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Instructional Design Models for Blended Learning in Engineering Education

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The purpose of this study is to develop instructional methods and processes for designing authentic contexts of blended learning in engineering education. Design strategies for the reproduction of professionals' authentic contexts are suggested with guidelines for the actual development of a blended learning course. According to the development research methodology, along with a prototype e-learning course, six design strategies were developed as follows: (1) select and identify authentic tasks that practitioners or experts can solve; (2) analyze the context of solving the authentic task; (3) model experts' cognitive and behavioral processes of solving the authentic task; (4) develop assessment tools for the authentic task; (5) apply instructional strategies to provide authentic contexts by using technologies; and (6) develop instructional resources and environments. Two task analysis methods, activity theory and PARI (Precursor–Action–Results–Interpretation), were employed to identify authentic troubleshooting problems of energy auditing. Constructivist learning models and strategies were implemented; they had been adopted from situated learning, anchored instruction, cognitive apprenticeship, and goal-based scenarios. The research implications and limitations are discussed for generalization in future studies.

Keywords: blended learning; activity theory; PARI; troubleshooting problems; constructivist learning models

1. Introduction

PBL (problem-based learning) is considered one of the most powerful instructional models to provide students with opportunities to experience real-life problems in school settings. However, there are some arguments about whether PBL can deliver essential knowledge to students or not [1, 2]. Little research has been conducted on developing systematic instructional methodologies to design authentic contexts that are needed to solve such PBL-related issues.

Traditional PBL originated from medical schools where students needed to build up their professional reasoning skills with content knowledge [3, 4]. Since PBL implementations were disseminated to other disciplines, such as law, biology, and nursing, there have been several adjusted transformations of PBL in the field of educational contexts. Furthermore, PBL has been implemented in many engineering programs throughout the world, such as the mechanical engineering program at Imperial College in the United Kingdom, the biomedical engineering program at Technische Universiteit in the Netherlands, and the aerospace engineering program at Massachusetts Institute of Technology in the United States [5, 6].

It is thought that PBL is applied to engineering programs to train novices to become experts with problem-solving skills as well as content knowledge. However, research on PBL strategies implemented in mechanical engineering and biomedical engineering concluded that certain limitations make PBL less suitable as an overall strategy for engineering education [5]. The researchers argued that PBL students failed to learn essential concepts and principles, leaving them unable to construct the "right" knowledge required to solve real-life engineering tasks. Therefore, as strategies to support PBL implementation, they suggested direct instructional outlines, demonstrations of expert problem-solving, teacher-guided discussions, and problem-solving tutorials with specially structured group work.

In this study, having taken into consideration the aforementioned issues, methods and strategies for designing learning contexts were developed in a blended learning environment in which students, with the essential knowledge, can practice solving authentic problems. This paper introduces instructional design models, methods, and processes that adopt systematic approaches originated from the field of educational technology.

2. Literature review

2.1 Knowledge states of troubleshooting problems

Compared to novices, expert troubleshooters can more quickly and efficiently identify problematic states of systems, construct a mental model of the problem, diagnose the symptoms based on their previous knowledge and experiences, and finally provide solutions [7]. The characteristics that expert troubleshooters exhibit indicate that trou-

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bleshooting competence is a predominant cognitive task [8]. The cognitive components of troubleshooting problems have been studied in terms of the importance of knowledge states [9]. The most recent study categorized essential knowledge for troubleshooting into: domain, system (device or conceptual), performance (procedural), strategic, and experiential knowledge [10]. Domain knowledge refers to the theories and principles upon which systems or devices were designed. Domain knowledge is more necessary for novice troubleshooters than for experts. It is more effectively used when novices transfer skills to different systems [11, 12]. System (conceptual or device) knowledge includes topographic and functional knowledge. Topographic knowledge is an understanding of what the structure of the system is, how the components of the system work, and how they are related to the system as a whole [13–15]. Topographic knowledge represents the spatial location of the components of a system [16]. Experienced troubleshooters more effectively use a mental image or diagram of the system to convey topographic knowledge [7]. More skilled troubleshooters search for more correct topographic descriptions of the systems [10]. On the other hand, functional knowledge is the comprehension of what the individual function of a component is in a system and what the causalities between the components and their structure are [17]. When troubleshooting electronics problems, experts use more causal relationships than the linear, physical organization of a system that novices more commonly use [18]. The amount and organization of system knowledge is the primary difference between novices and experts in troubleshooting [7]. Skilled troubleshooters are more likely to use functional knowledge, whereas novices more commonly depend on topographic knowledge [19]. Functional knowledge is referred to as the core component needed for causal reasoning in the process of problem solving [10]. Therefore, novice troubleshooters are encouraged to obtain topographic strategies based on functional knowledge of the system in order to solve problems more efficiently.

