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Problem-based learning approach in accomplishing innovation and entrepreneurship of civil engineering undergraduates*

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A distinct feature of the civil engineering undergraduate study of Hong Kong Polytechnic University is a major assessment exercise in the form of a problem-based learning (PBL) group project. With the imminent implementation of an outcome-based accreditation assessment by the Hong Kong Institution of Engineers, student performance on this project can become a significant indicator of learning outcomes. This final year group project can be viewed as the culminating learning experience of the engineering program and the quality of student output can be used as an indicator of the quality of the program as a whole. In this paper, the approach and attitude to the layout, management and assessment of this engineering project are presented. The experience gained in the operation of the project is shared. The evaluation by its key stakeholders, which are students, preceptors and employers, is also highlighted. The results authenticated that this PBL approach could accomplish innovation and entrepreneurship of civil engineering undergraduates.

INTRODUCTION

IN HONG KONG, quality assurance procedures of professional engineering qualification have been monitored by the Hong Kong Institution of Engineers (HKIE) since 1997. It has conducted accreditation visits to institutions offering engineering programs every five years. The recent shift of HKIE from content-based to outcomes-based accreditation process allows educational institutions in Hong Kong to have greater flexibility of program curriculum design. However, they need to put in extra efforts to assess and demonstrate that their graduates have achieved a set of learning outcomes established for the specific discipline by HKIE. Moreover, generic skills comprising innovation, business, entrepreneurship, communication, problem-solving and the ability to work successfully in teams are important. Engineering programs have to incorporate exercises that furnish development of these skills and assessment procedures that fairly reward achievement in these areas.

A distinct feature of the civil engineering undergraduate study of Hong Kong Polytechnic University is a major assessment exercise in the form of a problem-based learning (PBL) group project. Student performance on this final year group project, which is viewed as the culminating learning experience of the engineering program, can become a significant indicator of learning outcomes.

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Problem-based learning (PBL) approach

The aim of a PBL approach is to provide students with the opportunity to develop learning skills and attitudes that would equip students with the skills to become more effective students as well as independent lifelong learners. A PBL approach normally incorporates three categories of learning: cognitive; skills; and, attitudes. It helps enhance students' critical thinking and allows them to have opportunities to function more effectively in discussion and group work. Moreover, they are directed to develop attitudes on taking responsibility for their learning. This innovation is anticipated to empower students in their learning and personal development. In a PBL approach, students are in the core of the system and take the initiative in their learning.

The pedagogical system is designed such that students have to learn on their own, and teaching is a matter of facilitating students' learning. Students' assessment is by performance in tutorials and coursework instead of by examinations. Contrary to a traditional lecture-based method, minimum or even no lectures will be arranged under a PBL approach. Instead, the emphasis is placed on:

- syllabus design;
- problem or case writing;
- tutorial;
- group discussion;
- assessment.

A case is designed for a small group of students to solve. Students are expected to identify and fulfill their own learning objectives, through gleaning knowledge with all available resources from the library or the Internet. Woods [6, 7] suggested several tasks for students to work through during the process:

- explore the problem;
- create hypotheses;
- identify issues;
- formulate a trial solution;
- identify the requisite knowledge;
- prioritize the learning needs;
- allocate resources;
- identify tasks of team members;
- search for knowledge;
- share the new knowledge;
- formulate an updated solution;
- give feedback on effectiveness;
- reflect on the process.

PBL has been employed in a variety of subject areas, particularly in the medical field [1, 5].

During the past few years, there is a substantial amount of research and educational efforts in PBL in the engineering domain. Feland and Leifer [3] summarized a method for volatility measurement as an assessment instrument for design team performance prediction within the PBL environment. Cockayne *et al.* [2], delineated the development of the classification and its application in a comprehensive problem-based learning program. Fruchter and Lewis [4] addressed the Architecture/ Engineering/ Construction (A/E/C) industry's need to broaden the competence of engineering students to utilize the acquired theoretical knowledge and understand the role of discipline-specific knowledge in a multi-disciplinary A/E/C (PBL)-B-5 learning environment. Zolin *et al.* [8] presented key characteristics of a problem-based learning environment that determines its suitability as a data source for work-related research studies. It is worthwhile to share the experience how PBL works as a group project in an engineering domain.

