A proficiency-based learning algorithm applied to e-learning system for knowledge-oriented course

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Abstract. In the cognitive psychology domain, the memorization of knowledge is one kind of representation of memory capability. Humans often get the knowledge with knowledge-oriented courses. These courses are composed of the question banks with the fixed knowledge-based content. Learners can obtain the required cognitive knowledge through the repeated memory process. This study proposed a proficiency-based learning algorithm to simulate this kind of learning behavior and then implement an instruction-assisted system called proficiency-based adaptive and guided e-learning system (PAGE system), in which learners can study independently through a guided mechanism. The PAGE system is quite suitable for the knowledge-oriented courses, which are designed by several items with standard answers. Obviously the study indicated the PAGE system is validated in the learning process of memorization. The experimental result proved that the PAGE system can help learners to remember efficiently. All participants got positive progress and 80% of them achieved their criterion for cognitive knowledge growth. In addition, the experiment also showed that the learning attitude and active performance are crucial factors that affect learners' learning growth.

1 Introduction

The instruction objectives include the cognitive domain, affective domain, and psychomotor domain [1]. The cognitive domain can be separated into memory, thought, recognition, and application, and it is generally classified as essential knowledge and a higher level of intelligence and skill. The memory performance belongs to the cognitive domain [2-4]. The knowledge-oriented courses are the cognitive learning foundation in which they integrate the cognition with practice and skill. Hence learners can absorb the basic knowledge in the cognitive domain.

The knowledge-oriented courses belong to cognitive learning. The application of knowledge-oriented courses is popular with the certification fields, and learners gain the basic knowledge from the knowledge-oriented course of the specific field. The certification of International Project Management Association (IPMA) assesses the knowledge of project-management field by cognitive exam for the basic project-management ability in the level C and D [15]. The certification of General English Proficiency Test (GEPT) includes five levels to evaluate the English proficiency level, and the different fixed range of vocabulary is the basic cognition in levels [16]. The Council of Labor Affairs (LAC) in Taiwan currently holds around 202 occupational classifications for certification tests. Each occupational classification has three categories. Each class requires passing the practical and cognitive

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tests to obtain the technician certificate [5]. The mentioned cognitive certification test covers the essential knowledge aspect, and it is constructed in the form of questions and answers. Learners need to demonstrate the master cognition based on the questions. The cognitive test belongs to criterion-based style, and learners need to satisfy the level to pass. The LAC in Taiwan has implemented a regulation on "Technician Certification and Licensing" to improve the quality of technicians in September 1972. The LAC is formed with professional teams to the council for promoting certification and licensing training, and also to ensure the occupational classification of certification tests is suitable for business requirements and international standards [5]. Currently, almost vocational schools in Taiwan have integrated the regulation on technician certification in the skills education. The practical tests are adopted as a part of the skill training courses, and the cognitive tests are also used to knowledge-oriented learning courses. In general, the knowledge-oriented courses consist of standard questions with answers in the assigned cognitive content. Learners can remember and obtain the cognitive knowledge by the continuous assessment and practice.

Hence, this study observed the proficient learning cases and proposed a proficiency-based learning (PBL) algorithm which could be used to design the knowledge-oriented course in the e-learning system, and then a web-based instruction-assisted system called proficiency-based adaptive and guided e-learning system (PAGE system) was implemented. In the PAGE system, learners can learn independently by the PBL algorithm and without teachers' involvement. Finally, learners can master their cognitive knowledge in the proficient learning process.

2 Design of the PAGE system

This paper presents the design of the PAGE system based on the aspects of system structure, knowledge-based learning course, and proficiency-based learning algorithm.

2.1 Design of the system structure

The study uses a web-based interface to implement the PAGE system. Learners can conveniently learn regardless the limitation of time and distance by utilizing the Internet and www-style operating interface.

The proposed PAGE system emphasizes that the system can guide learners to study independently and proficiently. In terms of system components, the PAGE system consists of a registration subsystem, guided learning subsystem, proficiency-based adaptive and guided learning subsystem, question and answer subsystem, and a learning portfolio subsystem. The system components are illustrated with Figure 1.