Performance (procedural) knowledge is specific to the systems and tools needed to complete routine maintenance jobs. Strategic knowledge helps troubleshooters confirm hypotheses and solutions or seek new alternatives, which consequently reduce the problem space and conduct the reduction process [20, 21].

2.2 Situated learning for authentic learning environments

The criticism that current public education is ineffective, abstract, and decontextualized means that what is taught and learned in schools is different from what is actually encountered in everyday life. That is, well-structured, decontextualized problems that students solve in schools are quite different from ill-structured, contextualized problems that they run into in the real world [22]. The well-structured problems taught in schools are often provided without the contextual information that is needed to solve ill-structured everyday problems. Therefore, it is necessary to bring the out-of-school, ill-structured problems into classrooms so that students can solve authentic, real-world problems [23].

Knowledge is situated and influenced by the activity, context, and culture in which it is used [24]. The understanding of knowledge cannot be separated from the context in which the knowledge is used [25]. Situated learning has been defined as "the notion of learning knowledge and skills in contexts that reflect the way that the knowledge will be useful in real life" [26, p. 2]. According to the model, knowledge should be provided within the authentic contexts of the real world [27, 28]. It emphasizes that learning should be understood within the contexts of activities because human activities occur in the contexts [29].

The core characteristics of situated learning are stories, reflection, cognitive apprenticeship, collaboration, coaching, multiple practise, articulation of learning skills, authentic assessment, and technology [30, 31]. The situated learning environment facilitates the transfer of information and discoveries through stories where real-world contexts are presented. Situated learning promotes the integration of experiences with reflective thinking so that students enable abstractions to be formed [24]. Based on the notion of cognitive apprenticeship, situated learning provides a context designed to enculturate students into authentic practices through activity and social interaction [24, p. 37]. Collaboration gives students the opportunity to work together for the construction of knowledge. Skills are cultivated through repeated practices that enable novices to become experts. The teacher's role of coaching and scaffolding of support helps students more closely experience expertise. Situated learning environments enable students to articulate tacit knowledge to the formation of explicit knowledge. The assessment is seamlessly integrated with the activity that requires students to craft products or perform. Technology gives classroom contexts more real-world relevance.

More specifically, the role of authentic tasks has been considered most important for designing situated learning environments. This is because they help students to experience the professionals' cognition and behavior, even though there is no complete provision of real-world contexts [32]. The most recent research provides an extensive literature review through which nine critical characteristics of situated learning were suggested. The research comprehensively embraces the characteristics of authentic tasks. The nine characteristics of situated learning which were adopted as design strategies for this study are as below [33, 34, p. 26–27]:

1. provide authentic context that reflects the way the knowledge will be used in real life;
2. provide authentic activities;
3. provide access to expert performances and the modeling of processes;
4. provide multiple roles and perspectives;
5. support collaborative construction of knowledge;
6. promote reflection to enable abstractions to be formed;
7. promote articulation to enable tacit knowledge to be made explicit;
8. provide coaching by the teacher at critical times, and scaffolding and fading of teacher support; and
9. provide for integrated assessment of learning within the tasks.

3. Development research context and procedure

This study employed development research methodology, along with a prototype e-learning course, which was the very first of such efforts in the field of energy auditing. The development of a blended learning course was launched as a government-funded project with the purpose of training novices to become expert energy auditors.

The extensive literature review selected the most representative and validated research results, which provide nine design strategies of situated learning for this study [34, p. 26–27]. The development research project had the time limitation of one semester before the Department of Industrial and Manufacturing Systems Engineering submitted a prototype of the blended learning course to the government.

