

A Cooperative Learning Model Combines between PBL and CDIO

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Abstract

This paper proposes a novel learning model to connect two models of engineering education reform, Conceive–Design–Implement–Operate (CDIO), and Project-Based Learning (PBL). CDIO and PBL have formed two learning communities which are different in definitions, curriculum design, engineering projects, relation to disciplines, and change strategy. An effective learning model that combines them indicates specifically what the communities can exchange from each other. We experimentally deployed on the Google Sheets a novel cooperative learning-model called PCA which combines PBL method, CDIO syllabus, and Agile team organization. Analysis results of feedback from 746 students in the large classes showed that, with less time on the classes, the novel model outperforms the traditional one in the percentage of students who acquire benefits and learning outcomes. This learning model can effectively deploy a CDIO syllabus by the PBL learning method for the Agile project environment.

Keywords: Cooperative learning, project-based learning, CDIO, agile team organization

1. Introduction

From 10 initial schools, in 2014 the CDIO Initiative celebrating its 10th anniversary has been adopted by over 100 schools within aerospace, applied physics, electrical engineering and mechanical engineering (www.cdio.org). As such, after 10 years, the number of schools that deploys this educational framework has increased more than 10 times. CDIO is the name of a framework for educating engineers, formed at the Massachusetts Institute of Technology in the United States in the 1990s. It stands for Conceive, Design, Implement, and Operate, which correspond to the four major phases of a developmental process ranging from products such as mechanical machines, electrical devices, or software to services such as automobile repair, graphical design, audit, or tour guide. CDIO was formed while American education was influenced by an educational reformer John Dewey, with his famous philosophy "Education is not preparation for life, education is life itself" [1, 2]. As the cornerstone of CDIO, CDIO Syllabus offers rational, complete, universal, and generalizable goals for undergraduate engineering education. For widespread deployment, CDIO syllabus 2.0 has been localized into Chinese, French, Russian, Spanish, and Vietnamese (www.cdio.org). However, the effectiveness of learning models that combine learning method and CDIO syllabus is often a controversial issue in a university, and comparisons are often considered between CDIO and the others, especially Project-Based Learning [3].

Project-Based Learning (PBL) was conceived in the 1960s and 1970s with various versions such as Problem-Based Learning, Paper-Based Learning [4]. In the PBL learning method, projects are the foundation for students to achieve competence, and to link the disciplines together for analyzing as well as solving multidiscipline-problems. The skills like self-study, project management, collaboration, build and communication of collaborative knowledge are taught in an integrated way through hands-on experience. A basic principle is that students must master the learning process; the teacher provides the scaffolding and guidance by presenting some ideas, methods, and tools of the learning. The *traditional model* of learning considers "students are empty boxes" and teaching them is to pour "knowledge" into the boxes through direct instruction and homework. The traditional model is a passive learning model which is very popular in high school. A lot of students are familiar with such model at the first school year. More proactively, the PBL considers "students as employees" and teaching them is to develop project-based skills and confidence in solving unconventional problems. PBL requires a guidance-fading effect, so that the learners are early able to confidently "driving car" without the instructor beside. Students only need just-in time learning, face-to-face communication, group interaction, positive interdependence, accountability, and must coordinate with each other in the project. Similar to CDIO, PBL is often used in technical universities around the world as well. PBL and CDIO formed two learning communities which are differential in definitions, curriculum design,

engineering projects, relation to disciplines, and change strategy. There are efforts to combine them for exchanging benefits from the two communities.

