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Research Paper

Problem-based learning: Enhancement of students' learning experience and professional development in a study tour

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Abstract. Stressing the importance of the problem-based learning approach in recent years, The Hong Kong Polytechnic University (PolyU) and Sichuan University (SCU) jointly organized a programme that embedded a short study trip as well as problem-based learning on environmental sciences and green chemistry topics. Twenty-three students participated in this 7-day programme in August 2018. A series of laboratory visits, research seminars, site visits, cultural activities, and discussion sessions helped students to exchange their ideas and apply their academic knowledge in problem-based learning for the assigned projects. In addition to the performance assessment of the projects, the students' learning experiences were evaluated through pre- and post-project questionnaire and open-ended reflective questions. Participants showed significant improvement in all the five desirable aspects – (1) competent profession; (2) creative problem solving; (3) effective communication; (4) education of global citizens; and (5) self-confidence. The overall results indicated highly positive feedback for the integration of problem-based learning into study tours and group projects for better students' learning and holistic development.

Keywords: Problem-based learning, desirable graduate attributes, student exchange, global citizen, learning experience.

INTRODUCTION

Description of the programme

Supported by the Ten Thousand People Scheme, a group of university students from the Department of Civil and Environmental Engineering in PolyU was sponsored to visit the College of Chemistry in SCU in August 2018. Throughout the 7-day study trip, a mix of 11 PolyU students and 12 SCU students participated in a series of cross-disciplinary workshops and cultural exchange activities. Students from both sides worked together in different groups on four pre-designed problem-based learning projects with interdisciplinary research topics on ''Utilization of Agricultural and Food Waste Resources''. The students were requested to share their academic knowledge, explore the techniques used in different disciplines, and evaluate the related industrial processes and safety measures. The student projects were assessed in the form of a group presentation at the end of the programme. Furthermore, the students' learning experiences were assessed to quantify the effectiveness of problem-based learning through the study tour. In addition to the problem-based learning projects, students from both sides were supplemented with various sources of information through technical workshops, site visits, and cultural exchange activities, etc. The problem-based learning programme effectively increased students' participation and enhanced their self-directed learning behaviour.

Alignment with PolyU's strategic plan and university graduate attributes

The problem-based learning approach aligned and

supported the achievement of PolyU's Key Goals set in learning and teaching in the Strategic Plan.

PolyU's Key Goal 1: Provide a supportive and caring learning environment

The academic team of this project comprises expertise from different disciplines of different Departments and Faculties. The diverse background could stimulate new ideas and exchange experiences for providing a supportive and caring learning environment to the students for their comprehensive learning and skill development.

PolyU's Key Goal 2: Provide a curriculum that promotes social responsibility and embeds practical experience

This project fostered students' sense of social responsibility by using problem-based learning to introduce students the real-life problems in our society and other regions. Students have deepened their understanding of the need for sustainable development in society and realize how their respective professions could help fulfill their social needs. The project also promoted a self-directed and reflective learning process among the students. Based on the findings of this project, we could gather interdisciplinary perspectives to integrate problem-based learning for developing students' self-confidence and practical experience in applying their professional knowledge and skills for solving real-life problems and cultivating the passion for community commitment.

PolyU's Key Goal 3: Enrich students' learning experience

The problem-based learning approach in this project enabled the students to experience a mix of learning and teaching approaches including case studies, group discussion, self-learning, presentations, and peer-review, etc. The project emphasized bilateral communication between and instructors and learners, and among learners via interactive activities, thus evolving from the unidirectional information delivery in traditional lectures. The cross-disciplinary nature of this project also allowed educators in different Departments and Faculties to reflect on our own practices and establish new collaboration for enriching students' deep learning in the future.