The course development was conducted with the actual objective of providing senior undergraduates and first year graduate students with practical experience and training regarding industrial energy auditing. The learning environment provides troubleshooting problems for the students to perform a competent energy audit which requires them to obtain a combination of two skill sets: technical knowledge of energy systems and problem-solving ability.

To develop the blended learning environment, above all, the performances of professional energy auditors needed to be observed and analyzed. The three steps identified as comprising the entire energy audit process were pre-audit analysis, walk-through analysis, and recommendation and follow-up. Before the actual site tour for walk-through analysis, pre-audit analysis was conducted by the energy audit team, which consists of one expert professor, two skilled graduate students, and a group of capstone design course students. In fact, two experienced graduate students took the role of subject matter experts. As for the initial analysis, three types of data were submitted by Duke Manufacturing: pre-audit form; electronic usage; and plant layout. Based on the data, potential fault states of energy and production systems were analyzed.

Afterwards, the energy audit team and instructional design team had a site tour at Duke Manufacturing for a walk-through analysis. During the tour, we were informed of the overall energy usage by a manager of the company. Most importantly, we observed how professional energy auditors conducted walk-through analysis with measuring tools to investigate energy systems and analyze their usage data.

Lastly, the recommendation and follow-up analysis was conducted to determine the assessment result and recommendations based on evidence of the energy usage problems found in the walk-through audit. The energy audit team concluded by submitting a final report and made an oral presentation to Duke Manufacturing.

4. Instructional methods and processes for designing authentic contexts

The abovementioned processes of the energy audit were all observed and analyzed by the instructional design team. Based on activity theory and PARI applied to instructional process, six steps for designing professionals' authentic contexts were developed as follows [33, 34].

4.1 (Step 1) Select and identify authentic tasks that practitioners or experts solve

The course development included complex troubleshooting tasks that a professional energy audit engineer solves by isolating and diagnosing faulty states of energy systems and by producing appropriate solutions.

Step 1 requires instructional designers to observe the experts' specific problem-solving environment so that they may be able to understand the whole context that the professional engineer faces and experiences in the real world. Therefore, the instructional design team observed all the actions undertaken throughout the processes as well as the tools

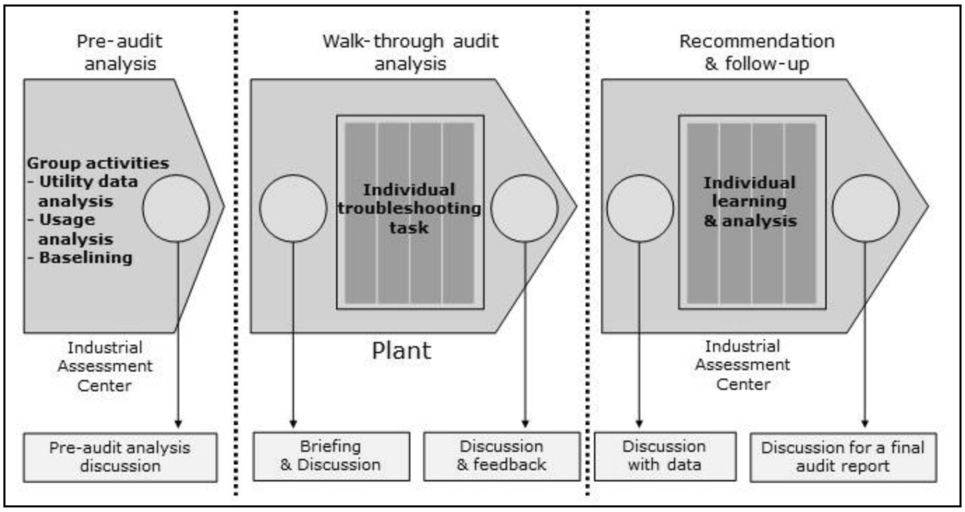

Fig. 1. Actual troubleshooting problem-solving context and learners' tasks.

