activities that promote collaborative learning for the proper optimisation of these strategies. In this way, learners monitor each other's work, evaluate each other's ideas and produce knowledge based on shared skills and resources. Activities such as joint problem solving, group projects, think-pair-share among others, are guided and facilitated by the learning strategies shared by students as they actively interact in the achievement of their learning goals.

6. Conclusions

A preliminary investigation on the learning strategies utilised by undergraduate students was implemented using a subset of the MSLQ. The results show that learners optimised the use of these strategies to be successful learners and to achieve academic excellence All learning strategies received a mean score of more than 5.0 in the Likert scale. The learning strategy associated with effort regulation received the highest mean of 5.85 and the lowest standard deviation of 1.01 in the Likert scale. This strategy is under the resource management strategy category. This indicates that students associated more with the statements referring to this strategy. Alternatively, the lowest mean score of 5.10 and the highest standard deviation score of 1.67 was observed for the rehearsal strategy, which is under the cognitive and metacognitive category. However, all learning strategies received a mean score of more than 5.0 indicating that students understand the relevance of MP techniques for improving the sustainability of process systems. These are made possible because of the employment of these learning strategies that proved to be effective in facilitating their own learning. It is important that these strategies be internalised by students to promote effective learning and self-regulation. It is also interesting to investigate how explicitly teaching these learning strategies to the students may affect their learning behaviours and their future academic performance. Further research is currently in progress on comparison of student cohorts across different cultural contexts, which will also be essential to gauge the robustness of innovative pedagogy.

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