With the concept of outcome-based education, many universities also stress the importance of professional competence and all-round development of university students. Learning and teaching activities are usually designed to nurture and sharpen desirable graduates' attributes. Four essential graduate attributes are stressed alongside in all academic programmes in PolyU. Each university student is expected to demonstrate the following four attributes, as defined below, upon his or her graduation:

1. Professional competency: Graduates should be able to integrate their academic knowledge into real working practice at the entry-level.
2. Problem solving skill: Graduates should be able to define, critique, and resolve problems in a logical and workable manner.
3. Effective communication skill: Graduates should demonstrate effective communication skills in both daily and working environments.
4. Educated global citizens: Graduates should acknowledge their social responsibilities and engage in services or activities at local and international levels.

RATIONALE FOR PROBLEM-BASED LEARNING

Principles of problem-based learning

Problem-based learning is characterized using real-life and ill-structured scenarios, which are complex and generally have multiple responses as starting materials, in contrast to the typical classroom setting where the teachers simply assign the required readings, deliver the lectures, guide students through a solution for a textbook question. Problem-based learning adapts well-balanced and multi-disciplinary learning approaches, as shown in Figure 1, which can enhance self-directed learning behaviour and deep learning of the students (Higgs, 1988; Jiusto and DiBiasio, 2006). PBL approach vividly illustrates the linkage of students' understanding of academic content and applying their technical knowledge in the real-world setting (Prince and Felder, 2006). Students are expected to identify problems associated with the scenario and use these problems to drive their individual learning processes. Their inquiry and exploration on their own can lead to learning key concepts, principles, content knowledge, and strategies necessary to solve the challenges presented by real-life problems. The teacher's primary role is to support the student inquiry rather than lecturing the contents and providing the solutions. Problem-based learning is recognized as highly appropriate for developing professional competence and a wide range of generic abilities. In particular, problem-based learning fosters the development of deep understanding and higher-order thinking skills of critical thinking, application, and problem-solving, etc. Throughout the process, the students can also learn to make use of different available resources to solve the actual problems at hand. It also provides conditions that are conducive to the development and practice of self-directed learning, while small groups provide conditions for improvements in communication and teamwork skills.

PolyU's initiatives on problem-based learning are to

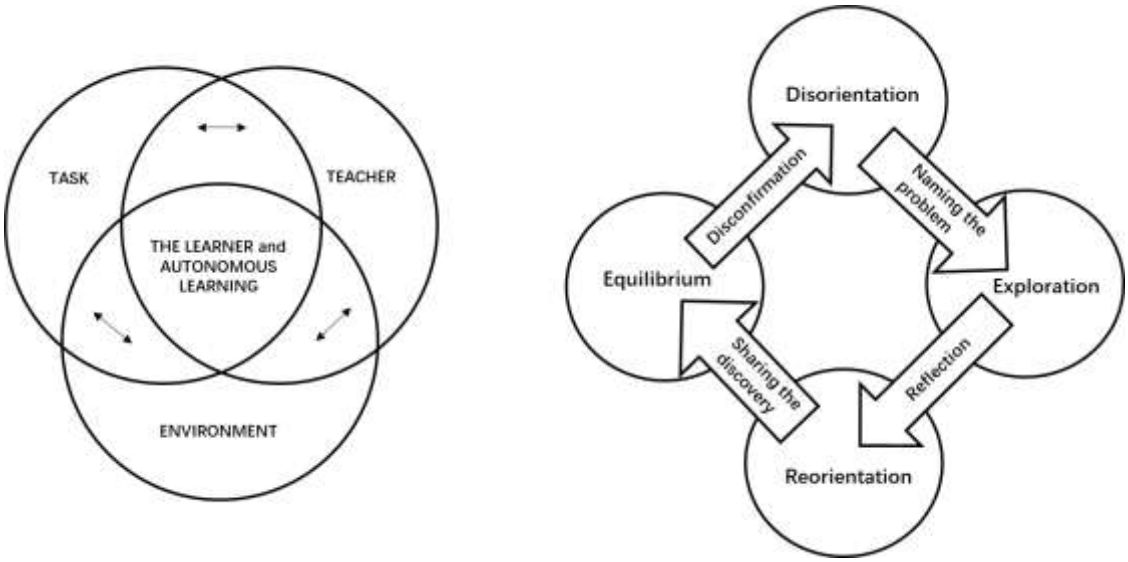

Figure 1. Autonomous learning and self-directed learning (Higgs, 1988).

