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Evaluating the Problem-Solving Studio Approach for Teaching Facilities Layout Planning & Design

Dimantha Samarajeewa Kottawa Gamage

Dimantha S. Kottawa Gamage is an Industrial Engineering PhD student at Montana State University. He received his bachelors degree in Management and Information Technology from University of Kelaniya, Sri Lanka. He has served in the industry for 5 years as a lean practitioner and a change agent.

Durward K. Sobek (Vice Provost)

Durward K. Sobek II currently serves as Vice Provost at Montana State University after many years as a Professor in Industrial and Management Systems Engineering. He holds Ph.D. and M.S. degrees in Industrial and Operations Engineering from the University of Michigan, and an A.B. degree in Engineering Sciences from Dartmouth College.

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Abstract

The Problem-solving studio (PSS) was designed with the objective of teaching students how to solve engineering problems without relying on rote memorization while attaining learning objectives related to course topics. Subsequent studies have supported this claim. Hence, an adapted PSS approach was used to teach facilities layout planning and design in a facilities design course which is a part of the senior year curriculum of an industrial engineering program. Attainment of learning objectives was measured using two sources, case studies which were developed and executed using PSS techniques, and quizzes. For case studies, an assessment of three real-world case studies was compared to an identical assessment of a similar case study utilized in a prior year. For quizzes, an assessment of quizzes was compared to identical assessments in the two prior years. Quantitative techniques were used to analyze the outcomes of the case studies and the quizzes, while a thematic analysis was used to analyze the post-case study feedback. This study analyzes the results of the three cohorts to understand the effects of using the PSS approach for teaching this subject.

Key Words: Problem-Solving Studio, classroom research, learning outcomes assessment

1. Introduction

The problem-solving studio (PSS) is a pedagogical technique that focuses on problem-based learning. Because of PSS's features, instructors can adjust the level of support they provide in real time, as well as the difficulty level of the problems, to ensure that each student is challenged at a level that is beyond what they could achieve on their own, but at the upper end of what they can achieve in a PSS setting [1]. This approach was initially implemented in the Biomedical Engineering program at Georgia Institute of Technology to improve the problem-solving skills of the students while improving the conceptual understanding of material and energy balance [2]. The study found that the PSS significantly enhanced both aspects in students.

A subsequent study was carried out by one of the authors to teach facilities layout planning and design using an adapted PSS technique. The purpose was to improve students' ability to use layout planning techniques to generate facility layouts that meet customer requirements, specifically the ability to execute steps of the Systematic Layout Planning pattern. These include acquiring the necessary input information, using the specific tools, generating alternative solutions, and evaluating solutions using criteria that are important to stakeholders. The study concluded that in using the PSS approach, students demonstrated a strong achievement in some learning outcomes and performed no worse on others compared to the prior year [3].

With the success attained, a modified version of the prior approach was implemented the following year with the objective of further enhancing the outcomes. These outcomes were measured through summative assessments and were compared to identical summative assessments carried out for the two prior years when the PSS technique was introduced in one course module and when the PSS technique was not used.

This paper analyzes information captured across the three cohorts to understand the impact of the PSS approach in attaining learning objectives. The next section presents a literature review that explains the concepts of active learning, problem-based learning, PSS, and their connectivity. The ensuing sections discuss the research setting, methods used, analysis approach, and results with discussion.

2. Literature Review

Even though many students claim to understand engineering concepts, they often struggle when asked to solve open-ended problems. Problem-solving entails a variety of metacognitive strategies that allow students to understand how they think and experiment with different problem-solving methods [1]. Students need to utilize these metacognitive strategies for effective problem-solving. However, many students use a rote problem-solving approach in which they 1) write down the known and unknown variables found in the problem statement, 2) look for a formula or equation that uses these variables, and 3) enter the numbers into the formula and calculate an answer [2]. In most real-world scenarios, this approach is ineffective [1].

Therefore, for students to solve open-ended and ill-structured problems effectively, they must develop problem-solving skills in addition to technical knowledge, which requires appropriate classroom teaching approaches. Instructors should implement teaching practices that focuses on more than using formulas and performing mathematical operations.

