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An Instructional Method for Mobile Technology-Enhanced Collaborative Problem Solving in a Complex Engineering Course

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The purpose of the article is to address a new instructional approach to a complex engineering course. We design a novel instructional method that combines mobile technology, simulation program, collaborative teamwork, problem-solving process, and a variety of evaluation techniques. We suggested five instructional principles that might be required to change the fundamental educational process by which learning is done. The proposed instructional method is expected to aspire for new perspectives on complex learning environment. Nevertheless we solely began by the research on the development of students' complex problem-solving performance in a complex engineering course, the new instructional method in the article can promote the adoption of new instructional methods and strategies across different knowledge domains. In addition, the instructional method can provide a valuable bridge to acquisition and transfer of problem solving, motivation, and meaning learning.

Keywords: instructional method, mobile technology, simulation program, complex engineering course

Introduction

The abilities to solve real-life engineering problems in a logical and efficient manner and to collaborate in a teamwork environment are becoming crucial assets for practicing engineers more than ever. However, most of engineering courses in the higher education

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still adopt an instructor-led, lecture-based instruction style (Swain, 2003). This delivery mode is often hindered by limited real-life, hands-on problem solving opportunities, visual representations of real-life engineering problems and solutions, and collaborative working environment. Recent publications of the ASEE (American Society for Engineering Education) emphasized that most engineering programs in the U.S. universities confront difficulties in nurturing engineering students as competent problem solvers. This situation can lead to a severe crisis in the current and future competitiveness of business and industry, where professional engineers often encounter complex problems.

Some engineering educators have redesigned their educational curriculum with an on-demand curriculum that focuses more on the acquisition of knowledge and skills needed for proficient problem solvers and therefore increases the capability of business and industry in competing with global enterprises. Not only have these endeavors embraced curriculum redesign, such as setting up new courses and benchmarking prominent existing courses, but they also have adopted new curricular and instructional design theories. Although these initial actions have attracted engineering educators, only a few of these educators have changed their fixed ideas on traditional engineering education.

There are many reasons why engineering educators are persistent in maintaining traditional views of engineering education. A key reason is the lack of instructional design knowledge and skills to develop effective curricula and courses that support engineering students to become professional problem-solvers. As cited in the ASEE article (Duane, 2004):

> "Along with the realization of the need to revitalize our curricula, we also have to admit to ourselves that, as engineering educators, our inadequate background in educational psychology (thinking, problem solving, cognition) has limited our creative ability to develop a more effective engineering curricula [& courses]"

In addition, many of the case studies reported rely heavily on simple description of new teaching and learning procedures, which results in the phenomenon of "*the case study is just a case*," and not a study. That is, considerations for new teaching and learning methods and their potential to improve the quality of engineering education in conjunction with engineering students' problem-solving performance have been unintentionally neglected. In particular, limitations in knowledge and skills on instructional strategies such as collaborative problem-based work and the prevalent tenet – "*new media technology always brings significant learning outcome,*" – serve as major obstacles to advancing engineering education.

Thus, new collaborative efforts among several disciplines are required to improve current engineering education courses by diffusing innovative teaching and learning strategies. The mobile and network technology can extend the students' learning domain into outside the classroom and promote collaboration. A repository of 3D simulation-based case studies and comprehensive, interactive, engineering problems can strengthen the students' capabilities to tackle real-life problems and provide creative, optimal solutions. The instruction and learning can be accessed and managed through an integrated software, and can be supplemented by a variety of evaluation tools – both at the individual and group levels – that can provide constructive feedback throughout the course, which is another strong feature of the article. The incorporation of each of the aforementioned techniques has proven to be successful in a classroom environment, as reported by a number of research groups in the world.

The article aims at developing and implementing a novel technology-enhanced instructional method that combines mobile technology, simulation-based delivery, and collaborative problem-based learning in order to overcome the limitations. The uniqueness of the instructional method in the article is the *integration of the proven methods into a unified instructional paradigm* to maximize students' problem-solving performance, motivation and meaningful learning. Such an article is likely to contribute to building a knowledge base of Science, Technology, Engineering, and Mathematics (STEM) by: (1) creating new learning materials; (2) designing innovative instructional method and web-based supporting program; (3) implementing new technology; and (4) evaluating the impacts of these procedures on the improvement of the quality of engineering courses.