accomplish the following objectives:

1. Foster idea/experience exchange and collaboration among PolyU's faculty members and students, enabling them to address relevant science, technology and policy issues in university education related to problem-based learning and inductive instructional methods.
2. Foster good teaching and learning practices for providing rigorous and inquiry-based education for PolyU's students to solve complex real-life problems that involve scientific, technological, societal, regulatory, and business issues, etc.
3. Enhance university teaching and students' development with self-directed and reflective learning attitude through the integration of problem-based learning methods at the levels of individual courses and programme curriculum.
4. In the long term, create a significant international and local impact on the promotion of educational research on both discipline-specific and interdisciplinary problem-based learning in Hong Kong and the Greater Bay Area

The initiatives on problem-based learning will contribute to PolyU's education strategy by contributing leadership, energy, and vision to a well-balanced and multi-disciplinary approach in enhancing students' self-directed learning behavior and deep learning approach (Higgs, 1988). This approach will strengthen and fulfill PolyU's commitment to high-quality teaching, foster existing strengths and passions, enhance cooperation among PolyU's teachers and colleagues, and improve current teaching practices to tackle new challenges in the study and learning environment of PolyU students. Through this approach, we will raise awareness among PolyU teachers the importance and skills in problem-based learning, explore and discuss innovative and practical ways for more and more teachers (Objective 1) to engage students in the lectures through problems that vividly illustrate the linkage from understanding the key concepts, principles, theories, to internalizing and applying in the real-world setting. To facilitate a multidisciplinary emphasis, the initiatives stress member's collaboration on PolyU teachers' experience sharing and thought stimulation on PolyU students' education in solving some of the world's "wicked" problems (Objective 2) – for example, climate change mitigation and adaptation, smart city, urban planning, food system imbalances, social and economic inequality, technology or governance innovations, etc. Therefore, PolyU teachers who are new and curious to know about problem-based learning will be in a better position to develop students' sense of mission in coursework and inductive learning attitude, as illustrated in Table 1 (Prince and Felder, 2006). This project aims to foster students' engagement by active learning via a problem-based learning approach in different subjects and programmes in multiple disciplines across PolyU (Objective 3). The interactive activities and real-life practices will increase the chances of communication and collaboration between PolyU's teachers and colleagues, and also demonstrate the solid function of different professions in the community. The initiatives will promote across PolyU a good understanding of problem-based learning in multiple disciplines as a means of development for students into self-directed and life-long learners (Jiusto and DiBiasio, 2006), and lead collaborative and interdisciplinary teaching research projects on problem-based learning in Hong Kong and the Greater Bay Area in the long term (Objective 4).

Integration of problem-based learning projects

Previous educational research studies have shown the importance of engineering education and problem-based

Table 1. Common methods for promoting inductive learning (Prince and Felder, 2006).

Feature ↓ Method →	Guided Inquiry	Problem-based	Project-based	Case-based	Discovery	Just-in-Time
Questions or problems provide context for learning	**1**	2	2	2	2	2
Complex, ill-structured, open-ended real-world problems provide context for learning	4	**1**	3	2	4	4
Major projects provide context for learning	4	4	**1**	3	4	4
Case studies provide context for learning	4	4	4	**1**	4	4
Students discover course content for themselves	2	2	2	3	**1**	2
Students complete and submit conceptual exercises electronically; instructor adjusts lessons according to their responses	4	4	4	4	4	**1**
Primarily self-directed learning	4	3	3	3	2	4
Active learning	2	2	2	2	2	2
Collaborative/cooperative (team-based) learning	4	3	3	4	4	4