The combination of the PBL method and CDIO syllabus has been implemented in higher education institutions around the world. Although the two models of education are different, it is easy to combine them to improve the effectiveness of education [3, 5, 6]. This combination allows CDIO skills to be integrated into the learning process through product development projects [7], research projects [5], even industrial projects [8]. This learning model has been applied in the field of Accounting [9, 10], Tourism Management [11], and other social fields. The association between PBL and CDIO can also be applied to first-year students [12]. Although many organizations have deployed the model successfully, the application of this approach to achieve high efficiency with different models of project management still is a challenge. The traditional project management model is an established methodology where projects are run in a sequential cycle. It follows a fixed sequence: initiation, planning, execution, monitoring, and closure. PBL is based on this sequence. In contrast, Agile is an advanced project management model that relies heavily on teamwork, collaboration, time-boxed tasks, and the flexibility to respond to change as quickly as possible [13]. In an Agile team, there is a free flow of communication, anyone can present their ideas within the team. Although Agile is not a new model, the application of Agile in the implementation of the CDIO syllabus is a new approach in training engineering students. The ownership does not lie on the project manager like a traditional model. It has the concept of shared ownership, i.e., every team member is equally responsible for their individual contribution. In the traditional model, customers are involved only in the initial phases of requirements gathering whereas their involvement is crucial for the Agile model to prove its mettle. The combination of PBL and CDIO for a traditional project for exchanging benefits between two communities has been around for a long time, but a structured combination of CDIO and PBL for an Agile project is still a challenging approach in the trend of educational technology 4.0 [3, 7]. If the two communities are better connected through an effective collaborative learning model in the Agile project environment, the experience can be exchanged from the two CDIO and PBL communities, and they can play compatible and mutually supporting roles; thus it can effectively combine with educational technical reform. As such, the research question is: what is the effectiveness of the novel cooperative learning model that combines between PBL and CDIO for an Agile project?

We proposed a novel cooperative learning-model called PBL-CDIO-Agile (PCA) which cooperates

between PBL method, CDIO syllabus, and Agile team organization. Google services were used to create share folders and a template spreadsheet which cooperate together as the PCA software to links the CDIO, PBL, and Agile. After the PCA software was set up to test this learning-model, we collected and analyzed feedback data from 746 large-class undergraduates of Information Technology to compare the effectiveness of the novel learning-model with that of the traditional learning-model. The benefits of learning a subject are remuneration, employment, new relationships, practical experience, analytical skills, electronic communication, and other mental or material things that students may have beyond the learning outcomes which are statements of minimum competencies that students will be able to do at the end of a period of learning time. Analysis from the feedback showed that, with less time on the classes, the novel learning model outperforms traditional one in the percentage of students who acquire benefits and learning outcomes. The learning model effectively implemented the CDIO syllabus by the PBL method for the Agile project environment.

2. Experiment

We experimentally deployed PCA for 4-year undergraduate classes at Hanoi University of Industry, a public university of applied sciences with over 30.000 undergraduate and graduate students. The university has started an educational project to deploy CDIO since 2016 to present, and has been encouraging faculty to apply new learning methods to effectively perform CDIO syllabus. In the pilot phase of the project, a few traditional syllabuses of Software Engineering curriculum were chosen to convert into CDIO syllabus 2.0 for evaluating the design and learning-method of CDIO syllabuses. We used one of them, namely ICT-Project Management which responds 13 learning outcomes for all goals of the CDIO framework. In general, a CDIO syllabus has 04 main goals for students: G_1) Technical Knowledge and Reasoning, G_2) Personal and Professional Skills, G_3) Interpersonal Skills, and G_4) CDIO competency. How to respond to 04 above goals is a problem that can be solved by the solution of PCA learning model, in which the Lecture method responds for G_1 and G_2 , the Agile team responds for G_3 , and Project-based leaning responds G_4 (Fig. 1). In this case, Agile is a learning solution whereas CDIO syllabus is a learning requirement. Therefore, Agile is different from CDIO. Agile and PBL are two different solutions responding to G_3 and G_4 , respectively. Based on the structure of the PCA learning model in Fig. 1, we designed an electronic handbook spreadsheet on a Google Sheets file which includes sheets whose data link to each other as a network that allows the lecturer and students to enter in-permission data at nodes of the network (sheets) by smartphone or computer.

