

PLASTIC BOTTLE STRUCTURE DESIGN TECHNIQUE USING VIRTUAL REALITY LINKED WITH FINITE ELEMENT ANALYSIS

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Abstract

The purpose of the study reported in this paper was to design, implement and test a virtual reality system (VRS) linked with finite element analysis (FEA) using e-learning and social media to support higher-education students' learning in plastic bottle design and top-load testing. Five stages of learning activities were designed. Participants in both the experimental and control groups (20 in each) were fourth-year undergraduate students majoring in Product and Package Design in the Faculty of Architecture at a Thai University. The study was carried out over a period of eight weeks in five stages, two groups per week. Testing was conducted using a VR system, a design project, a scoring rubric, a checklist, a top-load tester and a questionnaire assessing students' satisfaction. Results showed a significant difference between the experimental group and the control group in the post-test ($p = 0.001 < 0.05$), while the results of the students' top-load testing skill achievement in the experimental group also revealed that they had improved. The results from the questionnaires on students' satisfaction revealed that the system enhanced motivation.

Introduction

Larson [1] explained that 29 billion polyethylene terephthalate (PET) drinking water bottles are used annually in the United States. This amounts to almost 900,000 tons of plastic, which would consume around 17 million barrels of oil in its production. This is a significant concern because the production of one ton of PET adds 3 tons of carbon dioxide to the atmosphere. The bottles themselves are highly desirable because of their light weight and

suitability to be designed in a variety of shapes. Thus, the sustainable design of such packaging is very important in the context of today's society. Sustainable design encompasses the notion of creating designs with economic, social and environmental sustainability in mind. The potential for recycling of products is an important component of this philosophy. In the context of packaging design, the products and processes should be developed to permit their re-use on a commercial basis wherever possible. One further aspect of sustainable design is to "eliminate negative environmental impact completely through skillful, sensitive design" [2].

Consequently, sustainable thin and lightweight packaging is the industry's design objective in developing eco-friendly innovations in packaging. It is important to reduce the amount of plastic material used in production along with the label size, the transportation costs and environmental pollution. However, the strength of the package during both storage and transportation can fail to meet the required standards as a result of this reduction in plastic material costs.

These requirements create learning challenges in project design, especially for package designers. Students need to understand the limitations both of science and engineering in order to limit the effects of problems such as impractical design or using excessive raw materials for production. However, plastic materials and other instruments are very expensive for testing. Thus, it is difficult to use them for practice in the instructional process and for students' own practice.

For this reason, construction using foam or other materials, together with lectures, is the current approach for students' learning of the design process and for packaging testing in class. Yet this approach can lead to a lack of knowledge and understanding in the Package Design course, limitations in design and packaging testing, and in particular a lack of practical skills with the real instruments for testing, which may subsequently cause damage to the instruments or injury to users. One of the most important tests for use within the drinking water bottle manufacturing industry is top-load testing, which shows the ability of sustaining top-loads of plastic bottles. Top-load testing is considered an indicator of the durability of the plastic bottle during transportation. In addition, performing this test with instruments will use less plastic material, while providing the same top-load values at a reduced cost.

A virtual reality (VR) system has the potential to allow students to explore and experience various new objects in a manner that authentic real-life situations do not allow [3]. The students can experience packaging testing using a VR system and can also interact with various objects as though those items existed in the real world. Computer-Aided Engineering can be used for plastic bottle testing to analyze the strength of the plastic bottle; for example, with Finite Element Analysis (FEA), the software can analyze the structural design in the pre-production phase for time and cost reduction [4]. In addition, FEA software can provide test results close to the actual test results. According to Belblidia et al., [5] FEA has capabilities which are useful for evaluating the optimum design solution of aerosol cans. However, the user needs to understand the specific engineering knowledge for FEA software applications in order to analyze accurately for the optimum results, and it is also necessary to purchase the expensive FEA software license, which makes this approach inconvenient for both general users and industrial users.

A solution to this inconvenience is to combine FEA and VR. Using this combination, students

experience the packaging testing by viewing and moving the object themselves as well as receiving the real test results. They learn the design principles and skills of instrument use for the adjustment of the designed shape of the plastic bottle while saving the costs of materials and instruments for prototype testing. VR is particularly useful in helping to achieve knowledge, skills and expertise through training in situations where real-life practice might be dangerous, inconvenient or too expensive [6-8].