Note: 1–by definition, 2–always, 3–usually, 4–possibly

learning in the curriculum (Bull *et al.*, 2009; Jiusto and DiBiasio, 2006). The problem-based learning approach can be effective for students to be self-motivated and learn by themselves to address climate change, global overpopulation, agriculture and water resources, and health-related environmental and social issues. The programme of this study tour covered a range of students' activities and assessment components to evaluate the effectiveness of students' learning experiences. In particular, six learning outcomes, namely (1) problem characterization, (2) problem understanding, (3) information search and review, (4) development of understanding, (5) evaluating criteria and constraints, and (6) decision making, were addressed in the project-based learning projects with reference to previous studies (Downey *et al*., 2006; Marshall and Harron, 2018).

RESEARCH METHOD

Problem-based learning projects

With the consideration of different students' academic backgrounds in PolyU and SCU as well as the intended learning outcomes of this study tour, problem-based projects related to ''Utilization of Agricultural and Food Waste Resources'' were designed as a cross-disciplinary, real-life topic for the students' group projects. About one-third of food production is going to wastage globally and around 1.3 billion tonnes of food wastes are produced each year (Gustavsson *et al*., 2011). There is an increasing need for sustainable biomass waste treatment methods. The problem-based learning projects were designed to motivate the PolyU and SCU students to join hands and exchange different subject knowledge to resolve non-sustainable agricultural and food waste disposal problems. Their group projects should develop practical solutions to mitigate significant greenhouse gas emissions and preserve scarce land resources in the local context. Students from both sides were engaged in problem-based learning and knowledge exchange for self-directed research on state-of-the-art biomass waste treatment. Considering the students' academic interests and study background, students formed groups and reviewed the technologies for the utilization of agricultural and food waste as renewable resources. In addition to reviewing the international practices, the associated safety and health risks were critically assessed for various biomass waste treatment options. Every project group was asked to present the project findings as per the given sub-topics at the end of the programme. The project performance was then evaluated by the assessment rubric as shown in Table 2.

Questionnaire survey

Pre- and post-project questionnaire surveys were

Table 2. Assessment rubrics of group presentations and reports.

	Criteria	%	Description
Technical Content	Introduction	5	Identify the problems Explain the project objectives
	Application of the Engineering Knowledge	25	Identify and apply relevant engineering knowledge to address the problems Explain the feasibility of the adopted approach
	Evaluation of Proposed Engineering Solutions	25	Evaluate the proposed solutions Compare the feasibility and effectiveness of different solutions
	Conclusion	10	Summarise key findings Provide conclusions and recommendations
Organisation and Presentation	Coherence	15	Structure contents in a logical manner and maintain consistency throughout the presentation
	Presentation and Language	20	Deliver ideas clearly and manage time properly Quote up-to-date and relevant references
	Total	100	

designed to assess students' experiences in terms of students' graduation attributes and self-rating of the problem-based learning. Based on the graduate attributes at the undergraduate level and intended learning outcomes of the study tour, the questionnaire was divided into two parts with 20 questions in total. The first four sections involved 14 questions for the assessment of graduate attributes: (1) competent professionals, (2) creative problem solvers, (3) effective communicators, and (4) educated global citizens. Six questions were set to assess their self-confidence for (1) identifying the problems; (2) understanding the problems; (3) seeking relevant and useful information; (4) developing the necessary understanding; (5) evaluating criteria and constraints; and (6) making decisions and evidence-based recommendations. All 20 questions adopted a Likert scale score ranging from 1 (strongly disagree) to 10 (strongly agree). Each student was asked to rate all questions before and after the programme.