PROJECT DEFINITION AND CONTENT

The key objective of this group project is to develop the undergraduates to be competent and innovative in taking the role of a civil engineer in the implementation of engineering infrastructures. It is tailored to assess professional readiness and to demonstrate the ability to independently conduct a project and to effectively communicate the business process and results in a professional written form. The project is defined in close consultation with industry and thus has as unstated objectives the professional apprenticing of students to a particular industrial working environment for development on entrepreneurship.

Students are trained to develop a sense of business discipline, which includes adherence to deadline, statutory requirements, to name a few. They are allowed opportunities to acquire skills in problem-solving and decision-making during the business process. It enables students to combine their theoretical and analytical skills and their practical appreciation in an operational and entrepreneur sense. Such skills, supported by a developing practical appreciation, are applied to the process and the solution of practical engineering problems, which often entail extensive knowledge from various disciplines such as financial auditing, cost engineering, architecture, building services, electrical and mechanical services, quantity surveying, fire engineering, structural engineering, geotechnical engineering, logistics, urban planning, landscape architecture, etc. Whilst the students are acquiring experience and analytical ability towards rationalization of alternatives in a real-life multi-disciplinary construction project, they can demonstrate creativity and innovation at the same time by generating new ideas into the conventional building practice. Furthermore, they can develop the communication skill with others in a clear and concise manner.

Students are required to participate in the formulation of a conceptual solution to a large scale civil engineering problem, appraisal of the feasible schemes, detailing of the selected scheme, setting up of a business organization, financial planning, cost estimation, tendering and business involvement amongst different parties. For example, a direct connection or highway bypass in the form of a flyover or tunnel is required to join two separated places via an area where the underground conditions are extremely poor and site access is very limited. Students may be required to examine the technical feasibility and compare the cost of various proposed elevated road crossing or tunneling schemes and implement the selected bridge or tunnel structure including foundations and associated earthworks. Students would also consider the construction techniques, the scheduling and business management of the construction phase of the project, and costs. It requires the complete implementation of a civil engineering scheme, with individual students concentrating on different major components of the overall scheme after a conceptual solution has been worked out by the student group as a whole.

TEACHING AND LEARNING APPROACH

In order to mimic the real business process as far as practicable, support from the industry is sought. The supervising team for each type of project comprises two industrial supervisors and two academic staff. The visiting lecturers, who are experienced practicing civil engineers currently working in government authorities, consultant firms or contractors, can contribute to formulate projects that are based on real engineering problems and bring in up-to-date practical engineering and business knowledge. It fosters students' responsibility at work by learning from practicing professional engineers. The project lasts for one semester and the number of contact hours is 42. This creates a better atmosphere for them to acquire business experience and knowledge and lessens the pressure due to limited allocated time to finish the project.

The whole class is divided into a number of teams, each of which consists of a maximum of five students. The purpose is to foster team spirit and coordination with members. Each team can have a choice to select a project from few types of civil engineering project. The team is required to produce a sound proposal and scheme to satisfy the requirements and constraints as set out in the project brief.

The project is broadly divided into four stages:

- feasibility study and scheme appraisal;
- formulation of plan and procedures;
- implementation of the selected scheme;
- report preparation.

Since it is not easy to have long term commitment from senior professional engineers for the whole semester, the schedule is designed delicately considering this factor. Table 1 shows the schedule of project activities. A project briefing, a site visit, consultation sessions, discussion sessions, presentations, and feedback of the projects are arranged. The briefing session is used to introduce to the students the objectives, requirements, operation and assessment method of the course. Moreover, the details of the site, the client's requirements, business procedures and supplementary information of the project are also furnished in this first meeting. A site visit helps enhancing students' insight and appreciation on real-life construction technologies.

In general, students are expected to spend three hours a week on group discussion and consultations with their supervisors. Several consultation sessions, which provide communication among the supervisors and students, are arranged so that students' progress would be duly monitored to ensure that the requisite depth of knowledge has been searched. They are on single group basis to stimulate project activities. Students can raise any questions related to the project whilst the supervisors can assess the individual performance of team members.