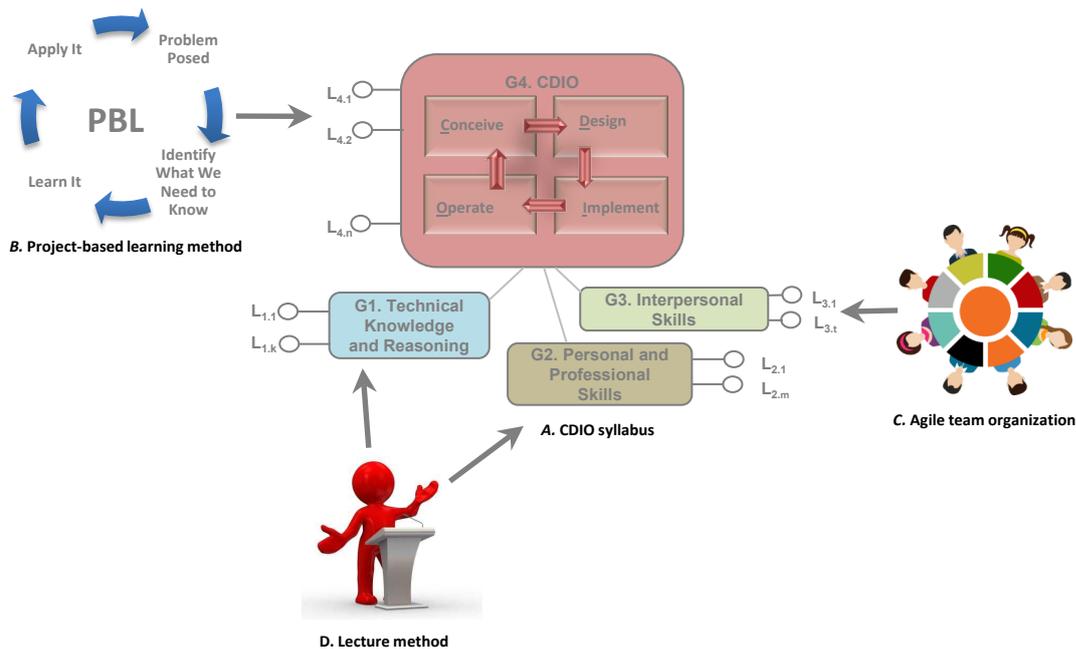


Fig. 1. The structure of PCA learning-model. (A) CDIO syllabus. (B) Project-based learning method. (C) Agile team organization. (D) Lecture method.

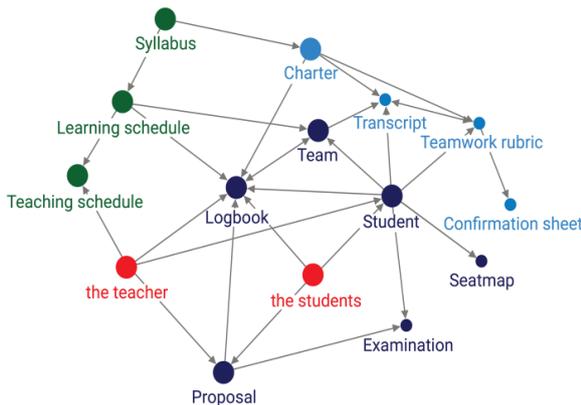


Fig. 2. The structure of PCA software (the Google spreadsheet for the deployment of PCA learning model in Table S2 of the Appendix)

In Fig. 1, (A) CDIO syllabus, learners aim at the main goal G_4 (CDIO competency) by reaching 03 goals G_1 , G_2 , and G_3 . The levels to meet the goals are assessed through learning outcomes L_{ij} . (B) Project-based learning method, learners experience with 04 learning phases to meet learning outcomes L_{4n} . (C) Agile team organization, learners exploit thoroughly teamwork features of Agile to meet learning outcomes L_{3t} . (D) Lecture method, learners listen to the lecture and do homework to meet learning outcomes L_{1k} and L_{2m} . With a few simple Excel commands added in, this PCA software incorporates 03 data groups of CDIO syllabus, PBL method, and Agile team organization to constitute an online classroom where attendees can instantly interact with each other on the structural sheets by typing texts or clicking the hyperlinks to

videos, images or other multimedia documents (Fig. 2). In Fig. 2, each node and each edge represent a sheet, where records data labeled by name of the node, and an information flow from source to destination respectively. *Syllabus* and end-users (red) are the input of the system. This graph is composed of modules: 1) PBL including Syllabus, Learning schedule, and Teaching schedule; 2) CDIO including Charter, Transcript, Teamwork rubric, and Confirmation sheet; and 3) Agile including Team, Logbook, Student, Seatmap, Examination, and Proposal. Size of the node indicates the core level of the system.