Mid-programme reflection

Open-end reflective questions were set to supplement the quantitative findings from the questionnaire survey. Each student was asked to complete seven reflective questions for the reflection of their learning experiences as well as personal development halfway through the programme. In terms of learning experiences, students were asked to specifically comment upon their project experiences. In terms of personal development, students were asked to think of their challenges and ways to overcome them.

RESULTS AND DISCUSSION

Attainment of intended learning outcomes

All students were divided into four groups, with a mix of both PolyU and SCU students. Each group was asked to work on one of the four research directions – sugar conversion (Group A), biomass conversion and utilisation (Group B), bio-oil preparation (Group C) and green catalytic synthesis (Group D). All four groups of students reviewed the current practices, investigated the feasibility of industrial practices, and discussed the future research plan as per the given topic. Each group summed up their review findings into a specific plan for applicable industrial practices and implications of future research in a 30-minute presentation at the end of the study trip. Each presentation was followed with a short question and answer (Q&A) session by peer students and teachers from both sides. Students were asked to apply their critical thinking skills before reaching mutual consent of responses. Each group was given comments from teachers and then assessed with reference to the rubric as shown in Table 2. The overall feedback from the students and teachers was positive and constructive. With the collaborative efforts from PolyU and SCU students, all groups demonstrated a good understanding of the given

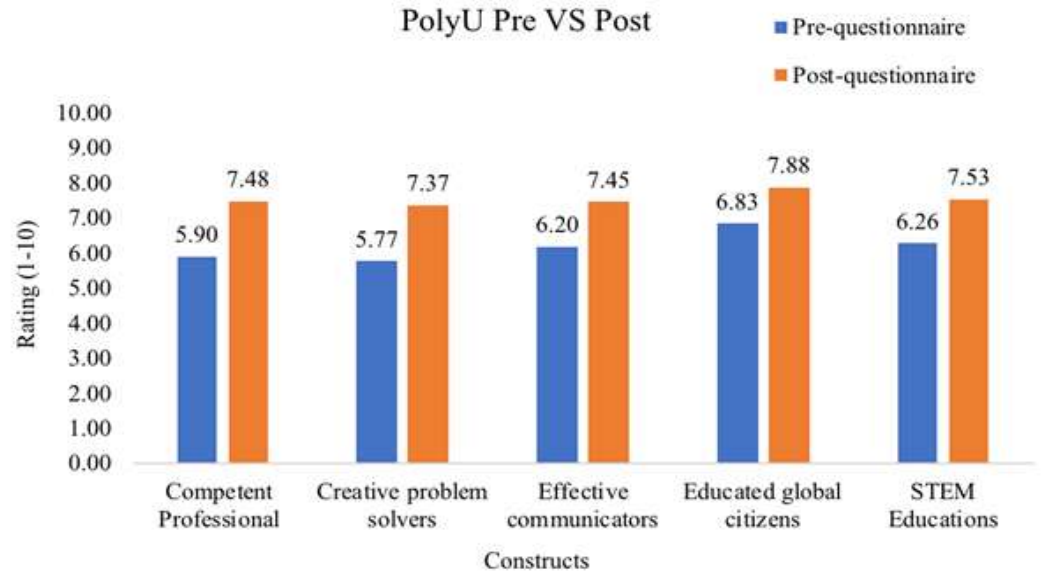

Figure 2. Comparison of scores before and after the study trip of the PolyU students