Designing Instructional Principles

Based on previous research about engineering education, educational psychology, instructional technology, and high technology, we produced the state-of-the-art instructional principles, which increase students' problem-solving performance, motivation, and meaningful learning. To generate the proposed principles effectively, we focused on the following instructional objectives:

- Identify and design complex real-life problems to be given to engineering students
- Transform these problems to computer-based simulation materials and displaying them thereby
- Generate and validate mobile-based and collaborative problem-solving method
- Facilitate engineering student collaboration and interaction in a designated group
- Evaluate the quality of the course based on engineering students' problem-solving performance

Given recent educational paradigms and limitations of current engineering education, five design principles for generating the instructional method emerge. These principles play a role as a guide how to design the instructional method. The rationales and basic assumptions of these principles are as follow.

Principle 1. Providing complex real-life problems

Problem solving, which is a process of identifying a problem, selecting and implementing alternatives for a solution, and evaluating the outcomes to solve the problem, has been regarded as one of the most important activities in human life (Anderson, 1995; Jonassen, 2000; Meacham & Emont, 1989; Sternberg, 1994b). Some problems are fairly simple and routine so that people have little difficulty understanding the nature of the problem and solving it effectively and efficiently (Jonassen, 2003; Simon, 1978; Smith, 1991). Some problems are extremely complex and difficult and require the evaluation of unexpected risks for accomplishing multiple goals (Brabeck & Wood, 1990; Dillon, 2000; Greeno, 1980; Sinnott, 1989; Voss & Post, 1988).

With complex problems, it is challenging to identify both the problem and its solution. For example, people sometimes interpret their clinical symptoms in terms of their feelings about themselves, rather than objective measures such as body temperature or weight loss. However, instructional problems are designed as learning tasks with the intent that practicing problems can result in the capacity to solve difficult problems. It is obvious that the complexity of learning problems affects successful problem solving performance, in the educational environment, and in the work environment (Meacham & Emont, 1989). Therefore, it is suggested that complex real-life problems in the manufacturing engineering field should be provided to engineering students to increase the possibility of successful problem-solving performance.

Principle 2. Promoting the collaborative work

Collaborative learning in education, which has been regarded as one of the most effective instructional activities, involves a group of learners in solving a wide variety of problems across different knowledge domains. Collaborative learning draws a group of learners' diverse knowledge and skills together by engaging them in shared cognitive process to solve problems that they encounter (Hathorn & Ingram, 2002). Collaborative learning also provides the learners many opportunities to exchange their critical views on solving the problem and taking responsibility for the decision-making process based on the consensus building. Additionally, in collaborative learning, by facilitating discussion, a group of learners produces a more various range of solutions than the individual learner does. Such collaborative learning would create a new environment that group learners have never experienced when they work alone.

A series of studies conducted on collaborative learning ensures the benefit and interest-level of collaborative learning over conventional instructor-led instruction and individualized learning in terms of: (1) collaborative knowledge construction (Leinonen, & Järvelä, 2003); (2) multiple perspectives (Naidu, & Olsen, 1996); (3) shared goal and responsibilities (Shaffer, 2004); (4) various types of interaction (Daradoumis & Marquès, 2002; Murphy, Drabier, & Epps, 1998); and (5) reflective thinking (Nicholson & Bond, 2003). Given the impacts of collaborative learning, it is necessary to incorporate the collaborative work activity in engineering education. After engineering students graduate, they will work in the field as one of teammates. The collaborative work experiences in the class that they have gone through will positively impact their problem-solving and team collaboration skills in their potential workplaces.

Principle 3. Improving the quality of learning materials

The engineering education field has been seeking to improve the quality of learning materials being used in engineering school because engineering educators often face the perceived ineffectiveness and unattractiveness of learning materials. For this reason, many researchers in engineering education have focused much of their attention on identifying influential interventions that can increase the quality of learning. These interventions guide them to design more effective instruction by directly applying sound treatments (Hayes, 1989; Silver and Marshall, 1990; Jonassen, 2000; Smith, 1991). Many studies (e.g. Jonassen 1997, 2001; Silver and Marshall, 1990; Zhang, 1997) suggest that varying degrees of the quality of learning material are attributed to, in part, lack of meaningful representation of real situations. These studies argue that real situations had much to do with the quality of learning materials. Thus, any intervention incorporating real situations will be a key to enhancing the quality of learning materials.