The registration subsystem mainly provides the interface needed for registration, including the columns of personal account and password, basic information, and target grade setting. The target grade setting will affect the analysis result of the personal learning path and the critical judgment in every stage-examination. After registration, the PAGE system guides students into the pre-test and generates a personal learning path based on the pre-test result.

The function of the guided learning subsystem is to remember the last learning progress and guide learners to study with their customized personal-learning paths until they obtain enough cognitive knowledge.

The proficiency-based adaptive and guided learning subsystem mainly guides learners to adaptively learn by the proficiency-based learning algorithm. When learners already finish learning one of subjects, the subsystem will hold the stage-examination to them. If the exam result does not correspond to the target setting, students must to study again the same stage until passing the criterion. When learners completed all subjects, they must to attend the final-examination to test their knowledge level.

The main function of the question and answer subsystem is to provide the standard questions and answers interface recorded and identified learners' proficiency.

The learning portfolio subsystem provides learners' study tracks, including the target grade, pre-test and post-test result, personal learning path, and learning effectiveness.

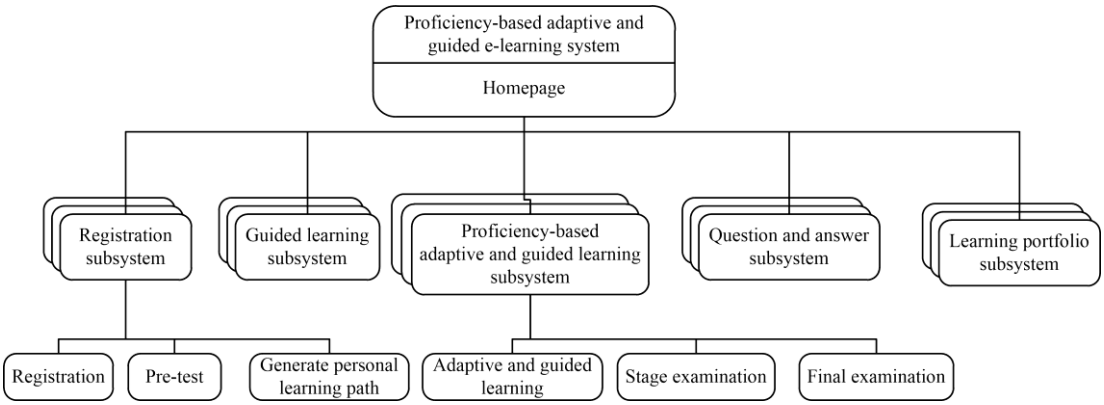


Figure 1. Description of system components.

When learners connect to the PAGE system server on the Internet, the server would respond with a web-based interface to learners. The operating process as followings:

First, learners must register their basic information and target grade in the registration subsystem, and the PAGE system will analyze their personal learning paths according to the pre-test result. The learning paths will be stored into the database as learning and guiding in the future.

When learners access the system, it would guide them to learn by the proficiency-based adaptive and guided learning subsystem, which will remain the last learning record and check the personal learning path. The question and answer subsystem immediately provides the learning content with Q&A style to students, and it also carries out the stage-examination, feedbacks, and final examination. Finally, learners' learning records are stored into the learning portfolio database, and they can check their records and learning status anytime and anywhere. The operating system structure is shown as Figure 2.

2.2 Design of the knowledge-oriented course

The study defines the cognitive course as the knowledge-oriented course. The study uses a web-based interface to implement the PAGE system. Learners can conveniently learn regardless the limitation of time and distance by utilizing the Internet and www-style operating interface.

Because the proficient learning character of the PAGE system, it is quite suitable to cognitive learning in the knowledge-oriented courses. Hence the construction of knowledge-oriented courses can be separated with sub-courses by different subjects, and the each sub-course context is designed on the Q&A format. For identifying learners' guided learning path, this study suggests containing at least a half of questions in the pre-test of every subject. The structural decomposition diagram of the knowledge-oriented course is shown in Figure 3.