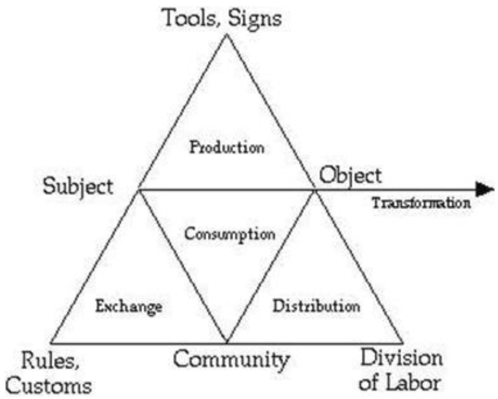

Fig. 2. Activity system.

used for the audit, while one expert professor, two skilled graduate students, and a group of capstone design course students were participating in a site tour for the actual energy audit at Duke Manufacturing.

The audit processes include pre-audit analysis, walk-through audit analysis, and recommendation and follow-up. Figure 1 shows how the energy audit procedure and context was constructed in terms of the number and types of activities that professional engineers commonly perform. Consequently, the figure illustrates what students perform and learn in the blended learning environment.

4.2 (Step 2) Analyze the context of solving the authentic task

Activity theory was applied to identify the context of professional engineers' activities, such as the nature of the tools used in the activities, the social and contextual relationships between the collaborators in the activities, goals and intentions of the activities, and outcomes of the activities [35, 36].

Figure 2 delineates what components of the activity system should be identified to analyze the contexts of students as well as those of experts [37]. Table 1 presents how the activity system was applied to analyze the context surrounding students as well as experts. Step 2 helps to identify the discrepancy of context between professionals and students, which should be decreased with instructional design prescriptions.

The outcomes from Steps 2 and 3 can be used to write performance objectives in order to bridge the gaps between professionals and students. Which components consist of authentic tasks as well as which resources are available for situated learning environments should be taken into consideration, based on the performance objectives. In addition, most of the outcomes from Steps 2 and 3 can be used as fundamental components to develop learning resources and environments in Step 6.

4.3 (Step 3) Model experts' cognitive and behavioral processes of solving the authentic task

PARI cognitive analysis was used as the core method to bring professional engineers' workplace authenticity to the learning environment. The purpose of the method is to analyze domain knowledge, system knowledge, procedural knowledge, and strategic knowledge which are precursors to solving troubleshooting problems in real-world environments [35, p. 121].

To articulate professional experts' reasoning in solving problems, PARI requires two professionals to make a pair: one as problem poser, the other as problem solver while they deal with authentic problems (tasks). After the problem poser presents a problem, the problem solver performs actions and provides the results of these actions and then the problem poser interprets the results.

Table 1. Activity analysis outcomes

Subsystem	Component	Analysis
Production	Subject	(1) Auditors (students) (2) Technicians (from local Industrial Assessment Center or energy consulting company)
	Object	Energy Efficiency Report, Recommendations, etc.
	Outcome	Energy efficiency, better productivity, energy saving, cost reduction, etc.
	Tools, Signs, & Mediators	(1) Pre-audit Analysis ▪ Forms: application form, self-audit form, etc. ▪ Software: QuickPEP, AirMaster+, MotorMaster+ 4.0, etc.
		(2) Walk-through audit analysis ▪ Auditing equipment: thermometers, gauges, sensors, detectors, etc. ▪ Safety equipment: safety glasses, ear plugs, gloves, rubber boots, etc. ▪ Tools: cutters, compasses, screw drivers, etc.
		(3) Recommendation & follow-up ▪ Hardware: Printer, paper, etc. ▪ Software: MS Word, MS Excel, Adobe Acrobat, etc.
Consumption	Community	(1) Company: floor manager, operators, etc. (2) U.S. Department of Energy: field manager
Distribution	Division of labor	U.S. Department of Energy, Industrial Assessment Center, other companies
Exchange	Rules	Business regulations & laws, industrial safety and health laws, company policies.

To accomplish the purpose of Step 3, the performances of two expert graduate students were analyzed. The students took central roles as expert engineers because of their extensive experience in energy auditing. Based on observations and interviews with them, how experts think and act to solve troubleshooting problems was identified along with the essential knowledge that is necessary for the process of energy auditing in the blended learning environment.

