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Project Based Learning with Implementation Planning for Student Engagement in BIM Classes*

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The Architecture, Construction, Engineering and Operation (ACEO) industries are in urgent need for students with the capabilities to successfully implement BIM projects with sound strategies. Educators notice that project-based learning (PBL) can help students to understand the practice and challenges of the industries. But few researches paid attention to implement the PBL approach that could cultivate the expected BIM competences using capstone and real-world projects. In order to respond the problem, this research proposes a process framework of BIM project execution planning (BIM-PEP) for capstone with the integration of PBL and real world project information, The BIM-PEP includes steps of implementation and team roles, learning schedule, response collection and evaluation criteria. This research uses case studies to collect data for the group and instructions responses of the framework implementation. The results indicate that the students are able to conduct the chosen BIM uses according to process mapping in the early phases of PBL following the procedure of BIM-PEP. The responses also show the strengths of BIM management and technology and point out the possible improvements such as flexible capstone schedule and early preparation. This research provides a novel method of process framework and a case study for BIM-PEP capstone, which embodies the knowledge body of BIM education and PBL pedagogy to enhance student competences of engineering education. It provides a sound foundation for the instruction of BIM education in university teaching.

Keywords: project based learning; BIM project execution plan; construction and engineering management; capstone; student engagement

1. Introduction

Project planning is important in the Architecture, Construction, Engineering, and Operation (ACEO) industries [1, 2]. To incorporate project planning and student-centered education in ACEO majors, project based learning (PBL) provides a solid foundation to target student competencies. In the ACEO industries, the successful implementation of Building Information Modeling (BIM) in project relies on detailed and comprehensive planning [3, 4]. Thus BIM education should include the contents of detailed design and documentation as well as project planning and execution throughout a facility's lifecycle. It is popular to develop, integrate and conduct BIM curriculum in the corresponding capstone courses. For example, Pennsylvania State University, Auburn University, and National University of Singapore have BIM capstone in their ACEO education programs [5–7]. They offer training on the BIM skills, cost estimation, 3D modelling, 4D modelling, energy analysis, etc. [8–10] Educators and researchers paid attention on the cultivation of interdisciplinary teamwork including collaboration among civil engineering, architecture, construction management student members [11]. However, there are insufficient studies paying attention on the combination of BIM project planning and BIM capstone with the application of PBL. The relevant research on teaching BIM capstone should focus on how to train students' competences of BIM management, process mapping and technology skills within the framework of project execution planning and guidance [12].

This research aims to design a process framework of BIM project execution planning (BIM-PEP) for capstone with the integration of PBL and real world project information. This research uses the PBL process chart as the organization flowchart for BIM-PEP capstone [13, 14]. The following steps are critical for research design of the process framework. (1) Set the climate to assign the roles and make/review ground rules. (2) Read the project problems to clarify key facts and terms. (3) Define the heart of the stated problems. (4) Collect learning responses collection. (5) Evaluate the outcome of PBL in BIM-PEP [14].

The contribution of this research is that it innovatively designed a PEP method for teaching and learning complex and comprehensive topics using PBL in engineering education. With the growing complexities in learning projects, especially in the courses of capstone, engineering students may be overwhelmed by the magnitude and frequency of

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project information and even fail to complete the requirements [15]. This research paper elucidates on the details of PEP techniques and uses in the improvement of student engagement in capstone. This paper analyzes the dimensions of project complexity and the way in which the complexities can be removed using PEP and PBL. A key finding of the research is that when using PEP to monitor and control capstone projects, instructors and students should pay attention to teamwork, group rules and process mapping. The project size largely influences its complexity, which in turn increases uncertainties in teaching and learning [16]. The PEP and PBL method can help different learning segments such as IT, manufacturing, logistics and installation [2, 17]. Considering the number of businesses today in the market, managing complex projects is an essential part of engineering and management skills [13, 14].

This research sheds light on the theoretical process-framework and provides practical operation details for the BIM-PEP capstone with PBL. The results show that students obtained the capabilities of BIM execution planning for academic performance and industry practice. One contribution of this research is that students get a chance to practice on solving problems that may arise at any time when managing projects. Project teams should design detailed execution plans and overview the planning processes to prepare for challenges in engineering management. For people in the ACEO industries, the process and technology discussed in this paper help to ensure the utmost benefit of BIM implementation in the early phase of projects. For educators, this research calls the attention to both PBL approach and PEP guidelines to match the industrial planning strategies in education. This research innovatively integrates the application of PBL to student engagement in learning and problem solving. This research strengthens the interdisciplinary integration between university-based and work-based knowledge, promotes student competences, skills and abilities through PBL and team based learning.

2. Literature review

2.1 Project based learning in engineering education

Project based learning (PBL) is developed from problem based learning model and considered as an innovative way to promote education and learning throughout society [15–17]. Comparing to problem based learning, PBL asks students to learn about a certain subject by working for an extended period of time, during which they explore and answer to complex questions, challenges, or problems. PBL has the features of real-world information, problem-centered and student-centered [13, 14, 18, 19]. The emphasis of PBL is that learning should focus on specific and complex tasks and problems, encourage students to learn independently, be with reflective processes, and develop students' comprehensive thinking abilities [14]. Now PBL has been widely used in education, engineering, architecture, business, law, economics, management science, mathematics, natural sciences, agronomy, and sociology disciplines [20–30].