The study suggests designing four entities including the subject entity, question entity, answer_sel entity, and question_pic entity to construct the knowledge-oriented course by data modeling process.

The subject entity describes all subjects of the knowledge-oriented course. The subject entity uses the primary key (PK) of subject_id attribute as the index for the question entity, and it also can link to the subject by foreign key 1 (FK1) in the question entity.

The question entity describes the character of standard questions in the knowledge-oriented course. The question entity is constructed of PK included by question_id attribute, FKs included by subject_id, quespic_id, and ans_id, and other attributes included by type attribute, ques_num attribute, and question attribute.

The quespic_id entity describes the question's picture source. The quespic_id entity uses the quespic_id attribute as the index for the question entity, and it associates with the question's pictures by FK2.

The answer_sel entity describes the answer and detail explanation of question. The answer_sel entity uses the ans_id attribute as the index for the question entity, and it gets the answer and detail explanation of question in the answer_sel entity by FK3.

This paper constructs the data modeling of knowledge-oriented course using the mentioned four entities, and it is illustrated with Figure 4.

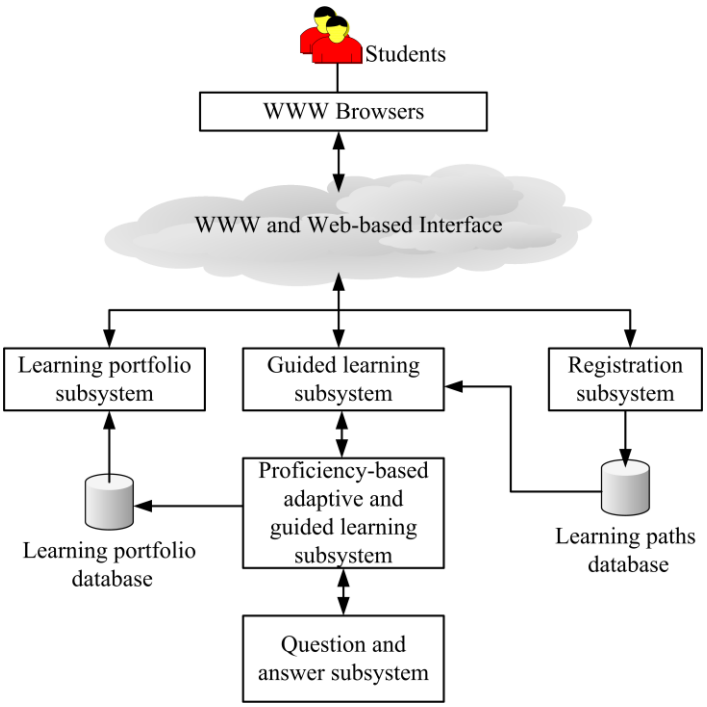


Figure 2. Description of the system structure.

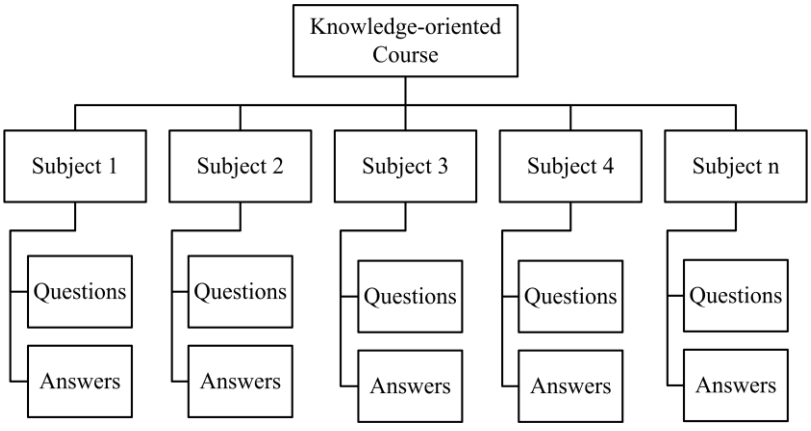


Figure 3. The structural decomposition diagram of knowledge-oriented course.