The Agile team requires participants of a project to have face-to-face interaction skills and collaborate with customers to create products as quickly as possible. We note that working positions in the Agile project are quite equal in responsibility. For an Agile environment, we initially asked students to organize groups of 3-5 students who play equivalent key roles in the project, including: Principal investigator (responsible for conceiving), Project manager (responsible for designing), Implementer (responsible for implementing), Supporter (responsible for operating). To exploit the PBL feature, students must actively search for topics outside the university under the suggestion of the main supervisor; to be encouraged to approach, negotiate and coordinate with clients (as their second supervisors) to help them identify and address issues. A feasible topic was collected and negotiated from relatives, lecturers, or friends of each member, then this topic was developed into a project during the course. Every week, except at

the lecture, learners must perform both types of activities simultaneously: teamwork under the Agile project model (Teamwork#) and solve the problem by the PBL method to met CDIO learning outcomes (CDIO#). Each activity was reported into the PCA software, consulted by the lecturer, and scored by learning outcomes of CDIO. In order to reduce the presence of the lecturer, CDIO# and Teamwork# activities were encouraged to be outside the classroom and recorded into videos for remotely evaluating by teachers. All learning activities were recorded in the PBL software. Finally, we made a survey, i.e., syllabus report, to evaluate the effectiveness of the learning model as discussed in the next section.

3. Results and Discussion

3.1. The Novel Learning-Model

This learning model is deployed on a popular application called Google Sheets which is a spreadsheet program included as part of a free, web-based software office suite offered by Google. The application also includes Google Docs and Google Slides, a word processor and presentation program respectively. Google Sheets is available as a web application, mobile app for Android, iOS, Windows, BlackBerry, and as a desktop application on Google's ChromeOS, and it allows multiple users online interacting to edit a file compatible with Microsoft Excel file formats. We designed a PCA spreadsheet template on Google Sheets. An experiment of over 6,000 college students demonstrated that the traditional teaching methodology had the highest learning efficiency of only 23%, while an interactive teaching method such as PBL effectively doubled [14]. Thus the effectiveness of a PBL-based learning-method like PCA has been reported [15, 16]. However, PCA is combined with features of the PBL method, CDIO syllabus, Agile team, and online learning mode, and the performance of this combination has still unknown yet. Therefore, it should be comprehensively evaluated.

For evaluating the performance of the PCA model, we examined the model on benefit and learning outcomes. To this end, we collected the feedback on

subject assignments, i.e. those of *ICT-Project Management*, to compare two learning-models: *PCA model* vs. *Traditional model* which parallelly teaching by 04 different lecturers on 03 versions of the syllabus: *2-credit CDIO syllabus*, *2-credit traditional syllabus*, and *3-credit traditional syllabus*. The lecturers were selected among teachers who had at-least-3-year experience in teaching the subject and had similar performance grades from the student feedback after each course in the two recent years. For better evaluation, we also collected more feedback from the *beginners* who have not studied the subject yet. In total, there were 12 regular undergraduates in the large classes whose students are approximately 70 per class and 01 high-quality regular undergraduate class of 31 students. The feedback data, which answer for the research question, include the following information: Personal information, Activities, People known, Benefits, Learning outcomes. The information was structured and designed on Google Form and sent to each student at the end of the educational process for collecting data. Details of data collected can be found in the sheet in Table S1. After the data collected, we removed outliers and statistically analyzed the data by app Google Sheets to evaluate the performance of PCA in benefits (Fig. 3) and that in learning outcomes (Fig 4). There were 746 students giving feedback on assignment results as Table 1. The students were selected from two different levels: cohort 10 (including 544 students trained by the same subject with different methods) and cohort 11 (including 202 students not learning the subject yet). The students of each level ensure the equivalence of knowledge, skills, and attitudes among students because the students shared the same major and cohort, and met the prerequisites of the subject. In Table 1, the students in 10 large classes learned 03 various versions of a syllabus, i.e., those of *ICT-Project Management*, in 15 weeks by 02 different learning models: *PCA* (PBL learning method and Agile team on the CDIO syllabus) and *Traditional* (Group work learning method on the traditional syllabus). The feedback includes Personal information, Activities, People known, Benefits, and Learning outcomes. A total of 746 students has responded with detailed data at Table S1.