Educational simulations have been highlighted as an effective method among instructional strategies, as it is capable of incorporating real situations to enhance problem-solving performance (Gredler, 2004). Educational simulation can provide learners with adequate models of the real world where the learners interact, a specific role for each student, a safe environment for learning, and repetitive activities that learners experience (Ferry, Hedberg, and Harper, 1998; Gredler, 2004). In addition, educational simulations make learning material more motivating and interesting and incorporate different educational philosophies and strategies (Allessi & Trollip, 2001). A learning simulation is expected to increase the quality of learning materials more effectively than traditional methods.

Principle 4. Implementing an innovative technology

Despite the fact that many engineering educators stick to the way they have taught in the past, many efforts have been made to improve the quality of engineering education by integrating new media technologies, (Spark & Hirsh, 2000). Thus, the adoption and use of new media technology has become an important issue in engineering education. As a result, e-learning, defined as technology-driven web-based learning, has emerged. However, recently, new media technology like handheld computers, Personal Digital Assistants (PDA), and Palmtops have been given attention because they are expected to overcome the limitations of the traditional computer technology as well as have various advantages for potential learning activities (Petty, 2002).

The use of these mobile media technology in engineering colleges is known as m-learning, which is defined as an extension of e-learning providing smaller learning objects in mobile technology devices to learners anytime and anywhere (Mills, 1999). M-learning has the following benefits: (1) using various mobile devices (PDA, tablet PCs, and digital cell phones) to achieve a higher level of accessibility; (2) focusing on instant messaging and WAP portals to support itself; (3) modularizing and delivering information into a smaller learning object; and (4) connecting necessary information anytime. Using mobile media technology such as Tablet PC's can be an essential part of innovative teaching and learning in terms of accessibility of learning resources, portability of devices, flexibility of collaborative group work, and feasibility of learning activities.

Principle 5. Applying a learning evaluation process(self, peer, and group evaluation)

Traditional evaluation has been interchangeably perceived as a test that reminds students of choosing a right answer in a multiple-choice question. There is a greater need to assess students during the learning process and provide feedback to help them improve their learning. However, the concept and applicability of evaluation is far more than that. Depending on who evaluates and how he or she evaluates, the meaning and the format can be extended to cover traditional evaluations and new types of evaluation like peer evaluation. Recently, the self-and peer-evaluations that are performed by the students have been focused on because its main focus is to improve the quality of learning (Mowl, 1996). Two evaluation methods are being used together. Self- and peer-evaluation help students encourage each other, take responsibility for their own learning, treat evaluation as part of learning, and think reflectively (Brown, Rust & Gibbs, 1994; Race, 1998; Zariski, 1996).

In addition, group evaluation can provide an opportunity for a group of engineering students to understand possible solutions and the processes through which they come about. The focus of peer evaluation is to evaluate the group in which the students are involved, whereas the group evaluation is to evaluate the other groups where each student is not involved. Various evaluation approaches can serve as an indicator of whether the program is carrying the activities that are originally planed. There are several benefits to this evaluation approach: students are provided with feedback; students are able to reflect, refine, and revise their ideas; there are multiple cycles of interaction with the problem; and students gain new perspectives.

Overview and Procedures of the Instructional Method

Based on the instructional objectives, we designed an instructional method that is designed to incorporate five instructional principles that will help the students to become better problem solvers and implement the mobile-based learning system. The overview of the instructional method of mobile technology-enhanced collaborative problem solving is addressed in Figure 1.

The implementation procedure of the instructional method of mobile technology-enhanced collaborative problem solving is illustrated in Figures 2.