Educational experts define active learning as learning that challenges students to engage cognitively and meaningfully with the materials by analyzing, synthesizing, and evaluating knowledge rather than simply receiving it passively [4]. When compared to traditional teaching approaches, active learning has been found to provide better learning results among engineering students. Rather than an expert delivering a lecture or working problems while students listen and take notes for the whole class session, in active learning classrooms, students interact with one another at one or more points throughout the class period to engage the content more actively. Thus, active students are cognitively engaged. This emphasizes broad notions such as thoughtfulness and willingness to exert the necessary effort to succeed and master complex skills and ideas.

Problem-based learning is thought to be the most successful way to ensure the integration of academic and operational approaches to higher education, as well as to instill a high degree of desire and the ability to engage in active learning [5]. Problem-based learning is a student-centered teaching style that uses real, carefully crafted real-world issues or challenges as the stimulus and focus for collaborative and self-directed student activity to teach information and skills within a knowledge domain [5]. In a problem-based learning environment, the teacher presents students with authentic, ill-structured problems before they receive any instruction [6].

Students involved in problem-based learning analyze difficulties, seeking for appropriate cross-disciplinary linkages, grappling with the problem's complexity, and generating solutions using newly acquired and existing knowledge. Because students collaborate while solving problems, their thought processes are visible and hence available to personal and peer criticism and revision. Students put ideas to the test, detect misunderstandings, and question one another's thinking. To gain more insights into the problem, members of a group must be familiar with a variety of roles and perspectives. Through increasingly self-directed study, students develop considerable knowledge bases. Students refine and increase their knowledge through collaboration with classmates. They offer, justify, and debate options when one is available to find the best potential solution to the problem [6].

The PSS is a specific problem-based learning approach. Le Doux and Waller [1] introduced this technique as a method that can help students grasp complex engineering concepts and, at the same time, acquire effective problem-solving strategies for open-ended problems. Unique features of the PSS approach are 1) working on open-ended problems which are more complex and less structured than text-book problems, 2) using dynamic scaffolding (instructional support) to provide students with an appropriate level of challenge, 3) using a two-person participant structure to support student learning, 4) sustaining engagement through a shared problem-solving space, and 5) just-in-time coaching and situated feedback [1].

3. Methodology

Through fall of 2018 (cohort A), a traditional approach was used to teach facilities layout planning and design in a facilities design course. However, the instructor utilized an adapted PSS approach in the fall of 2019 (cohort B) and fall of 2020 (cohort C). The course is a typical three-credit lecture course with three 50-minute class periods per week for the 15-week semester and uses Tompkins, et al.'s textbook [7]. The course is divided into modules, each concluding with a quiz to assess student learning. This study focuses on the three facilities layout planning and design modules.

Cohort A learned facilities layout planning and design through traditional methods such as assigned reading, lectures supported by PowerPoint visuals and examples, and homework to practice and reinforce the different concepts and techniques. Due to repeated disappointing student performance in Systematic Layout Planning, the instructor decided to try out the PSS approach for that module in Fall 2019.

As a result, for cohort B, a case study of a wood furniture production facility based on a prior client-based student project was developed and executed using PSS techniques. The case study focused on Systematic Layout Planning and was assigned during the layout planning module (refer to Table 1). However, since concepts scaffold through the course, the students had to apply the learnings of the two prior modules to arrive at final solutions. The students worked in pairs. The instructor acted as the client and the students had to go through the requirements of the case study and request necessary data from the instructor. The instructor did not lecture on Systematic Layout Planning; however, those materials were available through the course's online management system. These were the same materials used in lectures and as supplementary reading in prior years.

Table 1: Summary of Case Study Allocation

Module		Cohort A	Cohort B	Cohort C
Facilities Layout Planning & Design	Process Design	N/A	N/A	Wood Furniture Production Case Study – Part 1
	Facility Layout Requirements	N/A	N/A	Wood Furniture Production Case Study – Part 2
	Layout Planning (includes Systematic Layout Planning)	N/A	Wood Furniture Production Case Study	Wood Furniture Production Case Study – Part 3

To build on and improve upon prior offering, the case study from cohort B was expanded and split into three pieces for cohort C (refer to Table 1). Besides the case studies, additional changes were made to the instructional strategy due to the Covid-19 pandemic. First, the students were divided into three study groups and the instructor met each group one day each week on a rotating basis to accommodate social distancing in the assigned classroom. A flipped classroom approach was used where the students initially learned through content loaded into the learning management system, namely textbook readings, online lecture videos, and discussion boards. The instructor used the classroom time as work sessions to do practice problems, answer questions or work on case studies.