Currently, PBL related education articles mainly focus on the development of basic theories, reform of education modes, and pedagogical designs [30, 31]. Regardless of the adoption forms of PBL in teaching practice, its core concept lies in the following four aspects [32]. (1) The learning method is problem-oriented and project-based. It helps students to acquire knowledge, learn problem-solving skills, and self-construct knowledge through reflection. (2) The learning contents include multidisciplinary knowledge to solve specific problems. (3) Its learning form emphasizes on problem-solve abilities and knowledge sharing through cooperation, information exchange, and group work. Group work cultivates students' abilities of organization, self-management and collaboration. (4) PBL is student-centered learning. Students choose their own topics, set up goals, and engage in study as independent thinkers and learners.

2.2 BIM education with application of BIM project execution planning

The goal of BIM Project Execution Planning (BIM-PEP) is to stimulate planning and direct communication for project teams during early phases of projects [12]. BIM-PEP provides a practical manual for project teams to design their project strategies. The procedure of BIM-PEP guide includes the following steps: (1) Identify BIM demands with high values during project planning, design, construction and operational phases; (2) Design BIM-PEP by creating process maps; (3) Define deliverables in the form of information exchanges; (4) Develop contracts, communication procedures, and quality control to support the implementation [8, 12, 33–37]. The applications of BIM-PEP are mainly in engineering, applied sciences, architecture and computer science areas. There is deficiency in BIM-PEP applications in engineering education. The education practice indicates that there is an urgent need for the discussion on BIM-PEP capstone in ACEO, particularly for the application of PBL approach in the course.

To successfully implement BIM, a project team must perform detailed and comprehensive planning [12]. A well-documented BIM-PEP will ensure that all parties are clearly aware of the opportunities and responsibilities associated with the incorporation of BIM into the project workflow. A complete BIM-PEP should define the appropriate uses of BIM on a project (e.g., design authoring, design review, and 3D coordination), along with the process for BIM management throughout a facility's lifecycle. Once the plan is created, the team can follow and monitor their progress against this plan to gain the maximum benefits from BIM implementation.

2.3 Gap in knowledge

PBL pedagogy is effective for cultivating the student-centered learning and competences in engineering education [38]. The implementation of PEP deals with the learning difficulties of a complex matter which requires the mastery of theoretical knowledge and certain specialized technology, such as software tools [1, 2, 8]. Other applications of PEP include environmental sustainability and the optimization of return on economic investments [6]. With this highly valuable practice for companies and society in general, there is gap-in-knowledge on how the understanding of PEP can contribute to the best learning of difficult and complex contents in engineering fields, such as graduation capstone or professional learning projects [1–4]. This will be highly interesting for educators and researchers with attentiveness in engineering education of comprehensive and practical issues. Additionally, few researches focused on the implementation of PBL in BIM education. The ACEO industries need the training of BIM project execution planning (BIM-PEP) urgently [12, 39] . The curriculum design discussed in this paper can help to implement the PEP with PBL approach in BIM capstone and provide both theoretical procedures and practical case implication.

3. Methodology

This explorative research uses the process chart of PBL and BIM-PEP as the foundation to guide the curriculum design of an engineering capstone. The implementation of BIM-PEP with PBL includes the following 9 steps. The first step is to set team climate, which includes (a) assign the roles; (b) review ground rules; and (c) review thinking and learning processes. The second step is to read the project problems, which includes clarification of key facts and terms and connection of the problem to students' own experiences. The third step is to define the heart of the problem and ask the question: What are the initial ideas? The fourth step is the brainstorm of ideas/explanations to find responses to the problems and examples from students' own experiences. The fifth step is to discuss and synthesize the problems and interpret the problems. The sixth step is to identify learning contents, which include a list of things that need to study further. The seventh step is to perform an independent study and prepare to discuss at the next PBL session. The eighth step is to collect learning responses. The ninth step is to evaluate the outcomes of BIM-PEP with PBL.

The participants of the study include the instructor and 4 undergraduate students in civil engineering and construction management majors. After the definition of the research question, the research continues with literature review on PBL, BIM and PEP. It also collects real world project data for case studies. All the participants attended the aforementioned 9-step framework and performed level 1 and 2 mapping processes. To verify the curriculum design, the research gathers data through questionnaire survey on group response and instruction response. The results provide insights and reflections for future adjustment.

Table 1 shows the evaluation criteria of the learning outcomes of the BIM-PEP capstone. The following items are the key aspects of student work: (1) Students should form a group of 4 people and identify project goals. (2) A BIM project should be in the early planning stages. (3) The implementation of BIM should be for multiple uses and span across the planning, design, construction and/or operational phases. (4) Team cooperation and information sharing are critical to successfully development of the BIM-PEP. (5) Students need to obtain the approval of the course instructor of their projects prior to proceeding with Submittal 2 listed in Table 1.

4. Case study

The goal for developing this structured procedure of BIM-PEP with PBL in capstone is to stimulate planning and direct communication among student teams during the early phases of a project. To successfully implement BIM management strategies, a project team must perform detailed and comprehensive planning. Following the structured procedure of BIM-PEP guide, after a team identifies the areas of BIM uses, the next step is to design the BIM-PEP by creating a process flowchart. Once the flowchart is created, the team can follow the execution plan and monitor their project progress against this plan to gain the maximum benefits from BIM implementation.

In this building project, there are 1 basement and 3 floors above ground. It includes a framed and raft-based structure for an irregular shape of the building. The designed service life of the building is for 50 years, with seismic fortification intensity of 8 degrees. The total construction area is 3607.77 m^2. The proposed site is generally high in the north and west corners and low in the south and east corners. The geomorphic unit in the site is Grade I terrace on the east bank of Fenhe River, which indicates that the strata near the river bed are mainly sand beds, with clay and silty clay.