This study conducted the Taiwan LAC cognitive test of class C technician certification of computer software applications as the experimental course. It was designed by standard questions and answers. This course had 700 cognitive questions and was divided into five subjects based on different characters.

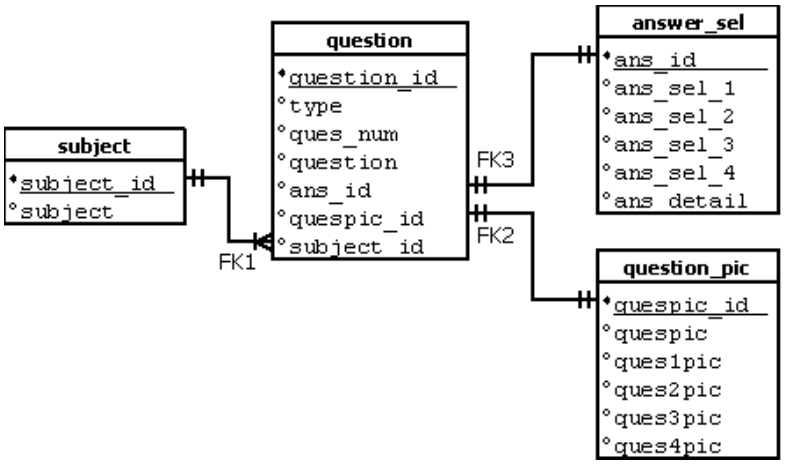


Figure 4. The data modeling of the knowledge-oriented course.

2.3 Design of PBL algorithm

The competency-based education (CBE) theory is an outcome-based teaching method which focuses on the learner and emphasizes the cultivation and mastery of specific and measurable skills throughout various stages of development [6-8]. The standard CBE instruction process is a proficient instruction process following the processes of continuous assessment, feedback, and correction [9-14]. This study observes the character of proficient instruction process and applies it to the proficiency-based learning (PBL) algorithm. Figure 5 shows the PBL algorithm proposed in the study.

The cognitive content of knowledge-oriented course is randomly classified to different subjects as the personal learning path according the learner's pre-test result, termed as subject k, k=1~n. Every learner owns the different customized path, and the PAGE system will guide to study.

When learners finish studying each subject, PAGE system will guide student to test the stage-examination in the current subject, and use (1) to randomly generate 50% questions from the question entity for testing.

$$Questions\_Num(k) ::= Count(Questions(k)) * 0.5$$

$$Questions(k)' = RAND(Questions(k))|num=Questions\_Num(k) \quad (1)$$

After testing, the PAGE system calculates counts of right answers and conducts (2) to calculate the grade of the stage-examination.

$$stage\_question\_right(k) ::= the\ answer\ of\ Questions(k)\ is\ right$$

$$stage\_exam\_grade(k)=(COUNT(stage\_question\_right(k))/Questions\_Num(k))*100 \quad (2)$$

The PBL algorithm uses the method of symbol determination which judges the keyword 'test_result(k)' to determine the proficiency degree and guided consideration. First, calculating the arithmetic difference of test_check(k) using (3); it subtracts the grade of stage-examination from the predicted learning grade in the registration.