Furthermore, the amount spent on coaching students and the percentile grade allocated for the case studies were increased based on the feedback received from students of cohort B.

3.1. Assessment Approach

Three instruments were used to gather information on the success of the PSS approach:

- Case study deliverables
- Module quizzes
- Critical Incident Questionnaires (CIQ)

The deliverable of each case study was a memo to the client outlining the students' recommendations plus any associated deliverables (e.g., layout drawings). Students completed case studies in assigned pairs. Demonstration and the level of attainment of learning objectives were measured using the case study evaluation rubric (refer to Table 2) through assigning achievement levels. The case study for cohort B was designed to target a subset of learning objectives associated with Systematic Layout Planning. However, because the topics scaffold, students also had to demonstrate the learning objectives of previous modules to successfully complete the case study. The three case studies of cohort C were designed to target a subset of learning objectives of their respective module which, when aggregated, corresponded to the same learning objectives that were targeted through the cohort B case study.

Students of all cohorts demonstrated attainment of learning objectives through a timed quiz at the end of each module. For modules which had a case study assigned, the quiz was completed after submitting the deliverables of the respective case study. Each quiz consisted of five to six problems or short-answer questions that addressed specific learning objectives. Attainment level of learning objectives were measured using scores attained for each question. To do this, the quiz evaluation rubric (refer to Table 2) that has similar competency levels to the case study evaluation rubric was developed. Having similar competency levels makes quiz data comparable with case study data. Each quiz was designed to target a subset of learning objectives of the module it followed, some of which were also targeted in the case studies.

Table 2: Case study and quiz evaluation rubrics

Competency Level	Criteria	
	Case study	Quiz Item
Level I	Non-achievement of Learning Objective	Score <=20%
Level II	Partial achievement of Learning Objective	Score >20% and <75%
Level III	Complete achievement of Learning Objective	Score >=75%

Students of cohorts B and C reflected upon their experience and gave feedback using a critical incident questionnaire (CIQ) administered through the online learning management system at the end of each case study. The CIQ is an effective qualitative tool to assess student critical thinking during the process of learning and reflect on these findings as a source of professional development [8]. Each CIQ consisted of five open-ended, qualitative questions. These questions prompted students to reflect on a "critical event" that occurred, i.e., the case study. The CIQ responses were useful for understanding challenges students faced and the benefits they accrued during the case studies and the overall course.

3.2 Analysis Approach

Data from the summative assessments of each case study memo and quiz delivered in the facilities layout planning and design modules were analyzed using inferential statistical methods. The post case study feedback from CIQs was analyzed using qualitative methods. A summary of statistical methods utilized is shown in Table 3.

Table 3: Summary of statistical tests

Statistical Analysis	Instrument	Cohorts considered	Number of Tests	Sample Sizes (n_1 and n_2)
Chi-squared test for proportions	Case studies	B & C	12	n_1 and n_2 ranged from 11 to 12
Chi-squared test for proportions and Z-test for proportions	Quizzes	A, B & C	43 for each Chi-squared and Z-test	n_1 and n_2 ranged from 24 to 100
Two sample t-test and Mann-Whitney test	Quizzes	B & C	1 for each two-sample t-test and Mann-Whitney test	$n_1 = 5$, $n_2 = 12$
Thematic analysis	CIQs	B & C	N/A	N/A

To analyze data from the case studies of cohorts B and C, chi-squared tests for proportions were performed using 'The R project for statistical computing'. CQ_X and CR_X proportion values (Figure 1) were considered for each learning objective that was demonstrated in the case studies.

- CQ_X = Proportion of competency level III achieved by students of cohort B for learning objective X in the case studies.
- CR_X = Proportion of competency level III achieved by students of cohort C for learning objective X in the case studies.