4.1 Preparation

The preparation of the capstone includes setting team climate, understanding project problems, and definition of initial ideas. The student teams should be formed early in the class, with students acting as

Table 1. Evaluation criteria of the outcome of PBL-based BIM-PEP

<table>
<tr><th>ID</th><th>Item & %</th><th>T</th><th>Learning Objectives, Activities and Evaluations</th></tr>
<tr><td>1</td><td>Submittal 1 (10%)</td><td>Week 1</td><td>
Assignment: Project Background
Learning Objectives: After complete this module, students should be able to:
1. Select a project in the initial planning stage and plan to implement BIM through the project lifecycle.
2. Collect background information, summarize the planned BIM uses, and write project contacts.
Activities:
1. Complete BIM Project Execution Plan Cover Page (10 points)
2. Complete BIM Project Execution Plan Overview (10 points)
3. Complete Project Information (60 points)
4. Complete Key Project Contacts (20 points)
Evaluation: Total of 100 points
<table>
<tr><th>Activity</th><th>0 Error</th><th>1 Error</th><th>2 Errors</th><th>3 Errors</th><th>4 Errors</th><th>5 and More Errors</th><th>No Work Shown</th></tr>
<tr><td>1</td><td>10</td><td>9</td><td>8</td><td>7</td><td>6</td><td>5</td><td>0</td></tr>
<tr><td>2</td><td>10</td><td>9</td><td>8</td><td>7</td><td>6</td><td>5</td><td>0</td></tr>
<tr><td>3</td><td>60</td><td>58</td><td>56</td><td>54</td><td>52</td><td>50</td><td>0</td></tr>
<tr><td>4</td><td>20</td><td>18</td><td>16</td><td>14</td><td>12</td><td>10</td><td>0</td></tr>
<tr><td>Total</td><td>100</td><td>94</td><td>88</td><td>82</td><td>76</td><td>70</td><td>0</td></tr>
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</td></tr>
<tr><td>2</td><td>Submittal 2 (20%)</td><td>Weeks 2-3</td><td>
BIM Goals, Uses, and Processes
Learning Objectives: After complete this module, students should be able to:
1. Arrange meetings with the project team members to establish BIM goals for the project.
2. Based upon the goals, they determine recommendations for implementation based upon the team's goals and record the recommendations with the BIM Use Planning Template.
3. Develop an overview process map of the BIM Uses through the facility lifecycle.
Activities:
1. Updated Submittal 1 based on feedback and new information gained (10 points)
2. Complete Project Goals / BIM Uses (20 points)
3. Complete Organizational Roles / Staffing (20 points)
4. Complete Process Maps (See the example in Fig. 2) (150 points)
Evaluation: Total of 200 points
<table>
<tr><th>Activity</th><th>0 Error</th><th>1 Error</th><th>2 Errors</th><th>3 Errors</th><th>4 Errors</th><th>5 and More Errors</th><th>No Work Shown</th></tr>
<tr><td>1</td><td>10</td><td>9</td><td>8</td><td>7</td><td>6</td><td>5</td><td>0</td></tr>
<tr><td>2</td><td>20</td><td>18</td><td>16</td><td>14</td><td>12</td><td>10</td><td>0</td></tr>
<tr><td>3</td><td>20</td><td>18</td><td>16</td><td>14</td><td>12</td><td>10</td><td>0</td></tr>
<tr><td>4</td><td>150</td><td>145</td><td>120</td><td>105</td><td>90</td><td>75</td><td>0</td></tr>
<tr><td>Total</td><td>200</td><td>190</td><td>160</td><td>140</td><td>120</td><td>100</td><td>0</td></tr>
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</td></tr>
<tr><td>3</td><td>Consultation (10%)</td><td>Weeks 4-5</td><td>
Progress Review Meeting
Learning Objectives: After complete this module, students should be able to:
1. Schedule a 30-minute meeting with the course instructor to review their progress to date.
2. Prepare to discuss the information contained within the first two submittals, along with the information that they plan to include in Information Exchanges and Infrastructure submittal (Submittal 3).
Activities:
1. Attend the meeting on time and be prepared (10 points)
2. Be active in discussion (90 points)
Evaluation: Total of 100 points
<table>
<tr><th>Activity</th><th>Excellent</th><th>Good</th><th>Average</th><th>Fair</th><th>Poor</th><th>No Work Shown</th></tr>
<tr><td>1</td><td>10</td><td>9</td><td>8</td><td>7</td><td>6</td><td>0</td></tr>
<tr><td>2</td><td>90</td><td>80</td><td>70</td><td>60</td><td>50</td><td>0</td></tr>
<tr><td>Total</td><td>100</td><td>89</td><td>78</td><td>67</td><td>56</td><td>0</td></tr>
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Table 1. (*Continued*)