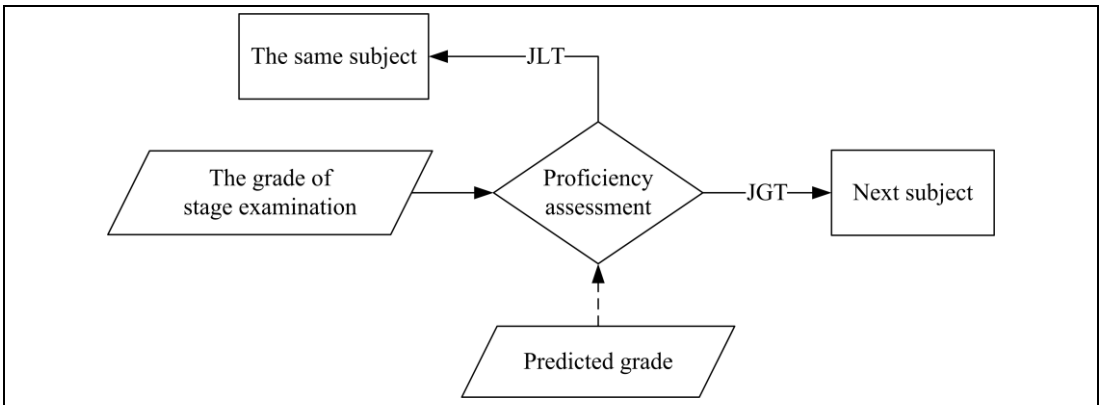
$$test\_check(k) = (predicted\_grade) - (stage\_exam\_grade(k)) \quad (3)$$

Next, assigning the result of test_check(k) to test_result(k) and deciding the modulus judgement of test_result(k) to generate the necessary decision symbol of PBL algorithm. This algorithm uses the threshold limit value by 'zero' to judge the relationship of test_check(k). If the test_check(k) is big or equal to zero, the decision symbol is appointed to '+'; otherwise the decision symbol is '-'.

$$test\_result(k) = test\_check(k)$$

$$\left|test\_result_{(k)}\right| = \begin{cases} +(test\_result_{(k)}), test\_check_{(k)} \geq 0 \\ -(test\_result_{(k)}), test\_check_{(k)} < 0 \end{cases} \quad (4)$$

After the decision symbol is judged, the PBL algorithm will enter the proficiency assessment procedure shown as Figure 5; this is the core process in the PBL algorithm. The proficiency assessment procedure conducts the variable 'SIGN(test_check(k))' to be the decision symbol. If the SIGN(test_check(k)) is '+', it means that the leaner is proficient in the subject and is permitted studying next subject; otherwise if the SIGN(test_check(k)) is '-', it means that the learner's proficiency is insufficient and needs to study the same subject again.



[Proficiency assessment procedure]
Assume predict-grade ::= the grade is the learner's predictive setting
Assume stage-grade ::= the grade is the result of stage-examination
If SIGN(test_check(k)) = = '+' then
Pass and study next subject
Elseif SIGN(test_check(k)) = = '-' then
Fail and study again
End IF

Figure 5. Proficiency-based learning (PBL) algorithm.

According to the PBL algorithm, when learners login the system, it will compare the last learning progress and guide to study by the guided learning subsystem.

The system proficiently guides learners to study the cognitive knowledge. When they obtain enough proficiency in the subject, the system will guide to the stage-examination for checking the proficient degree. If passing the stage-examination, the learners will move on next subject until all subjects are passed; otherwise, they need to study the failure subject again.

Finally, when learners complete all subjects and pass all examinations, the system will guide to the final examination and judge the final proficient degree.

2.4 System implementation

The PAGE system was implemented with the PHP version 5.1.6, MySQL version 5.0.45, and CentOS Linux 5.3 operating system.

The interface of the question and answer subsystem consists of the current subject title and standard questions and answers. In addition, the interface designs a check-button below every

question for checking whether learner is proficient at the question. The implemented learning interface is shown in Figure 6.

When learners finish the learning procedure, the PAGE system stores all learning records into the learning portfolio database and permits learners to track their study status through the learning portfolio subsystem. The learner's portfolio interface shown in Figure 7 includes the adaptive guided path, predictive goal, all examination records, and study performance.