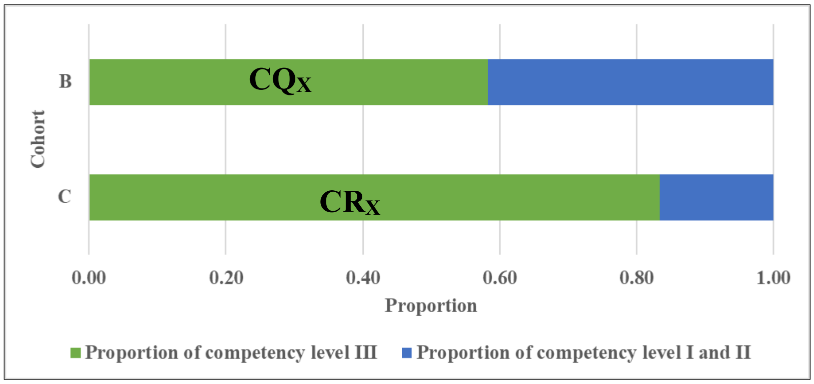

Figure 1: Proportion of competency level achievement by each cohort for objective X in the case studies

Students of cohort B and C demonstrated 12 learning objectives. Therefore, 12 hypothesis tests were carried out. Since the students of cohort C received more case studies, the hypothesis was that cohort C would have higher performance in terms of achieving learning objectives compared to cohort B.

To analyze data from the quizzes of all cohorts, both Chi-squared test for proportions and Z-test for proportions were performed using the R project for statistical computing and Minitab software respectively.

QP_X, QQ_X and QR_X proportion values (Figure 2) were considered for each Facilities Layout Planning and Design learning objective that was tested through the quizzes.

- QP_X = Proportion of competency level III achieved by students of cohort A for learning objective X in the quizzes.
- QQ_X = Proportion of competency level III achieved by students of cohort B for learning objective X in the quizzes.
- QR_X = Proportion of competency level III achieved by students of cohort C for learning objective X in the quizzes.

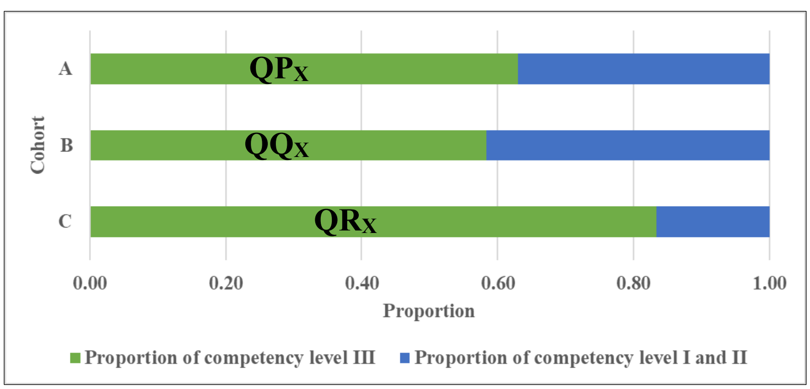

Figure 2: Proportion of competency level achievement by each cohort for objective X in the quizzes

A quiz which tested knowledge of a specific module consisted of slight differences across cohorts. Therefore, even though there were a considerable number of mutually tested learning objectives, there were a few learning objectives that were not tested for each cohort.

Furthermore, only two proportions at a time can be considered for a directional hypothesis test. Therefore, each cohort was compared against every other cohort generating three groups of tests (AB, BC and AC). For each group, these tests were carried out for the mutually tested learning objectives in the group.

Therefore, based on the number of mutually tested learning objectives,
- 15 tests were carried out for cohorts B and C
- 14 tests were carried out for cohorts C and A
- 14 tests were carried out for cohorts B and A

It is important to note that only students from cohorts B and C received PSS exposure where cohort C received the most. Since evidence from literature and previous experience indicated that the PSS method improves the attainment of learning objectives, the authors arrived at the hypothesis that cohort C would have the highest performance in terms of achieving learning objectives while cohort A would have the lowest.

Of the 17 learning objectives tested through the quizzes, five were also covered in the case studies while 12 were tested only through the quiz. To determine if performance was different on learning objectives that were covered by case studies compared to those which were not, two-sample t-tests and Mann-Whitney tests were performed for quiz item scores of cohort C using Minitab software. The two samples T and U were considered for the tests where,
- $T = \{T_1, T_2 \ldots . T_{12}\}$ where T_1 is the percentage of competency level III achieved for learning objective 1, which were not covered in the case studies (see Figure 3).
- $U = \{U_1, U_2 \ldots . U_5\}$ where U_1 is the percentage of competency level III achieved for learning objective 3, which were also covered in case studies (see Figure 3).