Table 1. Summary of feedback data on assignment results. Detailed data in Table S1 of the Appendix

No.	The number of students	Syllabus	Semester	Credits (Theory-Practice-Assignment)	Learning model
1	31	3-credit traditional	6	1-1-1	<i>Traditional</i>
2	192	2-credit traditional	6	1-0-1	<i>Traditional</i>
3	321	2-credit CDIO	6	1-0-1	<i>PCA</i>
4	202	Beginners	4	2-0-1	<i>Traditional</i>

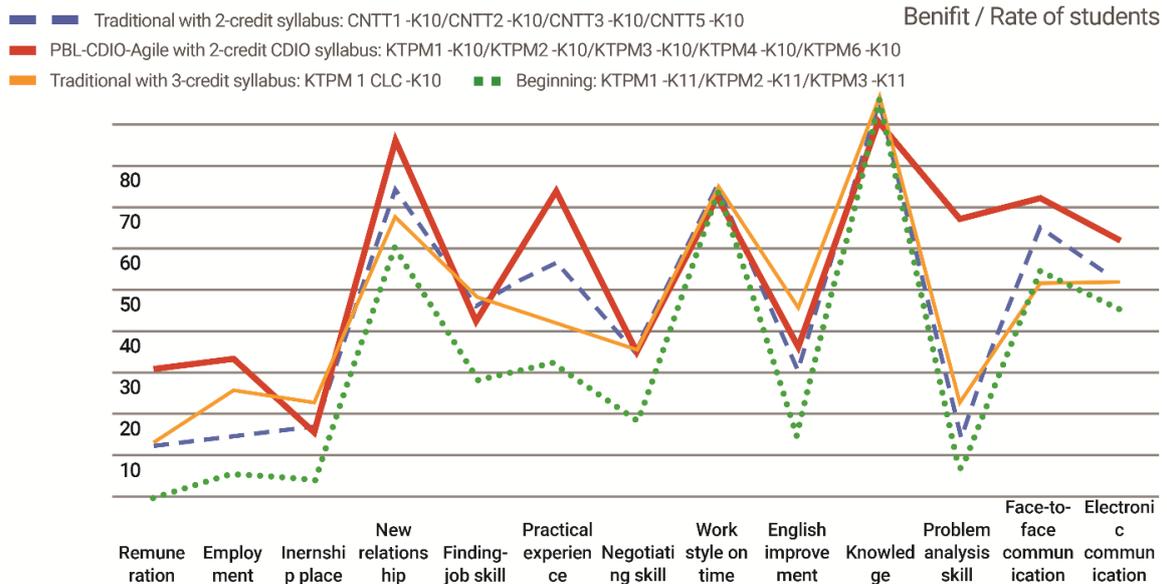


Fig. 3. PCA outperforms Traditional model in the rate of students who get benefits from assignments. The vertical axis is rate of students, and the horizontal axis is Benefit.

3.2. Outperformance in the Benefits Derived

To examine the model on benefit, we conducted a survey with the feedback data summarized in Table 1 to investigate the benefits students gained in the learning period. Based on the feedback data, we compared the benefits derived from the assignments between the *PCA model* and the *Traditional model* which were used to deploy 02 syllabuses respectively: *2-credit CDIO*, and *3-credit traditional*. It notes that, although less credit, *2-credit CDIO* still has a 15-week implementation period as much as *3-credit traditional*. The two syllabuses differ mainly in the structure of implementing time while their learning volumes are similar to each other. *3-credit traditional* focuses on on-classroom activity in 15 weeks of practice and theory while the remain concentrates on online learning in 10 weeks of assignment. In other words, *2-credit CDIO* reduces the amount of offline time to learn at the class (in the 4.0 technology trend), but increases the amount of online time to learn via the Internet by teachers (2-3 times) and by students (1.5 - 2 times). Fig. 3 shows that *2-credit CDIO* (solid bold line) gives assignment benefits higher than *3-credit traditional* (solid thin line), which is a high-quality programme with a small number of students and the on-classroom time doubled. In particular, *2-credit CDIO* outperforms in following indicators: 1) Remuneration; 2) Employment ; 3) New relationship; 4) Practical experience; 5) Problem analysis skill; 6) Electronic communication. This suggests that, when replacing the on-classroom activity with online learning with Teamwork# and CDIO# activities, the *PCA model* benefit learners more than the *Traditional model*. To clarify how PCA significantly outperforms two other models, we statistically compared each pair of learning models on proportion of each benefit to