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<td>4</td>
<td>Submittal 3 (20%)</td>
<td>Weeks 6-7</td>
<td>
Information Exchanges and Infrastructure
Learning Objectives: After complete this module, students should be able to:
1. Document the information-exchange needs for the BIM Uses selected in the previous step.
2. Document the infrastructure needs of the project.
3. Share the entire BIM Project Execution Plan with the project team for their feedback.
Activities:
1. Complete updates based on feedback and new information gained (20 points)
2. Complete Process Maps (20 points)
3. BIM Information Exchanges (at least 2 examples of information exchanges (1 per group member)) (20 points)
4. BIM and Facility Data (20 points)
5. Collaboration Procedures (20 points)
6. Quality Control (20 points)
7. Technological Infrastructure Needs (20 points)
8. Model Structure (20 points)
9. Project Deliverables (20 points)
10. Delivery Strategy / Contract (20 points)
Evaluation: Total of 200 points
<table>
<tr><td>Activity</td><td>0 Error</td><td>1 Error</td><td>2 Errors</td><td>3 Errors</td><td>4 Errors</td><td>5 and More Errors</td><td>No Work Shown</td></tr>
<tr><td>1</td><td>20</td><td>18</td><td>16</td><td>14</td><td>12</td><td>10</td><td>0</td></tr>
<tr><td>2</td><td>20</td><td>18</td><td>16</td><td>14</td><td>12</td><td>10</td><td>0</td></tr>
<tr><td>3</td><td>20</td><td>18</td><td>16</td><td>14</td><td>12</td><td>10</td><td>0</td></tr>
<tr><td>4</td><td>20</td><td>18</td><td>16</td><td>14</td><td>12</td><td>10</td><td>0</td></tr>
<tr><td>5</td><td>20</td><td>18</td><td>16</td><td>14</td><td>12</td><td>10</td><td>0</td></tr>
<tr><td>6</td><td>20</td><td>18</td><td>16</td><td>14</td><td>12</td><td>10</td><td>0</td></tr>
<tr><td>7</td><td>20</td><td>18</td><td>16</td><td>14</td><td>12</td><td>10</td><td>0</td></tr>
<tr><td>8</td><td>20</td><td>18</td><td>16</td><td>14</td><td>12</td><td>10</td><td>0</td></tr>
<tr><td>9</td><td>20</td><td>18</td><td>16</td><td>14</td><td>12</td><td>10</td><td>0</td></tr>
<tr><td>10</td><td>20</td><td>18</td><td>16</td><td>14</td><td>12</td><td>10</td><td>0</td></tr>
<tr><td>Total</td><td>200</td><td>180</td><td>160</td><td>140</td><td>120</td><td>100</td><td>0</td></tr>
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<td>5</td>
<td>Presentation (20%)</td>
<td>Week 8</td>
<td>
Procedure of Project Execution Planning
Learning Objectives: After complete this module, students should be able to:
1. Create a presentation that discusses each of the major areas of the BIM PEP Procedure.
2. Explain the decision making process for each part of the procedure and feedback.
3. Present to the instructor (time duration should be between 10 to 12 minutes).
Activities:
1. Complete and submit the PowerPoint presentation file. (100 points)
2. Present the work. (100 points)
Evaluation: Total of 200 points
<table>
<tr><td>Activity</td><td>Excellent</td><td>Good</td><td>Average</td><td>Fair</td><td>Poor</td><td>No Work Shown</td></tr>
<tr><td>1</td><td>100</td><td>90</td><td>80</td><td>70</td><td>60</td><td>0</td></tr>
<tr><td>2</td><td>100</td><td>90</td><td>80</td><td>70</td><td>60</td><td>0</td></tr>
<tr><td>Total</td><td>200</td><td>180</td><td>160</td><td>140</td><td>120</td><td>0</td></tr>
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<tr>
<td>6</td>
<td>Submittal 4 (20%)</td>
<td>Week 9</td>
<td>
Final Project Execution Plan
Learning Objectives: After complete this module, students should be able to:
1. Create documents.
2. Integrate information.
Activities:
1. Complete the final submittal of BIM Project Execution Plan, which should be updated based on the feedback received during the presentation. (50 points)
2. Summarize the process used to create the execution plan (including challenges, lessons learned and suggestions for improvement) and the feedback received from the project team. (50 points)
3. Complete a brief document (2 – 3 pages) that defines the process used to develop the BIM Project Execution Plan along with the core lessons learned. (100 points)
Evaluation: Total of 200 points
<table>
<tr><td>Activity</td><td>0 Error</td><td>1 Error</td><td>2 Errors</td><td>3 Errors</td><td>4 Errors</td><td>5 and More Errors</td><td>No Work Shown</td></tr>
<tr><td>1</td><td>50</td><td>45</td><td>40</td><td>35</td><td>30</td><td>25</td><td>0</td></tr>
<tr><td>2</td><td>50</td><td>45</td><td>40</td><td>35</td><td>30</td><td>25</td><td>0</td></tr>
<tr><td>3</td><td>100</td><td>90</td><td>80</td><td>70</td><td>60</td><td>50</td><td>0</td></tr>
<tr><td>Total</td><td>200</td><td>180</td><td>160</td><td>140</td><td>120</td><td>100</td><td>0</td></tr>
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technicians and supervisor engineers to identify BIM uses. Based on the career readiness and willingness of students, this research chose to implement the BIM-PEP from a contractor's perspective. There were 4 members in a student team, who were from Chang'an University (China). All the students were in civil engineering and construction management majors. The students learned primary skills of 3D modelling and site layout in previous training. The mentor and team members discussed and identified 10 BIM application goals (shown in Fig. 1) in the first meeting.

After the establishment of application goals, the team developed a detailed BIM implementation process and an agreement of individual responsibilities based on the identified goals. Each selected BIM application goal had a specific team member in charge. Meanwhile, there were class tutors as BIM managers to check the quality of the deliverables.

The students used problem statements to describe how to conduct the BIM project and follow the procedure of BIM-PEP to finish the real world project. The students visited the actual engineering structure and listened to the presentation of the construction process. During the visit, the students experienced the steel banding process, measured the heights of the floors, and visualized the construction sequence of the walls, slabs and columns in the frame structure.