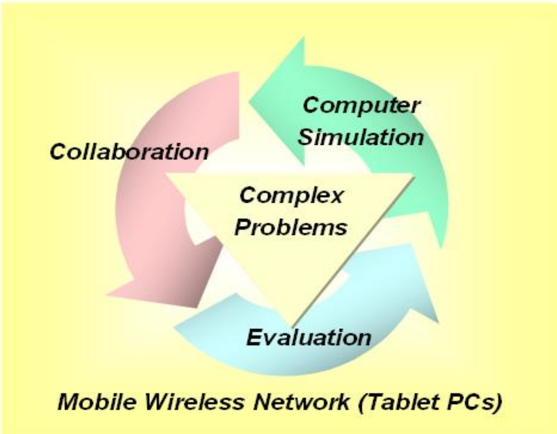

Figure 1. Overview of the instructional method

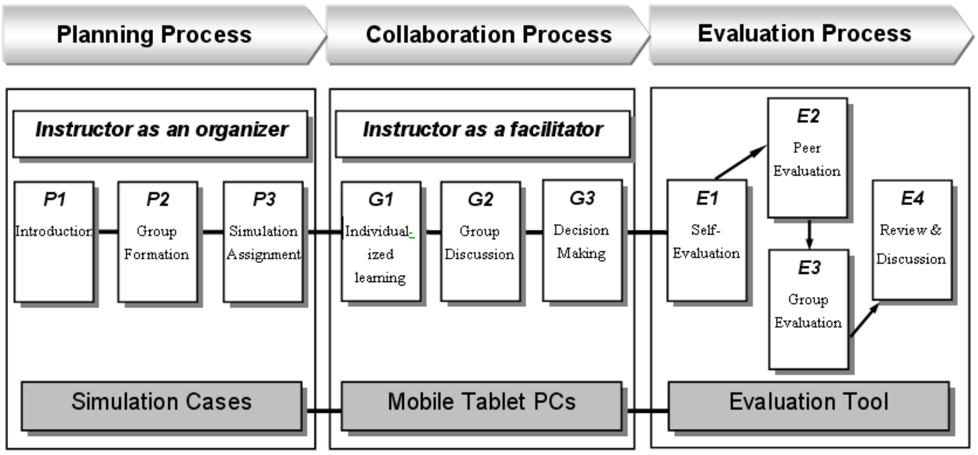

Figure 2. Procedures of the instructional method implementation

Step 0: Workshop

- Prior to the implementation of method, we should conduct a series of workshop to provide the faculty and the students with the introduction of the new instructional method. Once the faculty and the students attend the workshop, we should have gained the general principle implemented in the method and how the method will be conducted. All the students of the workshop should gain instructions on the usage of equipment and software (Tablet PC, mobile network, mobile-based learning system, etc.), collaboration activities, and troubleshooting..

Step 1: Preparation Process

- Introduction (P1) – Each student will be provided instructions explaining the specific purpose of the course, specific procedures to be used, potential risks and benefits, confidentiality of data, and voluntary nature of participation.
- Group Formation (P2) – The class is divided into small groups (about 3-4 students per a group). Each student will be randomly assigned to one of the groups. The students within a group will decide the role and responsibilities of each member.
- Simulation Assignment (P3) – The faculty will retrieve complex problems (simulation cases) from the repository and randomly assign two of them to the participating groups. The students will access the assigned simulation and play it individually.

Step 2: Group Process

- Individualized Learning (G1) – Each student will solve the problems individually and refine their solutions based on personal knowledge, experiences, and logic. They will save their knowledge-constructional process to produce the solutions in a personalized discussion board.
- Group Discussion (G2) – The students will meet together as a group and discuss how to solve the real-life, complex problem. They will identify the initial state, the goal state, constraints of the problems, operators and applications of concepts, and rules required for problem solving.

- Decision Making (G3) - They will then choose one of the best possible solutions for each problem and post it on the group discussion board with graphical display.

Step 3: Evaluation Process

- Self-Evaluation (E1) – After finishing problem solving, each student will evaluate himself by accessing self-evaluation tool. He will rate his own performance and activities based on ten multiple-choice questions.
- Peer Evaluation (E2) – Each student will evaluate his peers in the group. He will rate peers' performance and activities based on ten multiple-choice questions.
- Group Evaluation (E3) – Each student will evaluate other groups' performance and outcomes by accessing their group discussion board in the group evaluation tool.
- Review & Discussion (E4) – The faculty will review the solutions that each group has and review and discuss their solution process.