know if they significant difference each other. When the calculated *P* value is less than 0.05, the conclusion is that the two proportions are significantly different. In Fig. 3, *PCA* with 2-credit CDIO syllabus (solid bold line, mean = 55.2%) is significantly higher than *Traditional* with 2-credit syllabus (dashed line, mean = 45.2%); significantly at 06/13 benefits: 1) Remuneration (31% vs 12%; $P = 0.044$); 2) Employment (33% vs. 15%; $P < 0.0001$); 3) New relationship (86% vs 74%; $P = 0.0008$); 4) Practical experience (74% vs. 57%; $P = 0.0001$); 5) Problem analysis skill (67% vs. 15%; $P < 0.0001$); 6) Electronic communication (62% vs 52%; $P = 0.031$). *PCA* with 2-credit CDIO syllabus is also higher than *Traditional model* with 3-credit syllabus (solid thin line, mean = 46%); significantly at 4/13 benefits: 1) New relationship (86% vs 68%; $P = 0.0133$); 2) Practical experience (74% vs 42%; $P = 0.0004$); 3) Problem analysis skill (67% vs 23%; $P < 0.0001$); 4) Face-to-face communication skill (72% vs 52%; $P = 0.028$). In summary, the implementation of a CDIO syllabus with an advanced learning technology 4.0 like PBL will give higher efficiency, but it demands more activities of teachers than the traditional one (1.5 to 3 times). This is a reference to measure the cost of a CDIO syllabus implementation by modern learning methods of education 4.0.

3.3. Outperformance in the Achievement Of Learning Outcomes

Based on the feedback data, we compared *Learning outcomes* of the two models: *PCA model* and *Traditional model* which were used to deploy 02 syllabuses: *2-credit CDIO*, and *2-credit traditional* respectively.

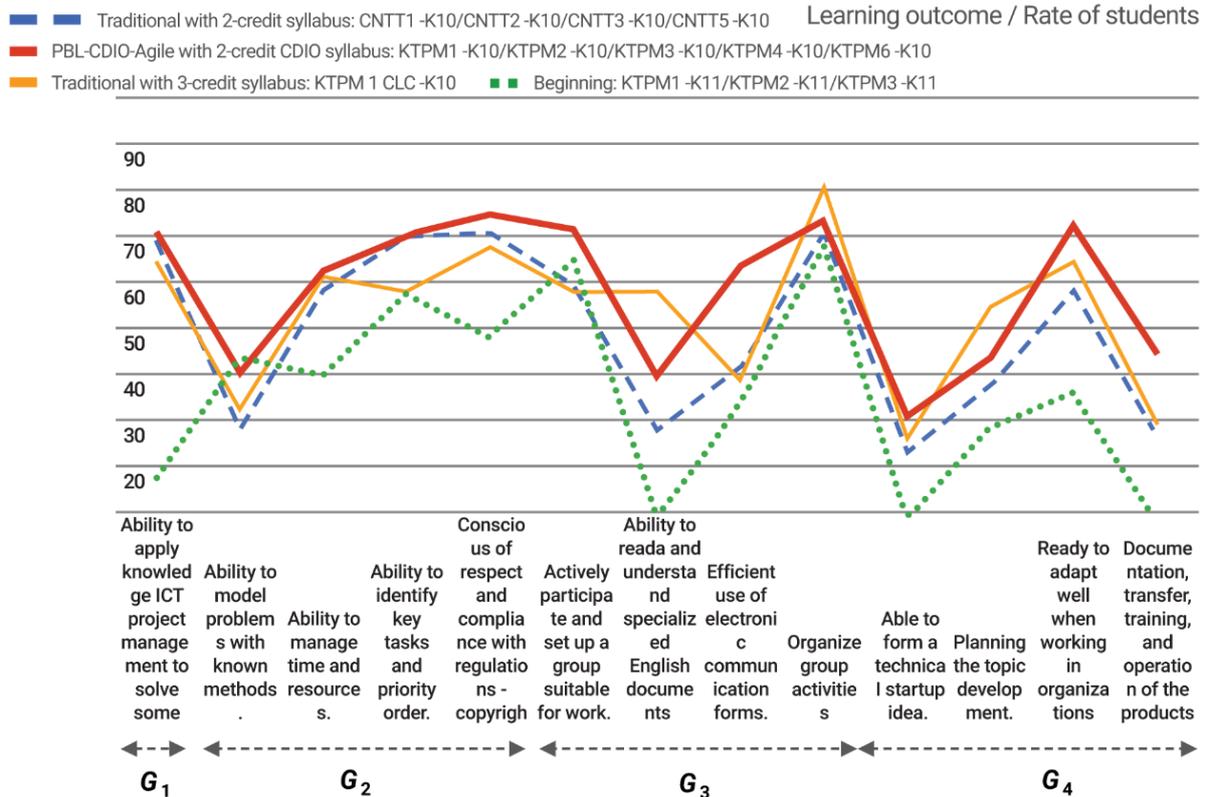


Fig. 4. PCA outperforms Traditional model in the rate of students who meet learning outcomes. The vertical axis is rate of students, and the horizontal axis is the Learning outcome.