The hypothesis was that the learning objectives that were tested using both case studies and quizzes would have a higher percentage of competency level III compared to learning objectives that were only tested using quizzes.

The CIQ responses were analyzed through a thematic analysis using the NVivo software. The authors went through feedback from ~20 students for five questions for each of the three CIQ's in cohort C and for the one CIQ in cohort B separately. The data was read and re-read numerous times to reduce the number of codes and group them into distinct themes. The themes were ultimately reduced to ~12 for each CIQ. Each theme consisted of seven to 22 references. Finally, all themes were summarized using a couple of sentences which presented the core messages of each theme.

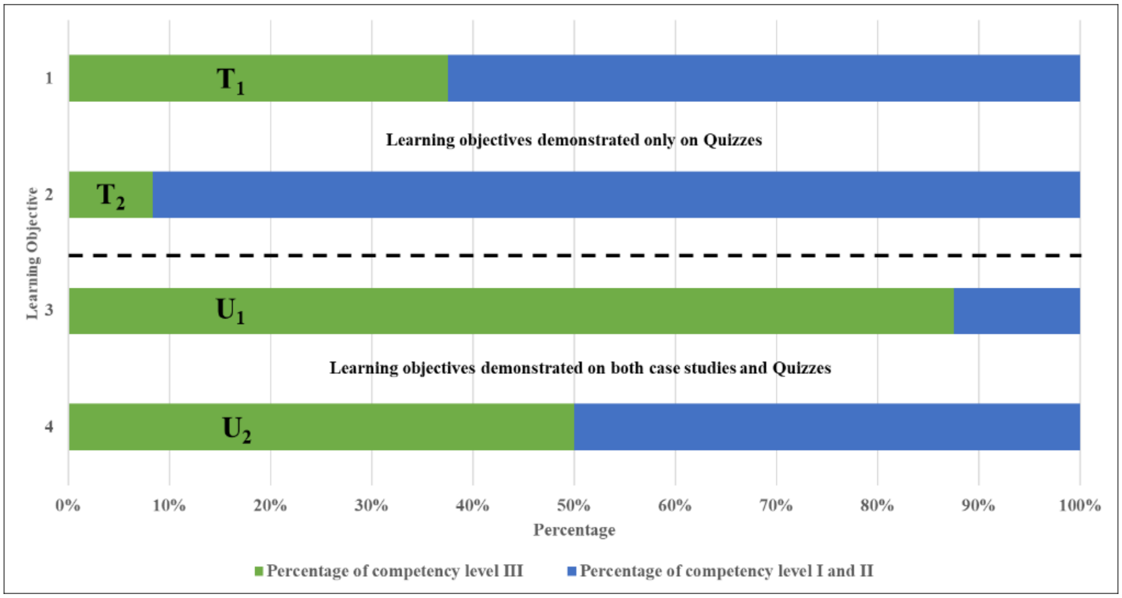

Figure 3: Percentage of competency level achievement for each learning objective

4.0 Results & Discussion

Table 4 shows the summary of the hypothesis tests that were performed on case study data (CQ_X and CR_X).

- CQ_X = Proportion of competency level III achieved by students of cohort B for learning objective X.
- CR_X = Proportion of competency level III achieved by students of cohort C for learning objective X.

Table 4: Case study hypothesis tests summary

Statistical Test	Chi-squared test
Sample size	n_1 and n_2 ranged from 11 to 12
Number of tests	12
Hypothesis	**H_0: $CR_X = CQ_X$**
	H_a: $CR_X > CQ_X$
Fail to reject null hypothesis	5 (41.7%)
Reject null hypothesis	7 (58.3%)

At a significance level of 15%, the null hypothesis is rejected in 7 of the 12 tests conducted suggesting that, overall, cohort C demonstrated higher attainment of the learning objectives targeted compared to cohort B. A higher significance level was utilized due to the very small sample size.

Table 5 shows the summary of the hypothesis tests that were performed on quiz data (QP_X, QQ_X and QR_X).