The Design of Mobile-based Learning System

Based on the proposed principles, we designed an instructional method that allows students to collaboratively solve complex problems, presented in the format of 3D simulations. To achieve the previous instructional objectives, we should provide the students with Tablet PCs to access the mobile-based learning system that contains a complex problem (i.e. simulation cases) repository, a personalized discussion board, a group discussion board, and evaluation tools.

A mobile-based learning system for supporting the instructional method with Tablet PCs should be developed based on the aforementioned five principles. The students will be able to access the system through a wireless network using Tablet PCs. The architecture of the mobile-based learning system consists of six main components as illustrated in Figure 3: (1) interface; (2) personalized discussion board; (3) extended group discussion board; (4) simulation case repository; and (5) faculty and (6) students support. The architecture of the system consists of: (1) searching the simulation case; (2) storing individual knowledge construction process; (3) accessing the extended group discussion board; (4) evaluation of learning tool; and (5) help system.

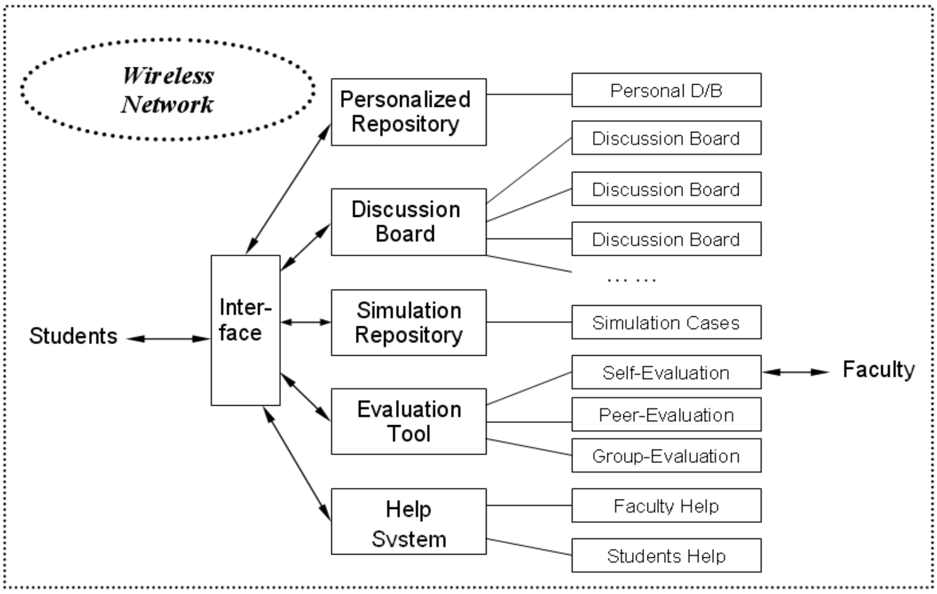

Figure 3. System architecture of mobile-based learning system

Students will be able to search a simulation case from for simulation cases, which will be preloaded with a series of problems. Each student will be able to save his/her knowledge construction process in a personalized discussion board. To support collaborative problem solving, discussion results of a group will be displayed in the extended discussion board, along with a visualization solution to the problem. The evaluation tool is incorporated in the program to support self, peer, and group work. When the students access the tool, they choose one of three evaluation areas (self, peer, and group) and input the ratings for evaluating self, peer, and group work. The data will be automatically collected through the tool and reported to students and faculty directly. Faculty and students support is designed to suggest just-in-time information for participating in the collaborative group work and using the program.

We should use 3D simulation cases that show selected processes of real situation and play narration and sound effects to maximize students' understanding and to stimulate their interests. An example of a simple 3D animation, illustrating a step-by-step procedure of jig system assembly is shown in Figure 4. (A "jig" is a type of workholder designed to hold, locate, and support a workpiece while guiding the cutting tool throughout its cutting cycle.) The components of the jig system were rendered to respective colors and textures depending on the type of material. The example animation incorporated: 1) translational

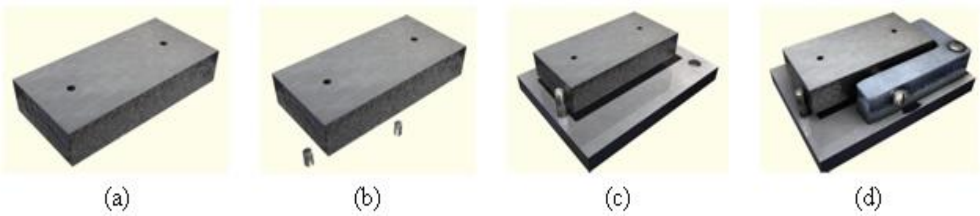

Figure 4. Snapshot images captured from 3D simulation of jig system assembly

and rotational motions of the components; 2) step-by-step assembly process; 3) semi-transparent coloration, whenever applicable; and 4) 360° views at various stages. These features provided the students with a realistic feel for how the assembly is actually performed and how the components interact with one another.