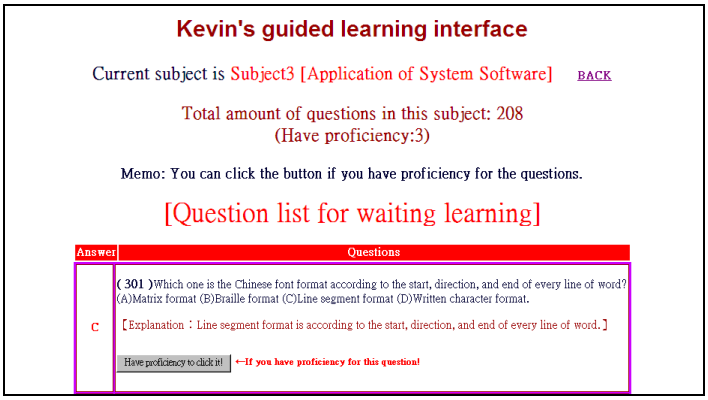


Figure 6. Courses learning interface with questions and answers (Q&A).

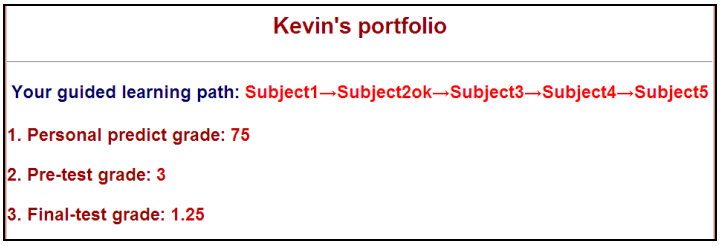


Figure 7. Students' portfolio interface.

3 Research methodology

3.1 Research limitation

This study considers the scope and duration of experiment and then set the research limitation on the following aspects: knowledge-oriented material, research participant, and experiment duration.

3.1.1 Scope of the knowledge-oriented material

The scope of the knowledge-oriented material in the study was the Taiwan LAC cognitive test for class C technician certification in computer software applications. It covered 700 knowledge-oriented questions and was classified to five subjects.

3.1.2 Limitation of the research participant

15 third-year participants in National Taitung Junior College were randomly selected from 261 members in the PAGE system. For the reason, all of them attended the 2010 class C technician certification in computer software applications, and their certification tests would be considered in the study. The study expected to analyze the system validity and participants' learning effectiveness by comparing the certification test result.

3.1.3 Limitation of the experiment duration

The experiment duration was held two months from September 1, 2010. During this period, participants learned the experimental knowledge-oriented course in the PAGE system independently without teachers' assistance. After the experiment, all participants attended the final examination for analysis.

3.2 Research design

Considering research limitations, the study designed the experiment process, PAGE system structure, teaching course, and adaptive and guided learning.

On the first step, the study chose research participant randomly from participants who attended the 2010 class C technician certification in computer software applications. The next step, the research participants studied independently in the PAGE system according the proficiency-based adaptive and guided learning function.

The experiment duration was two months, and the research participants had the final examination to check the proficient degree in the end of experiment. The experiment process is shown as Figure 8.

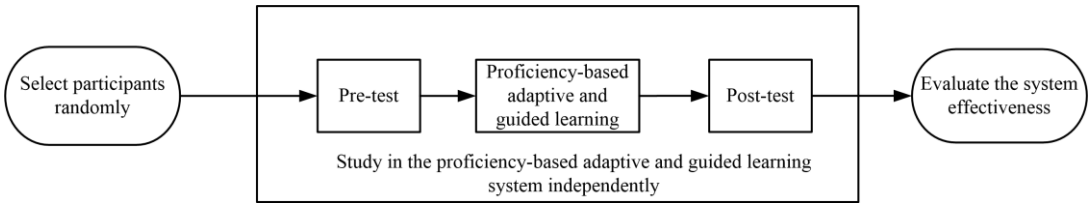


Figure 8. The experiment process.

4 Experiment and discussion

The study discusses and analyzes research results based on three aspects including the system validity, required learning time, and learning effectiveness. Finally the study expects to verify the PAGE system's proficient guiding ability.

4.1 Analysis of system validity

The analysis of system validity compares post-test with pre-test and determines the positive or negative growth of validity.

The grade growth comparison among participants is shown in Table 1. The Grade-growth is calculated by subtracting Pre-grade from Post-grade. If the Grade-growth is bigger than zero, the calculated result is marked by the symbol '+'; otherwise if the Grade-growth is smaller than zero, the calculated result is marked by the symbol '-'.