Each team is provided with various project offices for group discussion, general drawing work and other pertinent activities. The students are required to conduct two presentations: presentation on scheming in week 5; and presentation on entire project in week 13. In the presentations, questions are raised from the supervisors or other students about the proposed project and business arrangement. Two feedback sessions are arranged after the presentations so that errors committed by students could be rectified during the project period and constructive comments are made.

The arrangement mimics a working team relationship similar to that in the industry. In the inception of the project, the team is required to apportion their workloads among team members and distinguish explicitly the individual responsibility of each team member. A duty roster indicating the activities preformed and the students who carried out the works against each activity should be submitted to the supervisors after week 2. During the feasibility study and scheme appraisal stage, two alternative schemes appropriate to the given brief and site conditions (geotechnical and environmental) shall be formulated. Careful appraisal of the alternatives will then be carried out and the most suitable option selected. The alternative schemes are compared and appraised in terms of their suitability to satisfy the required function, feasibility in construction, economy, construction program, construction material and safety.

Only simple calculations with sound estimation are required in the report on initial scheming. This report is limited to 20 single-sided A4 sheets whilst attached drawings are limited to 5 A3 sheets. The final report shall contain the appraisal of alternative schemes, implementation details, construction method statement, bills of quantities for cost estimation, tendering documents, business

Table 1. Schedule of project activities

Week no.	Duration (hours)	Project activities		Remarks
1	3	Project briefing		
2	3	Consultation 0.5 hr	Discussion 2.5 hr	Submission of duty roster
3	3	Consultation 0.5 hr	Discussion 2.5 hr	
4	3	Site visit		
5	3	Oral presentation on scheming		Report on scheming
6	3	Feedback on scheming		
7	3	Consultation 0.5 hr	Discussion 2.5 hr	
8	3	Consultation 0.5 hr	Discussion 2.5 hr	
9	3	Consultation 0.5 hr	Discussion 2.5 hr	
10	3	Group discussion		
11	3	Consultation 0.5 hr	Discussion 2.5 hr	
12	3	Group discussion		
13	3	Oral presentation on entire project		Final project report
14	3	Feedback on final report		

arrangement, and construction drawings. This report is limited to 50 single-sided A4 sheets whilst attached drawings are limited to 5 A1 sheets. The portion of works for each member should be explicitly indicated. The duty roster showing the distribution of works within the team has also to be enclosed.

ASSESSMENT METHOD

The assessment, which is 100% coursework without any examination, is based upon group effort as well as individual contribution. Students are continuously assessed both summatively and formatively using a range of methods throughout the entire semester. The level of application, the feasibility and merit of the chosen solution, the completeness and rigor of associated detailing, the business organization, the costing implication, the quality and clarity of submitted drawings and both oral and written presentations are considered. Since group work is included, assessment is focused on both the product and the process. Individual performance should be differentiated from the group performance. A mechanism is employed for allocating marks to individuals based on the group work product and on student ability to work in groups.

Table 2 shows the marking distribution for various assessment components. The written reports account for half of the total marks whilst the combination of consultations and oral presentations takes the remaining half. Amongst the two written reports, the final report is slightly more important and hence deserves a relatively higher weighting than the written report on scheming, with a ratio of 3 to 2. The apportionment of weighting for individual contribution and group effect in the written reports is about 2 to 1. Since there are altogether six consultations, during which performance of individual student can be closely monitored, 5% is allocated to each consultation and the ratio of weighting between individual contribution and group effort is 5 to 1. For the two oral presentations, each with 10% of total mark, group interaction plays a more important role and hence the weighting between individual contribution and group effort is more balanced with a ratio of 3 to 2.

EVALUATION OF GROUP PROJECT

Evaluation of the group project includes student feedback questionnaire, supervisors' comments and employer surveys. A questionnaire has been completed by a total 232 students at the end of the group project for years 2001 and 2002. The questionnaire explored student perceptions about learning effectiveness of the group project as well as about effect of various factors including motivation, cohesion, interaction, and elaboration on team productivity. Table 3 shows the summarized results of the student feedback questionnaire survey. The results confirmed the learning effectiveness and the effect of motivational and cognitive factors on team productivity in PBL approach. Moreover, it was authenticated that the open-ended problem-solving approach facilitated students to seek out their own references in constructivist ways and to explore solutions innovatively.