- QP_X = Proportion of competency level III achieved by students of cohort A for learning objective X in the quizzes.
- QQ_X = Proportion of competency level III achieved by students of cohort B for learning objective X in the quizzes.
- QR_X = Proportion of competency level III achieved by students of cohort C for learning objective X in the quizzes.

Both the Chi-squared test and the z-test for proportions generated similar results.

Comparing cohorts B and C, at a significance level of 10%, the null hypothesis is not rejected suggesting that, cohort C did not demonstrate higher attainment of the learning objectives targeted compared to cohort B.

Comparing cohorts B and A, at a significance level of 10%, the null hypothesis is rejected in 8 of the 14 tests suggesting that, cohort B demonstrated higher attainment of the learning objectives targeted compared to cohort A.

Comparing cohorts C and A, at a significance level of 10%, the null hypothesis is rejected only 1 of the 14 tests suggesting that, cohort C did not demonstrate higher attainment of the learning objectives targeted compared to cohort A.

Table 5: Quiz performance hypothesis tests summary

Statistical Test	Chi-squared test for proportions and Z-test for proportions		
Sample size	n_1 and n_2 ranged from 24 to 100		
Number of tests	15	14	14
Cohorts being compared	C and B	B and A	C and A
Hypothesis	**H_0: $QR_X = QQ_X$**	**H_0: $QQ_X = QP_X$**	**H_0: $QR_X = QP_X$**
	H_a: $QR_X > QQ_X$	**H_a: $QQ_X > QP_X$**	**H_a: $QR_X > QP_X$**
Fail to reject null hypothesis	15 (100.0%)	6 (42.9%)	13 (92.9%)
Reject null hypothesis	0 (0.0%)	8 (57.1%)	1 (7.1%)

Overall, cohort B performed best, and cohort C performed worst in attaining learning objectives as demonstrated on quizzes. This is an interesting finding since the student performance on case studies improved from cohort B to C. Even though there could be a multitude of external and internal factors that could drive this type of behavior, the next logical question is whether the students performed better on learning objectives that were tested in both case studies and quizzes.

Table 6 shows the results of the two-sample t-test and the Mann-Whitney test performed on quiz data (T and U) with the objective of finding this.

- $T = \{T_1, T_2 \ldots T_{12}\}$ where T_1 is the percentage of competency level III achieved for learning objective 1, which was only demonstrated in the quizzes.
- $U = \{U_1, U_2 \ldots U_5\}$ where U_1 is the percentage of competency level III achieved for learning objective 3, which was demonstrated in both case studies and quizzes.

Table 6: Hypothesis Test data for the two-sample t-test

Statistical Test	Two sample t-test	Mann-Whitney test
Sample size	$n_1 = 5, n_2 = 12$	$n_1 = 5, n_2 = 12$
Hypothesis	$H_0: \mu_U = \mu_T$	$H_0: \eta_U = \eta_T$
	$H_a: \mu_U > \mu_T$	$H_a: \eta_U > \eta_T$
p-value	0.591	0.663

The large p-values indicate that the students did not perform differently in the quiz on the learning objectives covered in the case studies than they did on other learning objectives.

Summarizing the results of the quantitative study, the data suggest that although cohort C performed better on the case studies compared to cohort B, it did not demonstrate higher attainment of the learning objectives on the quizzes. Furthermore, data from the quizzes also suggests that cohort C students did not perform differently in the quiz on the learning objectives covered in the case studies than they did on other learning objectives.

Even though the data questions the impact of the PSS method in increasing the attainment of learning objectives, there could be several reasons behind this. Therefore, looking at the student feedback would be helpful for understanding their perceptions on the delivery and the overall experience (refer to Table 7).

Table 7: Summary of student comments on student experience and delivery

Theme		Cohort B	Cohort C
Delivery	Class structure and material	Students thought that the case study was discouraging because it was a lot of work for a very little amount of credit. Students thought that some materials were not adequate.	Students thought the materials were overall good but challenging, confusing and inadequate at times. They also thought that the class structure is very organized.