In Table 1, the analysis showed all participants had positive growth using the PAGE system, and 87% of them had positive growth above 10 points. This result indicated the system implemented by the proficiency-based learning algorithm could guide participants to study efficiently with proficient procedure. Participants got grade from the highest grade of 69.7 points to the lowest grade of 3.2 points; only two participants, who were Participant ID 1 and 14, were less than 10 points.

Table 1. Grade growth comparison among participants.

Participant ID	Pre-grade	Post-grade	Grade growth (Post-grade – Pre-grade)
1	88	91.2	+3.2
2	61	88.7	+27.7

Participant ID	Pre-grade	Post-grade	Grade growth (Post-grade – Pre-grade)
3	67	83.7	+16.7
4	41	82.5	+41.5
5	13	70	+57
6	31	78.7	+47.7
7	41	76.2	+35.2
8	27	82.5	+55.5
9	21	63.7	+42.7
10	33	95	+62
11	18	56.2	+38.2
12	30	82.5	+52.5
13	24	93.7	+69.7
14	35	40	+5
15	26	83.7	+57.7

In Table 2, the pre-test grade of Participant ID 1 was 88 points, and he was limited to improve his performance, but he only used 1.13 days to improve his grade to 91.2 points in the final post-test.

The pre-test grade of Participant ID 14 was too low against to the criterion. He spent all experiment duration 49 days to finish the study procedure, and his attitude was poor and lack motivation during experiment. The above reason would cause his low learning performance.

Table 2. Grade comparison among Participant ID 1 and 14.

Participant ID	Pre-grade	Post-grade	Learning days	Grade growth	Growth
1	88	91.2	1.13	3.2	+
14	35	40	48.96	5	+

Hence, the result showed the PAGE system had good performance on the proficient guided learning. The study also discovered the participant's active learning attitude would affect the learning growth when studying in the PAGE system.

4.2 Analysis of required learning time

Based on the comparison of results in Table 3, the system provided customized subjects to participants. If participants were proficient in some subjects, the system marked symbol "ok" in the learning path and did not guide to study to simply the learning time. In the experiment, Participant ID 1 to 3 were proficient in some subjects, and they do not need to study all subjects of the learning path. Participant ID 1 only needed to learn subject 2, and he finished learning and got the proficiency in 1.13 days. Participant ID 2 and 3 only needed to learn two subjects, and they finished learning and got the proficiency in 17.47 days and 11.11 days.

Table 3. Comparison of learning paths, learning period, learning subjects and goal achieved.

Participant ID	Procedure 1	Procedure 2	Procedure 3	Procedure 4	Procedure 5	Learning days	Goal achieved?	Subjects
1	Subject1	Subject2ok	Subject3ok	Subject4ok	Subject5ok	1.13	Yes	1
2	Subject1	Subject2	Subject3ok	Subject4ok	Subject5ok	17.47	Yes	2
3	Subject1ok	Subject2ok	Subject3	Subject4ok	Subject5	11.11	Yes	2
4	Subject1	Subject2	Subject3	Subject4	Subject5	38.24	Yes	5
5	Subject1	Subject2	Subject3	Subject4	Subject5	41.97	Yes	5

Participant ID	Procedure 1	Procedure 2	Procedure 3	Procedure 4	Procedure 5	Learning days	Goal achieved?	Subjects
6	Subject1	Subject2	Subject3	Subject4	Subject5	41.99	Yes	5
7	Subject1	Subject2	Subject3	Subject4	Subject5	42.01	Yes	5
8	Subject1	Subject2	Subject3	Subject4	Subject5	42.02	Yes	5
9	Subject1	Subject2	Subject3	Subject4	Subject5	47.13	*No*	5
10	Subject1	Subject2	Subject3	Subject4	Subject5	47.14	Yes	5
11	Subject1	Subject2	Subject3	Subject4	Subject5	47.28	*No*	5
12	Subject1	Subject2	Subject3	Subject4	Subject5	47.36	Yes	5
13	Subject1	Subject2	Subject3	Subject4	Subject5	48.45	Yes	5
14	Subject1	Subject2	Subject3	Subject4	Subject5	48.96	*No*	5
15	Subject1	Subject2	Subject3	Subject4	Subject5	48.96	Yes	5
Average						38.08	12	4.33

In order to clearly compare the difference with the learning subjects and learning period, the study figures out the learning time difference which is subtracted the average learning time from learning time, and the statistic is shown in Figure 9.