4.2 Communication

The communication of the capstone includes brainstorm, discussion and synthesis, and identification of learning contents. The instructor required the students to choose the uses of BIM based on their work intentions, technology constraints, and the 9-week time limitation of the capstone. The brainstorm process includes the following steps: (a) Students identify the playing roles of different parties in the construction project so students can take the associated responsibilities. (b) Students make meeting schedules to discuss how to solve the learning problems related to BIM software operation and process mapping. (c) Students make task plans for BIM uses. (d) Students identify team leaders to manage daily learning activities, direct the teams to follow the task plans, and record learning problems. (f) Instructor answers questions weekly. (g) Instructor maintains learning schedule to make sure the high quality of BIM-PEP capstone. (h) Students search for information from the university library, on Internet, and from cloud-based learning resource.

Figure 1 shows the specific learning schedule of the BIM-PEP capstone. The discussion and information synthesis in the class should follow the schedule. For example, the students used Luban® field fabric software on a 1:1 scale basis to convert an AutoCAD® overall plan of the project building. They needed to find the locations of temporary buildings, the road traffic around the jobsite, the storage of various materials, and the locations of processing sheds and tower cranes. In Weeks 3-5 of the class, the students started simulation and collision detection using BIM technology to achieve the goal of dynamic site layout.

Through group discussions, the students expressed their opinions of the main project goals, as listed below. (a) Define the overall goals of BIM implementation and information exchange process. (b) Clarify the potential values of BIM to the project and team members. (c) Define the knowledge and skills of 10 BIM uses as shown in Fig. 1. (d) Design an information exchange worksheet in the early stages of the project. (f) Capture effective learning resources and share with the team. For team colla-

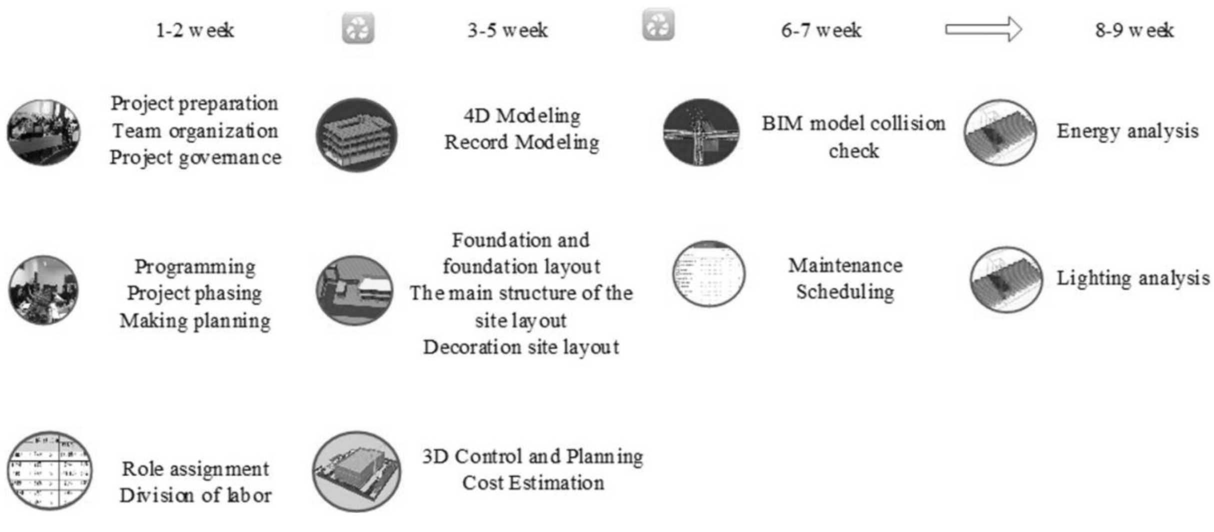

Fig. 1. Learning Schedule.

boration, they divided the parts of the process that needed to work together from the ones that do not necessarily require collaboration. An example of the collaboration tasks is the discussion of general project objectives. The individual tasks include defining the required file structure and defining detailed information exchange standards. The key to a successful project execution is to ensure that meetings are scheduled properly. In the BIM-PEP capstone, student teams had 9 meetings, which are shown in Table 2, which also shows the learning contents identified by the students.

4.3 Implementation

In the learning process, individual students performed independent studies to understand related knowledge. In the BIM-PEP capstone, the instructor held face-to-face meetings on a regular basis which are two hours each week. Students must attend one meeting per week.

In order to understand the students' BIM experiences and the status of virtual classroom discussions, this research adopts the Baasanjav U. [40] questionnaires to investigate the impact of the learning schedules on the BIM-PEP capstone. The