Theme		Cohort B	Cohort C
Delivery	Coaching and instructing	Students thought it was helpful to talk with the instructor about new ideas. But most of the students thought that the instructor was not around much to ask questions.	Students appreciated the guidance and the timeliness of responses by the instructor, however thought that they need more time allocated to ask questions.
	Using technology	Students enjoyed working with FactoryCAD and FactoryFLOW software.	Students liked the in-person classes compared to online or hybrid method but thought that given the situation the classes were managed well.
Student Experience	Group learning	Students felt engaged while working with other students to understand case study as well as study materials.	Students appreciated the help given by other team members to learn, discuss and clarify problems. They also thought team members bring in fresh and different perspectives.
	Application of knowledge	Students felt more engaged because they were working on a real scenario that made an impact. They also thought that the real-life application is different from what they learnt.	Students liked the fact that they are applying learnings on a real-world scenario which would help them out when they work in the industry.
	Skill development	Students developed soft skills ranging from problem solving to communication skills.	Students developed skills such as leadership, creativity, problem solving, planning, communication and time management.
	Working on the case study	Students thought the case study was open ended and complex. But some understood this was by design. They were also surprised by the fact that there is no right answer.	Students thought working on the case study was engaging but also said that they were confusing, open ended and a lot of work.

The student comments were focused on the case study experience for both cohorts B and C. Students seem to understand the value of the PSS approach even though they found the case studies too open-ended sometimes. Many students reported development of skills such as leadership, creativity, problem-solving, etc. which suggests that the PSS had an impact on students in developing metacognitive skills. It is interesting to note that the students did not comment about the attainment of learning objectives. From the feedback it also can be seen that the students from cohort C performed better on the case studies due to the experience students received through attempting multiple case studies, changes the instructor made by increasing the time spent on answering student questions and splitting the larger case study reducing the number of deliverables per case study.

Through analyzing all the data, and the observations of the instructor, the following could be identified as reasons for the unanticipated outcome of the quizzes.

In terms of delivery of the class, students of cohort C preferred in-person classes. This suggests that the modifications made for Covid-19 mitigation (e.g., instructor meeting with one-third of the class at a time) could be a potential reason behind the lower performance on the quizzes. Also, due to the pandemic a considerable number of students fell ill during the semester and hence missed important in-class discussions which ultimately impacted quiz performance. This same reason, however, did not impact the outcome of the case studies as much because the students met and worked via online channels.

Another potential reason could be the fact that the quizzes are timed, and the case studies are not. Students can take plenty of time and refer to materials while doing a case study. On the other hand, a timed quiz creates a stressful atmosphere. This significant difference of the environments could play role in the final score for the quizzes.

Case studies were attempted in pairs. This inevitably leads to students sharing workload and students not being exposed to all the learning objectives tested through the case study. Therefore, even though students the final score depicts an achievement of a learning objective, some students may not have the attained the same skills as their partner. Therefore, the case study data very well could be overstating the student achievement levels.

Another probable reason could be that the PSS technique might be most suitable to increase the attainment of certain type of learning objectives. For an example, while doing the case study, the students might not need to remember the procedure for applying direct clustering algorithms in facilities design since they could use notes from class or textbook. But while doing the quiz, the students might not remember this process. However, by doing the case study, the students might have attained the learning objective of identifying situations where the direct clustering algorithm could be applied. Not understanding the exact learning objectives that could and could not be tested using the PSS technique could result in unrealistic expectations of study results.

It is also worth to note that despite of the pandemic, students enjoyed the case studies and thought it was valuable for them to improve their metacognitive skills.

5.0 Conclusion

In conclusion, it was observed that the students did not perform differently in the quizzes on the learning objectives covered in the case studies compared to the learning objectives that were not covered in the case studies. However, the students highly valued the opportunity to work on real world case studies and reported that they developed skills such as leadership, creativity and problem-solving. The authors observe a significant improvement of the students' interest in learning facilities layout planning & design and associated tools and the improvement of metacognitive skills. Thus, the benefit of the PSS approach is demonstrated for this type of engineering concept.

It is also noteworthy that the increase of the number of case studies and the amount of coaching time made a significant improvement in student performance. However, it was also observed that moving to a hybrid approach due to the pandemic likely had a negative impact on the performance. In future deployments of the PSS approach, the instructor should divert back to in-class delivery for better student performance.

Acknowledgements

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