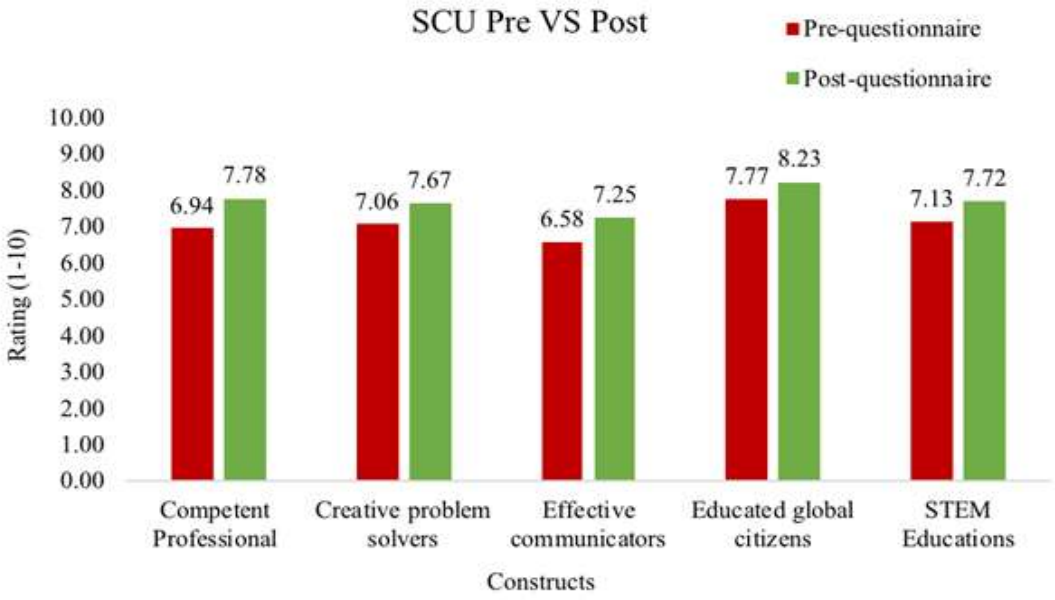

Figure 3. Comparison of scores before and after the study trip of the SCU students.

topics, they were able to apply their academic knowledge when discussing and proposing feasible solutions for the identified problems.

Comparison of students' desirable attributes before and after the study trip

In addition to the assessed project presentations, students were asked to assess their learning achievements. Figures 2 and 3 show the average scores rated by PolyU and SCU students, respectively. Overall, the learning experiences for both PolyU and SCU students were highly encouraging and positive. Each project objective showed an increase in the average mean score in the corresponding questions. The PolyU students showed a range of scores from 5.77 to 6.83 and improved to a range from 7.37 to 7.88 for all constructs. Before the trip, their corresponding scores as "competent professionals" and "creative problem solvers" were 5.90 and 5.77, respectively. This implied that the

Table 3. Agreement levels of the students' attributes and learning objectives.

Constructs	Question no.	Mean score differences between pre- and post-questionnaire	
		PolyU	SCU
Competent Professionals	Q1-5	1.58 ↑	0.84 ↑
Creative problem solvers	Q6-8	1.60 ↑	0.61↑
Effective communicators	Q9-10	1.25 ↑	0.67 ↑
Educated global citizens	Q11-14	1.05 ↑	0.35 ↑
Self-confidence	Q15-20	1.26 ↑	0.59 ↑

* ↑ represents an increase of rating

PolyU students demonstrated a strong agreement for their improvement in professionalism and creativity for problem-solving. Both scores were significantly improved after the trip. This also highlighted the learning achievement of the problem-based learning programme. In comparison, the SCU students showed relatively strong agreement levels of all constructs before and after the trip. The scores ranged from 6.58 to 7.77 before the trip and then improved to a range from 7.25 to 8.23 after the trip.

Table 3 shows the differences in mean scores of the five measured constructs. By comparison, PolyU showed a greater improvement after the programme in all the assessed aspects. This highlighted the successful knowledge exchange and inductive learning. The SCU students showed high confidence levels before this programme and displayed relatively moderate improvement of learning objectives. The average scores of PolyU increased significantly after the programme. The learning objectives for "competent professionals" and "creative problem solvers" were considerably improved by 1.58 and 1.60, respectively. Similar to PolyU students, the SCU students also considered it as the most improved area. They showed a better understanding of fundamental knowledge and better capability in applying the skills in real-life problems and integrating fundamental knowledge and skills required for functioning effectively in practice. For the area of creative problem solving, the PolyU students showed improved creativity to tackle problems by enhancing their ability to define problems, critique the relevant information, and come up with novel ideas and approaches.