Table 2. Nine meetings for the planning of PBL-based BIM-PEP capstone

Topic	**Week**	**Procedures**	**Expected outcome**
Determine BIM goals and BIM Use	1	• Introduce and discuss the current application of BIM. • Develop BIM Objectives (Refer to BIM Target Template Document). • Identify which BIM applications (refer to the BIM application worksheet). • Develop priorities and implementation sequences for BIM applications and discuss development of a BIM overview flowchart. • Identify responsible parties for each BIM application to develop a detailed BIM application flow chart, a two-stage flow chart. • Develop a project management system to ensure that the plan is followed. • Determine the supervision procedure of BIM project implementation plan. • The corresponding practical/transferable skills of BIM Uses. • The corresponding BIM knowledge.	Determine BIM goals and BIM Use. The first meeting should focus on the overall objectives of the project and identify BIM applications. After the initial meeting, the project team should identify who is responsible for what specific tasks and in what order the BIM application is being executed. The responsible party of the level 1 process mapping should be clearly documented and distributed to the project team for review before the next meeting. Each responsible party that has designated a BIM application should also draft its workflow prior to designing a BIM project implementation process meeting (meeting 2) so that it can be discussed at the meeting.
Design BIM project implementation process	2	• Check the initial BIM target and purpose. • Overview a BIM level 1 process mapping. • View more detailed workflows from all parties and identify overlapping parts of various modeling tasks. • Determine the main exchange of information in the process. • Identify the person in charge of coordinating the exchange of information. • Allow each clearing-house team to coordinate potential ad hoc meetings as needed to discuss information exchange requirements. • The corresponding practical/transferable skills of BIM Uses. • The corresponding BIM knowledge.	Design BIM project implementation process. The project-specific BIM application process map should contain a detailed process plan that clearly defines what information to perform at each step, who performs it, and what the process creates and shares later.
Conduct information exchange and identify supporting infrastructure for BIM implementation	3	• Overview a BIM level 1 process mapping. • Review Initial BIM Goals and BIM Use to Ensure Project Planning Aligns with Initial Goals. • Review the information exchange requirements previously established. • Identify the infrastructure needed to support processes and information exchange. • The corresponding practical/transferable skills of BIM Uses. • The corresponding BIM knowledge.	Before the meeting 3, Team members should be well prepared: After designing a BIM project implementation process meeting, the team must focus on communicating information. Each responsible party should take the lead in developing the exchange of information. The author of the exchange of information needs to coordinate with the recipient of the information to discuss it at the third meeting. Team members should also prepare their discussions on infrastructure needs at the third meeting. Team members should work out the software and hardware they use or want to use in the project to share with the team.

Table 2. (*Continued*)

Screen the draft of BIM project implementation plan draft	4	• Screen the overview/detailed BIM process mapping. • The corresponding practical/transferable skills of BIM Uses. • The corresponding BIM knowledge. • Reporting the process of BIM Uses. • Allow each clearing-house team to coordinate potential ad hoc meetings as needed to discuss information exchange requirements.	Before the meeting 4, Categories and information should be compiled into the final BIM implementation plan format and distributed to the project team to prepare the final plan review meeting. Once the meeting is completed, the BIM project implementation plan should be assigned to each responsible party. Team members should ensure that program monitoring and program implementation updates are synchronized to the project control system.
Information exchange and practical skills of BIM Uses (4 times)	5–8	• Surface the overview process mapping. • View more detailed workflows from all parties and identify overlapping parts of various modeling tasks. • Determine the main exchange of information in the process. • Reporting the process of BIM Uses. • Allow each clearing-house team to coordinate potential ad hoc meetings as needed to discuss information exchange requirements. • The corresponding practical/transferable skills of BIM Uses. • The corresponding BIM knowledge.	Team members should ensure that program monitoring and program implementation updates are synchronized to the project control system.
Finish BIM-PEP and prepare presentation	9	• Complete BIM Project Execution Plan updated based on feedback. • Brief document (2–3 pages) that defines the process used to develop the BIM Project Execution Plan along with the core lessons learned. • Also include feedback from the project team either as a section in your document, or as an appendix if they provided written feedback.	Team together prepared the final completed BIM-PEP and updated based on the feedback received during the presentation.

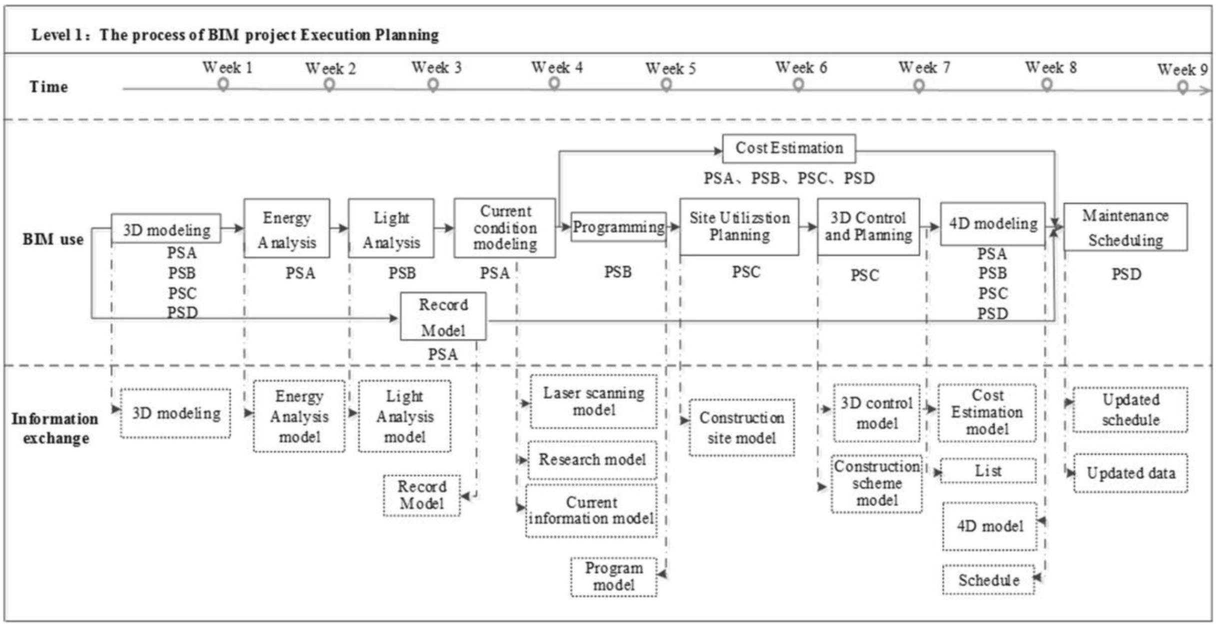

Fig. 2. Level 1 process mapping in the BIM-PEP capstone.

questionnaire includes multiple-choice and short-answer questions. Table 3 is the course evaluation and student responses.