4.4 (Step 4) Develop assessment tools for the authentic task

Step 4 is to develop tools to assess students' problem-solving performances. Based on the experts' domain, system, procedural, and strategic knowledge extracted from the PARI analysis of Step 3, the multiple-choice and short-answer questions were developed to evaluate students' basic understanding of energy auditing. Moreover, four writing tasks, such as a pre-audit analysis report, an individual

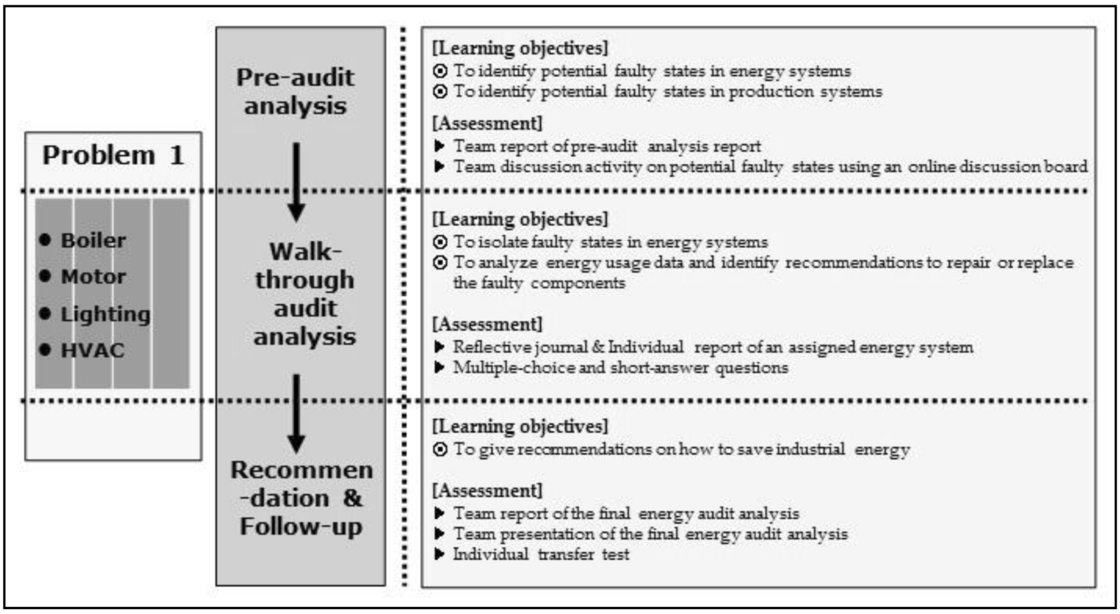

Fig. 3. Assessment design based on learning objectives.

walk-through audit analysis report, a reflective journal after the walk-through audit, and a final team audit analysis report were developed to evaluate students' performances. Those performance assessment tasks were seamlessly integrated with the activities that experts do in the real-world place of employment. Scoring rubrics were also developed to evaluate students' writing tasks. For the transfer test, a final troubleshooting task was developed in a type of problem scenario to investigate whether students can keep identifying faulty states of energy systems and suggest solutions or not. Figure 3 shows the types of assessment tools designed based on learning objectives.

4.5 (Step 5) Apply instructional strategies to provide authentic contexts by utilizing technologies

In Step 5, technology is one of the appropriate tools used to minimize the differences between the authenticity of the real-world work environment and the classroom simulation. Step 5 requires making effective and efficient use of technology to narrow the gap of authenticity between the workplace and classroom.

Figure 4 shows that the blended learning strategies were applied in order to promote learning and to support teaching according to four problem sets in two modes of learning delivery: offline and online. The four offline sessions were designed to provide the opportunity for guided team discussions as well as the expert professor's modeling, coaching, and scaffolding which would not be sufficient through the online learning environment. Figure 4 visualizes the integration of offline and online modes, which can be the proper technology selection to allow students to experience real-world workplace authenticity. Students can have more opportunities to experience professionals' cognition, behavior, and context, with the help of technology embedded in the e-learning environment: video clips, visual aids, interactive discussion boards, and the like.