Self-reflection – During the programme

Both PolyU students (P1-P11) and SCU students (S1-S12) were asked to reflect upon their experiences during the programme. The collected qualitative results were analyzed separately for comparison. For the learning experiences of the PolyU students, all of them agreed that the experiences at this programme reinforced their academic knowledge. Respondents P1 - P3 and P8 pinpointed the difference between their professional background and expertise. They pointed out that they had learnt much chemical knowledge in this problem-based project from the SCU students. Moreover, Respondents P2, P3, P9 and P10 agreed that the experiences enforced their understanding of laboratory safety, which was seldom considered during regular courses in the academic curriculum. It was useful for them to broaden their horizon and application of occupational safety across different industries.

As a whole, they all agreed that it was a good opportunity for them to compare safety practices and legislation in Hong Kong and China, which developed their flexibility in applying knowledge to different contexts under different systems. Most of the students faced a similar problem, which was the language barrier. In particular, respondent P2 brought up that there was a misunderstanding when they tried to exchange opinions, and the discussion was not as smooth as expected. Another common problem was the lack of chemical knowledge compared to the SCU students. Respondents P1 - P4, P6 - P8 and P10 highlighted the challenges during discussion across different disciplines. They would attempt to ask more questions to deepen their understanding of those unfamiliar issues, which showed a desirable and positive learning attitude. Overall, they found themselves anxious when facing stressful situations in ill-defined real-life problems.

Both PolyU students and SCU students agreed that the programme reinforced their respective academic knowledge in different disciplines. In particular, Respondents S1, S2, S6, S9 and S10 highlighted the differences in the academic focuses of PolyU and SCU students. PolyU students primarily focused on occupational safety and relevant legislative practices while SCU students focused on scientific innovation and fundamental reaction mechanisms. Respondent S7 commented that the PolyU students were more open-minded and dynamic by comparison to themselves at SCU. Also, Respondents S11 and S12 agreed on generally good English communication skills that the PolyU students possessed. Respondent S6 pinpointed that they had learned to combine theory and practice through collaboration with the PolyU students.

In general, the SCU students agreed that PolyU students were interested in the cross-disciplinary projects and

engaged in problem-based learning activities to foster their understanding of scientific research, local and international affairs, and different perspectives. They had faced similar challenges as PolyU students during the programme, which was due to different understanding of the professional knowledge, language use, and social norm and culture. It should be noted that they all managed to overcome such barriers by fostering more communication within groups and self-directed learning from related journals and literature. Nevertheless, they also found themselves anxious or even depressed when facing stressful situations of wicked problems in group projects.

CONCLUSIONS

PolyU and SCU jointly organized a programme that embedded a problem-based learning study trip with interdisciplinary projects on environmental sciences. The programme enabled students to experience a mix of learning and teaching approaches including technical workshops, site visits, group discussion, self-directed learning, presentation and peer review, etc. The student projects were assessed in groups as per the pre-designed assessment rubrics. All student groups were able to achieve the learning objectives by clearly defining the problems and applying relevant engineering/scientific knowledge for developing practical solutions. Moreover, the students' learning experiences were examined through pre- and post-questionnaire and open-ended reflective questions. The results indicated that the students' desirable attributes and self-confidence were effectively enhanced through this self-directed problem-based learning approach, especially for those who had comparatively lower starting scores. This fostered the students' sense of social responsibility by using problem-based learning to bring students to confront the complex and real-life problems in different cities with different cultures. Therefore, similar problem-based learning programmes are recommended to enrich students' inductive learning and all-round development inside and outside the academic curriculum. Students would develop a better understanding of the need for sustainable development in society and appreciate how their respective professions can help fulfil diverse societal needs.

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