4.4 BIM mapping process

For the identified BIM uses in Table 1, the process mapping includes 2 levels as shown in Figs. 2 and 3.

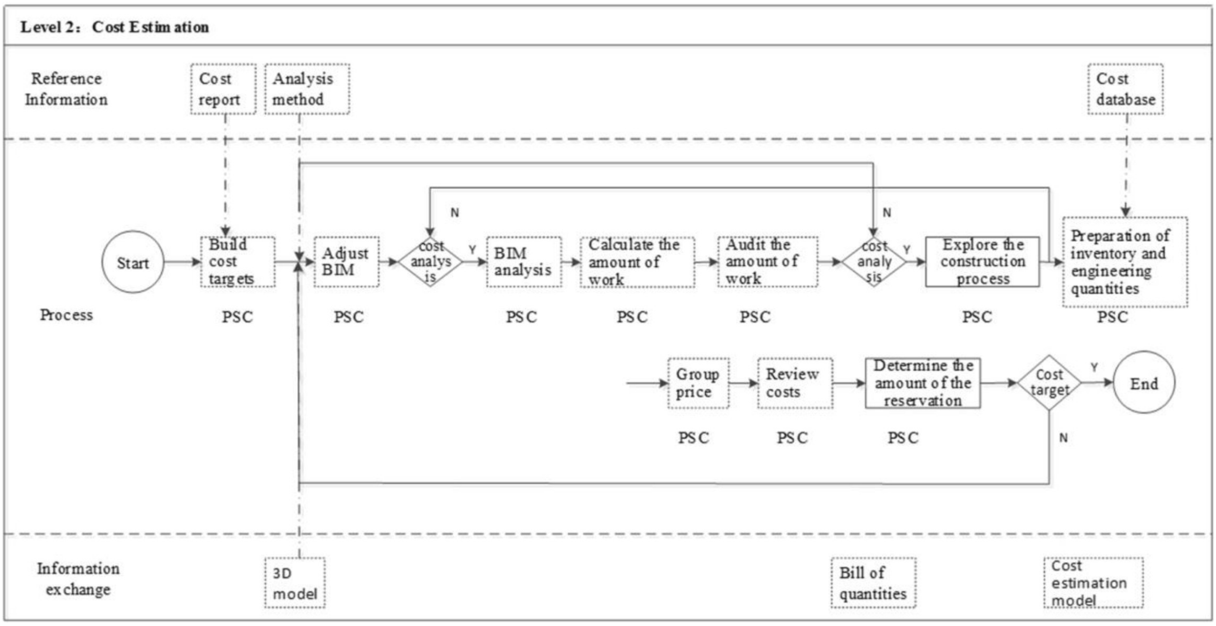

Fig. 3. Level 2 process mapping of Cost Estimation.

Table 3. Course evaluation and student responses

Question	**1–2 week**	**3–4 week**	**5–7 week**	**8–9 week**
1. How much experience do you have in BIM-PEP capstone with PBL approach?				
A. Very much	10%	25%	50%	90%
B. Much	30%	30%	28%	10%
C. Not necessarily	30%	22%	10%	0
D. Llittle	20%	15%	10%	0
E. Very little	10%	8%	2%	0
2. How competence improvement in BIM-PEP capstone with PBL approach?				
A. Very much	15%	20%	40%	70%
B. Much	25%	30%	25%	20%
C. Not necessarily	30%	25%	20%	5%
D. Little	20%	15%	10%	5%
E. Very little	10%	10%	5%	0
3. For what purposes do you participate in BIM-PEP capstone with PBL approach? (select multiple options)				
A. Help for study and work	10%	25%	50%	80%
B. Communicating using BIM	25%	30%	20%	10%
C. Creativity and self-affirmation	25%	20%	20%	5%
D. Acquire good scores	30%	15%	10%	5%
E. Gain BIM skill	10%	10%	0%	0
F. Others	10%	25%	50%	80%

Figure 2 shows the Level 1 Process Mapping, which is the flowchart of information exchanges in the 9 weeks of the BIM-PEP capstone. There are multiple flowcharts to identify important BIM implementation goals, including contractual structure, BIM deliverables, and information technology infrastructure. Figure 3 is an example of Level 2 process mapping of cost estimate in the BIM-PEP capstone. The timeline in Fig. 2 matches with the topic arrangements in Tables 1 and 2. Using the task of cost estimation as an example, Figure 3 shows that each individual student in a project group is responsible for the unique scope of work and how the work is connected between them. The students created these process mapping diagrams and discussed the planning and execution details with the instructor. The group response in this research also a strong correlation between "creativity and self-affirmation" and "PEP experience".

5. Response

5.1 Group response

Table 3 shows that students gained competence through the learning in the BIM-PEP capstone. According to the following analyses on student responses, 80% of students agreed that the PEP helped them to study and work; 10% agreed that PEP helped them to communicating using BIM. The students agreed that PBL was helpful. They participated in the capstone mainly for the purpose to help their work and study in future. Their expectations also included learning software skills, facilitate creativity, and self-affirmation through communication. The written suggestions collected from the students summarize 3 critical areas of PBL: teamwork, group rules, and process mapping.