Supervisors' comments were mainly used to streamline the whole process during the operation of the group project. In fact, many modifications have been implemented arising from experience gleaned in order to enhance fairness of the assessment and effectiveness of the exercise. They include re-scheduling of the site visit from week 7 to week 4, adjustments on the relative proportion of individual performance and group effort in the final assessment, the degree of involvement of practicing engineers from the industry, etc.

The evaluation of the employers cannot be overestimated because they are the ones who ultimately employ the graduates. The employer surveys can serve as a good chance for the institution to better understand its competitive position through benchmarking from the other academic peers. There are in total three universities in Hong Kong which currently offer civil engineering degree programs. It must be admitted that, owing to various reasons including history or scale of institution, the student entry standards of the peer departments in the other two universities are on average higher. However, the employer surveys in the past few years in general revealed that the graduates from the other two universities were more theoretical whilst our graduates had advantages in two distinct aspects: wider horizons; and, more innovative. Whilst it is difficult to objectively assess student horizons and/or innovativeness, it is

Table 2. Marking distribution for various assessment components

	Individual contribution (%)	Group effort (%)	Total (%)
Performance during consultations	25	5	30
Oral presentation on scheming	6	4	10
Oral presentation on entire project	6	4	10
Written report on scheming	13	7	20
Final written group project report	20	10	30
Total	70	30	100

Table 3. Results of the student feedback questionnaire survey at the end of the group project

Year Number of students	2001 119	2002 113
Learning t hrough the PBL approach was interesting.	3.9	3.9
Students could actively control the information flow, with highly initiative to pursue knowledge.	4.2	4.0
This rendered a positive change on students' learning attitude.	3.9	4.1
This allowed students to bring up learning issues to the supervisors, more for stimulation and confirmation purposes instead of getting an answer.	3.6	3.8
This allowed more interactions between supervisors and students.	4.1	4.0
This allowed more interactions amongst students in the team.	4.3	4.2
This trained students to acquire the ability to solve problems and being able to work independently and maturely.	3.7	3.9
The open-ended problem-solving approach authenticated students to solicit their own references in constructivist ways.	3.9	4.1
The approach allows students to explore solutions innovatively.	4.0	3.9
The consultation sessions were very helpful in furnishing direction onto the right track.	4.3	4.2
Students were more comfortable to ask questions in small-grouped consultation sessions than in large-sized classroom.	3.7	3.8
The feedback on initial scheming facilitated timely and effective means of furnishing feedback to students.	4.0	4.1
The content material was relevant to the future professional development.	3.9	3.8
The course workload was reasonable.	3.3	3.5
Motivation had significant effect on team productivity.	4.3	4.2
Cohesion had significant effect on team productivity.	4.2	4.1
Interaction had significant effect on team productivity.	4.0	3.8
Elaboration had significant effect on team productivity.	3.8	4.0
The overall learning effectiveness of the group project was higher than that of traditional lectures.	3.9	4.1

* 1 = Strongly Disagree, 2 = Disagree, 3 = Neutral, 4 = Agree, 5 = Strongly Agree.

believed that the wider exposure to business environments might stimulate students to generate more useful and practical ideas. Since the curriculum of these two peer departments are similar to that of ours except with the absence of this group project, its contribution and significance is apparent.

CONCLUSIONS

With the imminent implementation of an outcome-based accreditation assessment by the professional institution, student performance on the final year group project can become a significant indicator of learning outcomes. This group project is a complex performance-based assessment event which can have a major influence on decisions about a student's readiness to graduate and on the perceptions of the quality of an engineering program. A PBL approach for this project was proved to be an effective way of learning in providing an opportunity for the undergraduates to tackle a real engineering problem and in appreciating broader conceptual stages of engineering and business practice. Moreover, supervision inputs from practicing engineers to this group project are valuable in transitioning innovation best practices from industry to academia.

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