Situated learning is the major instructional design model for this development study. Anchored instruction is a manifestation of the situated learning model in the blended learning environment. Cognitive apprenticeship is also a core enculturation strategy to get novice students engaged in the experts' professional context. Goal-based scenarios enable anchored instruction and cognitive apprenticeship situated in the e-learning environment. Figure 5 illustrates how a problem was developed according to instructional design models.

4.5.1 Anchored instruction

Instead of giving direct instructions to students in order to present energy problems, the blended course makes students work on problem scenarios that are based on complex and real-world energy efficiency issues. Even though the scenarios are not fully delivered in the video format, they help students identify problems, diagnose symptoms, and produce solutions, while cognitively solving the problems in the blended learning environment.

4.5.2 Cognitive apprenticeship

While students are engaged in working on problem scenarios, they interact with experts (or instructors) who share their expertise and provide professional feedback. In addition, students discuss and cooperate with their peers who have different levels of knowledge and skills, but have the same goals to achieve. These kinds of learning activities and social

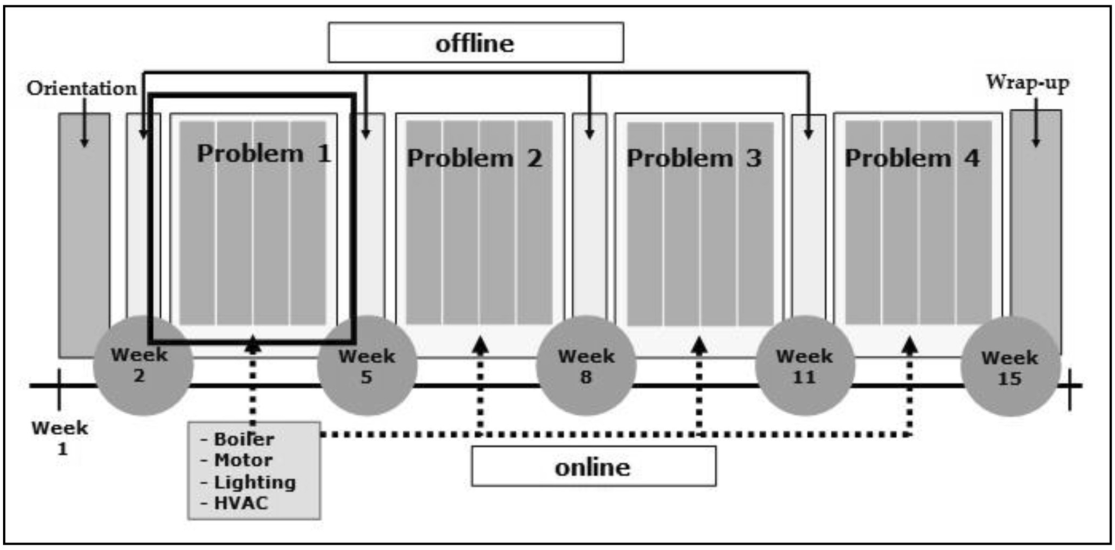

Fig. 4. Organization of four case problem sets in the blended learning mode.