Final Remarks

The aim of the proposed instructional method provides challenges and new opportunities to engineering education field, instructional technology field and national competitiveness in industrial and manufacturing business and industry. The Society of Manufacturing Engineers (SME) addresses their view of the field by saying that:

> "*Innovation, productivity, flexibility, and continuous improvement* are key ingredients to success in the constantly evolving world of manufacturing. At the core of everything SME does is the belief that *continuous learning* is the most effective way for individuals and organizations to accomplish these objectives and gain a sustainable competitive advantage"

The American Society for Engineering Education (ASEE) also addresses their mission by saying that:

> "The American Society for Engineering Education is committed to furthering education in engineering and engineering technology. This mission is accomplished by promoting *excellence in instruction, research, public service, and practice*; exercising worldwide leadership; fostering the

technological education of society; and providing quality products and services to members”

The proposed instructional method recognizes the missions of these two engineering education societies and aligns their specific objectives so as to accomplish the overall missions. Key concepts of the missions are innovation and excellence in instruction and practice. In other words, the missions reflect the needs of today’s engineering education field and competitive marketplace situation. The focus of the proposed instructional method lies in the construction of new educational initiatives that support the quality of engineering education and the needs of societies, business, industries, and universities. Broadly implemented, the proposed instructional method will make contributions to the instructional technology, media education, and educational computing fields.

In addition, the proposed method will impact both educational and technological fronts by introducing novel learning environment and system. The instructional method will incorporate 3D, interactive, computer-simulation-based instruction materials that will stimulate the students’ interests and enhance their learning by visually representing the approaches and solutions of realistic engineering problems. Also, it is expected that the mobile Tablet PCs and the mobile learning system will increase the students’ mobility, enabling their engagements in academic activities both inside and outside the classroom. The thorough, systematic evaluation tools will allow the instructor, students, and analysts to assess the effectiveness and outcome of the proposed instructional method.

In conjunction with educational and technological aspect of the proposed instructional method, the most significant benefit of the proposed method will be the production of competent, creative engineers that will play leadership roles in academia and industries. Through exposure to 3D, dynamic, interactive simulations, the graduates will have a faster grasp of engineering principles and be a team player in a collaborative environment, as compared to those who have been exposed to routine classroom lectures. By bridging the gap between classroom lectures and real-life engineering problems, the proposed instructional method will prepare students for successful engineering careers in an increasingly multicultural and diverse society, and provide the graduates with teamwork, communication, and engineering management skills.

However, the quality and benefit of the proposed instructional method should be conducted in classroom. Even though the purpose of the article was to suggest a new method that seems to be worthy, this method should be validated by iterative and systematic ways of evaluation, including formative and summative evaluation. In addition, although a new technology was implemented with Tablet PC, rather, it might require a more innovative and supplicated media accompanying new media and strategies. Future research will be necessary to determine which particular process and instructional sequences of the method contribute most to overall students' problem solving performance, motivation, and meaningful learning. The suggestions in this article provide a relevant model of the mobile technology-enhanced collaborative problem solving in an engineering class. However, it may be applicable to various field, courses, and class across different academic field and knowledge domain, which focus on the acquisition of problems solving skills.

Equally important, if any of the preparations of the method above are not met, the proposed instructional method will not be usable by potential performance; the knowledge and skills delivered in the method will probably be inert, ineffective, and non-transferable to workplace performance. If all of them are met, the instructional method could be an effective approach by which students can advance their skills and transfer them to the performance environment. The onus is on teachers, instructors, and instructional designers to integrate the proposed instructional method with mobile-enhanced learning system within learning and make dynamic instructional method timely and effective for students.

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