Teamwork should be ensured with a well-organized and timely division of labor and timely preparation with student engagement. For example, a student experienced a late start of the project. The learning time was not sufficient and the process was hasty. All students enjoy the learning experience of BIM-PEP capstone with PBL. This capstone was experimented in fall 2016 semester. Students further captured the software skills in the following winter break. With this teamwork experience, students had flexible time to conduct the work without hurriedly rushing through the learning schedule. Working in groups, students gain confidence on quality management of project deliverables.

Working in groups, students need to understand and have consensus of group rules. In this study, students agreed that they must be familiar with modeling rules and follow standardized procedures. For example, after completing the reinforcement and civil engineering parts of the modeling, students used cloud functions of BIM system to check the rationality of modeling. After the model was initially completed and checked, one group found several hundred mistakes. In this case, the group members met together to discuss on the responsibilities of revisions or corrections. They checked and made corrections on the component properties. The group also decided to combine both the automatic error-checking functions of the BIM system and manual inspections. Another example is mistake detection with collaboration. There were windows and doors on the project drawings without details because of negligence or omission. The group found that the software couldn't check out these mistakes. So it is critical to have group collaboration for quality assurance.

Process mapping plays an important role in this BIM-PEP capstone. Students should make records, screenshots, etc. to effectively avoid rework in the process and to find related materials when writing reports. For example, students used Luban Plan® software for construction scheduling, bar charts, and output schedules. They failed to use it to convert schedules to time-scale network diagram. For process mapping purpose, they started with hand-drawn charts and a time-scale network as shown in Figs. 2 and 3. Then they entered the network into the schedules. Both the instructor and students use PEP to guide the capstone process, schedule class activities, arrange resource, evaluate the completeness of work, and assess the quality, performance, and result of learning. Furthermore, the creation of PEP does not require professional knowledge. Instructors can encourage students to list the activities to complete a scope of work and arrange the order of the tasks.

5.2 Instruction response

For teachers, the PBL approach is a natural development of student abilities to learn in an open environment. In the steps of this PBL approach, the instructor guided the student-centered learning with a clear operational process, which is the BIM-PEP. The instructor intentionally created problem situations based on the real world project, and organized and participated in student discussions. The instructor encouraged students to ask questions, for the purpose to facilitate student learning and thinking when creating BIM models. The following observations summarize the teaching experience of the class to encourage student engagement, which are (1) to inspire student thinking by conversations and asking questions; (2) to pay attention to individual differences; and (3) to pay attention to student feedback.

It is important for an instructor to accurately grasp the timing and content of a learning issue. The authors observed that having conversations with students could help to find the best breakthrough point of thinking and inspire student's spark of wisdom. In the capstone, the instructor asked questions with appropriate depths of difficulties and breadths of contents. The grading measures (as shown in Table 1) should be appropriate to trigger positive thinking.

Instructors should pay attention to individual differences of students. The ways and means to inspire thinking vary from person to person. Instructors should follow the thinking progresses of students to understand them. In the capstone, the authors observed that the students developed their thinking progresses from concrete to abstract, individual to general, and simple to complex. Individualized and student-centered learning can make the thinking activities rhythmic and logical. In the capstone, the instructor paid attention to student feedback and made corresponding task adjustments promptly. Teachers should make timely and accurate evaluation of student feedback to strengthen student thinking progresses and arouse their engagement in problem solving.

6. Conclusions

The process framework and case analysis of this research provide a pilot study to apply the PBL approach in BIM-PEP capstone to improve student engagement in planning, execution and management in ACEO. This research discusses the education research of student-centered, undergraduate engineering education using PBL. It integrates knowledge of PEP into curriculum design in higher education. The study adopts process charts as the framework to explore curriculum design. For PBL, the study emphasizes on using real world project information as a learning context. Particularly, the characteristics of the capstone include: (a) definitions different learning objectives based on student's job interest, knowledge and skills, and time constraints; (b) group meeting schedule; (c) individualization in learning progresses; and (d) dynamic evaluation of learning outcomes. In order to evaluate the outcomes, this research develops a questionnaire to investigate student learning progresses and engagement. The research also uses interviews to further analyze student engagement. The results show that in general students are in favor of the curriculum design. Nevertheless, future teaching should pay attention to the preparation of background knowledge. Students agreed that practical cognitive process mapping on information exchange was very helpful in the learning process. Furthermore, the instructor invited industry experts as judges of the student projects and used the proposed grading criteria, process mapping, schematic overview, modeling demonstration, and presentations to evaluate the learning outcomes of the class. The instructor and industry experts together gave highly remarks on the competence displayed by planning, technology implementation and management with the BIM-PEP guidelines. The active team cooperation and co-creation to reach beyond teaching expectations left the judges with deep impression.

The theoretical contribution of this research is to stimulate the adoption of PEP in PBL to explore and deepen student-centered curriculum development. The curriculum framework proposed in this research responds to the urgent demand of BIM planning capabilities from the ACEO industries. The limitation of the research is the number of sample groups. It is restricted by the limited number of students in the class. In future research, the authors would participate presentations, share the experience to peer educators, and get more comparison results. It is for the first time that BIM, PEP, and PBL are integrated into undergraduate education of engineering management. It is a new attempt to encourage student participation in learning processes.

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