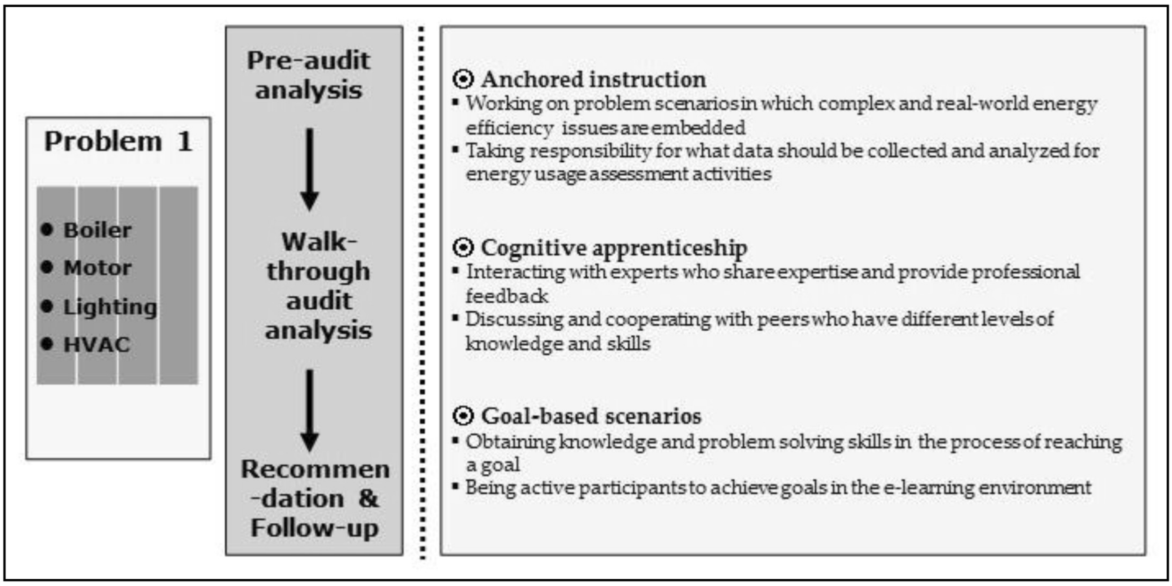

Fig. 5. Instructional design of case problem set.

interactions enable students to become familiar with authentic practices in energy auditing.

4.5.3 Goal-based scenarios

To perform a competent energy audit, students need to obtain both technical knowledge of energy systems and problem-solving skills. The course provides students with the opportunity to be active participants who have to achieve sub-goals as well as a comprehensive goal in each problem set. The comprehensive goal is to write an energy audit report while they develop their problem-solving skills. The sub-goals are to solve the energy efficiency problems of each energy system. The scenarios were developed by embracing real-world contexts from which students can obtain essential knowledge and develop problem-solving skills. Students take responsibility for what data should be collected and analyzed for energy efficiency assessment activities. The scenarios were developed authentically enough to enable students to pretend that they are working as intern auditors on location in companies or at other energy auditing sites.

4.6 (Step 6) Develop instructional resources and environments

In Step 6, the outcomes from the PARI task analysis of Step 2 were used to design and develop instructional resources and environments in order to bridge the gaps between the context in which professional engineers' work and the learning environments of novice students. The online learning resources and environments include the cognitive and behavioral steps of troubleshooting, authentic problem scenarios, visual aids, conceptual understanding questions, and interactive discussion boards, which embrace the essential states of knowledge and problem-solving processes.

Figure 6 shows what the online mode of the blended learning course *Analysis and Design of Energy Efficient Industrial Systems* looks like. Figure 7 presents that one problem's walk-through analysis process includes three different energy system issues, such as lighting, motors, and compressors. It also shows the global navigation menus of Home, Course Guide, Syllabus, Cases, and Contact Us, as well as the local learning menus of Learning Resources, Tools, Assessment, and Discussions.

Each problem of the course has a comprehensive problem scenario in which specific sub-problem issues of energy systems were developed, along with the conceptual understanding questions. The questions were related to the basic conceptual (system) knowledge needed to solve problems. The global menus Learning Resources and Tools offer diagrams of causal relationship among systems, flowcharts of the energy audit process, checklists of each energy system, pictures of devices, website URLs of energy efficiency organizations, energy assessment manuals, sample reports of energy audits, and so on. There are instructional descriptions of why and how learning resources and environments were designed to be used as follows.

4.6.1 Modeling

Diagrams help students to have a core understanding of causal relationships between systems' components and their structure. Flowcharts and checklists provide students with the opportunity

Fig. 6. A screenshot of the online mode of the blended learning course.

Fig. 7. A screenshot of the walk-through analysis process.

to recognize the procedures that experts choose in the process of performing an energy audit. They help students improve their performance by providing them with quicker and more accurate steps to follow when they troubleshoot.

Some key concepts of problem scenarios were hyperlinked to their descriptions, related pictures or figures on another webpage. Other learning resources were also embedded in the pages of local learning menus, such as Learning Resources, Tools, Assessment, and Discussion.

4.6.2 Coaching

The contents of the global menu of the Course Guide help students to recognize how the course is organized and how they can learn. The Course Guide menu illustrates how the course is organized, how students can learn from the course, and who teaches the course. The contents were organized into one figure and two tables in order to help students to intuitively recognize the original purpose of the development of the blended course.