Hence, Figure 9 shows that the Participant ID 1 to 3 reached the proficiency in a shorter period and were guided by a simplified personal learning path. These participants' learning effectiveness was still positive on the simplified learning period. This result represented the PAGE system could guide participants to study adaptively and effectively.

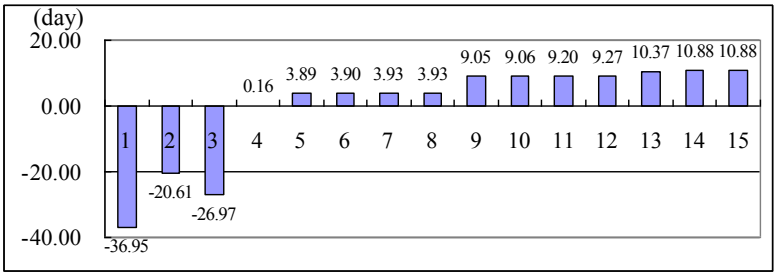


Figure 9. Learning days compared with average.

4.3 Analysis of learning effectiveness

The study analyzed participants' learning effectiveness by considering the participants' achieving on the target grade, shown in Table 4. Table 4 shows that there were 12 participants to reach the predict goal and get the proficiency, but there were also three participants not yet.

Table 4. Comparison of participants' learning effectiveness.

Participant ID	Predictive grade	Post-grade	Get goal?
1	80	91.2	Yes
2	70	88.7	Yes
3	70	83.7	Yes
4	70	82.5	Yes
5	70	70	Yes
6	70	78.7	Yes
7	70	76.2	Yes
8	70	82.5	Yes

Participant ID	Predictive grade	Post-grade	Get goal?
9	70	63.7	No
10	70	95	Yes
11	70	56.2	No
12	70	82.5	Yes
13	80	93.7	Yes
14	70	40	No
15	70	83.7	Yes
Goal achieved		Unable to goal achieved	
12		3	

Table 4 shows that 80% of the participants could achieve their target through the PAGE system. Even though there were 20% of participants could not, but they still had a positive learning performance from 5 points to 42.7 points as shown in Table 1. The result shows that all participants had positive learning effectiveness through the PAGE system.

5 Conclusions

The application of knowledge-oriented course is popular with the certification fields, and learners obtain the cognitive knowledge from the knowledge-oriented course in the specific field. The knowledge-oriented courses always offer a fixed learning format. Learners absorb knowledge through the memory process with continuous assessment and feedback proficiently.

Hence, this study observed the proficient learning cases and proposed the PBL algorithm which could be used to design the knowledge-oriented course in the e-learning system, and then a web-based instruction-assisted system called the PAGE system was implemented. In the PAGE system, learners can learn independently by the PBL algorithm and without teachers' involvement. Finally, learners can master their cognitive knowledge in the proficient learning process.

The study proved that the PAGE system had good performance on the proficient guided learning. All participants had positive growth with using the PAGE system and 80% of them achieved their proficient target. In addition, the simplified personal learning path did not affect participants' learning effectiveness and could help them to reach the proficiency in a shorter period. The result represented the PAGE system could guide participants to study adaptively and effectively. The study also discovered the participant's active learning attitude was the crucial factor that affected their learning growth.

The proposed PAGE system successfully corresponds to provide a proficiency-based adaptive and guided learning procedure to guide learners to study independently and proficiently, and all learners have the positive learning effectiveness through the PAGE system.

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