It notes that these two syllabuses are identical in content structure and were implemented in the same 15 weeks. They are different from each other only in learning methods during 10 end weeks of assignment. The traditional used Group work method while the CDIO uses the PBL method with Agile teams during those weeks. In other words, a 2-credit CDIO syllabus helps students reach the G_3 , G_4 goals of CDIO, i.e., interpersonal skills and CDIO skills respectively, which the 2-credit traditional do not equip. Fig. 4 shows that 2-credit CDIO (solid bold line) is better than 2-credit traditional (dashed line), significantly superior in 07/13 of learning outcomes in group G_3 , G_4 . This means that, not necessary to learn at class, deployment of the PCA model with activities of Teamwork# and CDIO# for remotely teaching could help students to meet the learning outcomes of a CDIO syllabus. To clarify how PCA significantly outperforms two other models, we statistically compared each pair of learning models on proportion of each learning outcome to know if they significant difference each other. In Fig. 4, PCA with 2-credit CDIO syllabus (solid bold line, mean = 58.3%) is higher than Traditional with 2-credit syllabus (dashed line, mean = 49.3%); significantly at 07/13 of learning outcomes mostly belong to G_3 , G_4 , specifically at 1) $L_{2.1}$ - Ability to model problems with known methods (40.2% vs 28.1%; $P = 0.008$); 2) $L_{3.1}$ - Ability to read and understand specialized English documents (39.3% vs 27.6%; $P=0.0098$); 3) $L_{3.2}$ - Actively

participate and setup a group suitable for work (71.7% vs 59.4%; $P = 0.006$); 4) $L_{3.3}$ - Effective use of electronic communication forms (63.6% vs 41.7%; $P < 0.0001$); 5) $L_{4.1}$ - Ability to formulate technical startup ideas (30.5% vs 22.9%; $P = 0.0779$); 6) $L_{4.2}$ - Ready to adapt well when working in organizations (72.3% vs. 58.3%; $P=0.0012$); 7) $L_{4.3}$ - Documentation, transfer, training, and operation of the products (44.2% vs 26.0%; $P = 0.0001$). PCA with 2-credit CDIO syllabus is also higher than Traditional with 3-credit syllabus (solid thin line, mean = 53.4%); significantly at 01/13 of learning outcomes: $L_{3.3}$ - Effective use of electronic communication forms (63.6% vs 38.7%; $P = 0.013$).

4. Conclusion

We experimentally deployed a novel learning-model of combination between PBL and CDIO called PCA with software created to link between CDIO syllabus and PBL method for the Agile teams of students. The PCA software supporting online mobile applications has been set up to deploy the learning model. Finally, we have made a survey report on the performance of the novel model.

The PCA software for the deployment of the learning model allows the lecturer and students to make an online classroom, the employers to join the learning progress, and the university to increase the presence on the Internet. This interactive-learning

model outweighs the traditional-learning model in Interpersonal skills (G_3), CDIO skills (G_4), insignificantly better in the two remained goals: Knowledge and reasoning (G_1), Technical personal and professional skills (G_2). The learning model is approximately as much effectiveness as twice the traditional model, while saving twice the teacher's class time. However, in addition to the cost of the Internet and smartphone, the learners and the instructors often consume online time as much as 1.5 to 3 times the offline time at the class.

We have successfully deployed a novel learning-model as the combination between PBL and CDIO for the Software engineering curriculum. Analysis results of feedback from 746 students showed that the number of students who acquired remuneration, employment, new relationships, practical experience, analytical skills, electronic communication, and the number of students who met the learning outcomes in the new model is significantly higher in the traditional one without needing to attend classes much. This research demonstrates that the learning model effectively implemented the CDIO syllabus by the PBL method for the Agile project environment.

Appendix.

Table S1. Feedback data on assignment results of ICT-Project management from 746 students at <https://goo.gl/1P3ZV9>

Table S2. Template of PCA software in Google Sheets at <https://bit.ly/3DejMPS>

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