In addition, feedback and argumentation from more experienced students as well as the professor and other experts coach students' learning through doing. For example, when students submit their reports and reflective journals via the online discussion board, the experts' corrective feedback encourages students to simulate their way of thinking and acting without traditional direct instructions.

4.6.3 Scaffolding

Five offline discussion sessions were developed for students to freely ask questions and discuss key topics with experts and peers. Even though students have access to the discussion board to communicate with professional engineers of the real workplace subject to the energy audit, the offline sessions are necessary because the online discussion board is not the best tool for developing students' convergent-thinking skills, such as reasoning, analyzing, and evaluating. The online discussion board is considered to be more appropriate for divergent-thinking activities, such as generating ideas.

Along with each problem scenario, there are several comprehension questions to investigate whether students have a clear understanding of conceptual, procedural, and strategic knowledge. Such carefully designed comprehension questions serve as scaffolds to help while students solve troubleshooting problems.

5. Discussion

Until recently, working with engineers and in the field of engineering had been challenging from the perspective of education majors. However, due to the importance and necessity of problem-solving competency for engineers, many educational technologists or instructional designers now have more opportunities to experience engineering fields and work with engineers.

Since PBL was implemented mostly in engineering design courses, many transformations of PBL have occurred according to specific educational contexts. The phenomenon has been understandably accepted because education is likely to be affected by the variety of environmental factors. Moreover, recent recognition is that other educational theories and models have not been introduced as widely as PBL in engineering education. Even though constructivist teaching and learning strategies are more appropriate for educating competent engineers, the fact is that the objectivist methods have prevailed in engineering education for a long time. The constructivist approaches using problems, cases, or tasks offer students activities, culture, and context in which students can experience real-world issues before they graduate. Design courses adopt the problem-based learning method, which is the most popular approach and is widely applied in engineering education. Except for PBL, however, not many constructivist methods have been investigated and applied in engineering education. Therefore, it is necessary for engineering faculty members and instructional designers to cooperate for more effective and efficient engineering education. The cooperation between subject matter experts and instructional designers is the most essential factor in developing a successful blended learning environment in engineering education.

Constructivist task analysis methods need to be investigated and implemented more actively. The literature review shows that photo-rich learning environments do not guarantee learning effectiveness [33, 34]. Rather, cognitive realism such as the process representation of problem-solving by experts is more important than the provision of pictures. The PARI method is a useful tool to identify problem-solving processes of expert engineers. Activity theory is a proper instrument to analyze a variety of contexts surrounding professional engineers. The outcomes of the task analysis methods are used for designing the actual representation of cognitive realism, which provides students with experts' strategies to solve problems.

The important research required for the designing of engineering tasks includes identifying the type of engineering problem, the knowledge states of the problem, and the recognition of the most influential knowledge state for problem-solving. The problem type affects problem-solving processes and methods by experts. For instance, the most important for solving troubleshooting problems is system knowledge, which consists of topographic and functional knowledge. Functional knowledge elicits experts' reasoning ability based on topographic knowledge [10]. Identification of the problem type provides engineers with a shortcut to solve problems.

The research limitation of this study is that this is a prototype course development case study that needs the assessment of learning effectiveness for generalization in future studies. Therefore, more actual implementation of instructional models and strategies developed in this study needs to be done in different situations of designing authentic contexts of blended learning courses.

6. Conclusion

The instructional methods and processes for designing authentic contexts of blended learning courses are: (1) to select and identify authentic tasks that practitioners or experts solve; (2) to analyze the context of solving the authentic task; (3) to model experts' cognitive and behavioral processes of solving the authentic task; (4) to develop assessment tools for the authentic task; (5) to apply instructional strategies to provide authentic contexts by using technologies; and (6) to develop instructional resources and environments. The methods and processes are based on the theoretical framework of constructivist theories. The overarching theory is situated learning with the practical application of anchored instruction, cognitive apprenticeship, and goal-based scenarios in the development case study of blended learning courses. Additionally, blended learning resources and environmental components are designed with the adoption of modeling, coaching, and scaffolding. Beyond the limitation of a prototype development case study, further studies need to be conducted for generalization.

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