Purpose and Objectives of the Study

The study reported in this paper aimed to design, implement and test a virtual reality (VR) system linked with FEA for student practice learning on plastic bottle design and top-load testing. The system was created specifically for use in higher education level Package Design classes with a number of different learning activities, and was subsequently tested empirically to assess the effects of its application in this manner.

Literature Review

Virtual Reality

VR involves the integration of graphic design, multimedia and image editing in a single product [9]. In addition, VR can also be defined as "an alternate world filled with computer-generated images that respond to human movements" [10]. These definitions are not identical, but sufficient similarity exists to allow the basic interpretation that VR entails computer-generated images which permit the user to feel fully immersed in an interactive simulated world. It is by these criteria that the advancement level of a VR system can be judged. Such a system can employ three-dimensional images which can be particularly valuable in the educational context [11-12]. Cronin [13] indicated that VR can be classified into three groups according to the nature of the immersive experience offered: 1) desktop VR, which typically consists of a desktop computer and is the least expensive and most common form of VR. No other sensory output is

supported so the user lacks any feeling of immersion; 2) a semi-immersive VR system, which uses workbenches or reach-in displays to create the impression of partial immersion, and 3) a fully immersive VR system, which cuts users off from the outside world by encasing them in head-mounted visual display units.

A recent innovation known as caves has also gained popularity. Caves are simply rooms in which the walls are used to display images which surround the user. Audio or sensory interfaces can add to the feeling of total immersion. The fully immersive versions of VR are widely considered to offer the optimal solution since the user can concentrate fully on the virtual surroundings. However, the costs of such systems are generally higher and the technological challenges involved are more complex. In contrast, desktop VR does not require any specialized equipment, and although the immersion level is lower, it is still suitable for use in a number of applications. These qualities keep the overall cost low and have resulted in its widespread educational use [14-15].

Moreover, the continual development of VR has reached a level where innovative training applications have become commonplace in higher education. One drawback, however, has been the high implementation and operational costs, which have placed this kind of technology beyond the budgets of many institutions. This is unfortunate, since the benefits of using VR include its ability to provide creative learning and training materials and environments, especially in engineering, and its ability to motivate students by allowing them to gain first-hand experience of the technology [16].

The learning environment created in cyberspace by VR allows greater versatility and flexibility than the old-fashioned classrooms which foster didactic teaching styles. Students can learn through interaction with the technology, with other individuals or with the applicable software and systems; the application of VR for educational and training purposes is

therefore a significant pedagogical advance building upon the age of computers, the internet and multimedia. Furthermore, VR will help trained personnel to achieve knowledge, skills and expertise when undertaking processes which are dangerous, inconvenient to operate, or too expensive to perform in real life [6-8].

Prior Studies Using VR

A number of studies have applied VR technology. For example, Galvan et al. [8] explained the training system for live-line operators of power distribution systems. Due to increased demand for uninterrupted electricity supplies, the pressure to correct faulty lines and to carry out maintenance of live lines has resulted in the development of live-line techniques; however, as the line-men and technicians are human they tend to make human errors, which results in a high rate of accidents due to shock and the tripping of wires. VR allows trainees to learn and practice appropriate live-line techniques in a safe and realistic environment.

Another study by Tideman et al. [17] explained a new product design method which integrated aspects from several trends in contemporary product design processes. Using scenarios and principles associated with gaming and allied to VR simulation, this new product design method allows a more pro-active role for other involved parties who are not directly responsible for the design, such as production engineers, marketing managers and maintenance workers. This approach was used effectively to create a lane change support system which helps drivers to undertake lane changing maneuvers. This particular design method is particularly successful in allowing the designer to draw upon the opinions, requirements and preferences of all the affected parties, thereby giving a comprehensive overview of what constitutes good design. However, the cost and time involved in using this method must also be taken into consideration to ensure that it is cost effective and user friendly.

VR Linked with the FEA

VR linked with finite element analysis (FEA) as the user interface of an FEA solver has matured from its character based command line driven implementation into easy-to-use graphical user interfaces (GUIs) or virtual reality. This results in an interactive setting where designers can observe and adjust the shape of parts, check how the shape might interfere with surrounding components, and assess the extent to which it undergoes various stresses in real time. Structural problems can now be analyzed and addressed conveniently and intuitively with this new generation of GUIs [18-19].

A review of previous studies found that VR linked with FEA can be used in machine design and engineering material which analyzes the structural design, or can be used before production to reduce the time and the cost of production. For example, a study by Ryken and Vance [19] explained that investigation of how VR methods might be employed in analyzing interactive stresses of a tractor lift arm component by FEA with VR to create an interactive environment was the main objective of their research. Another study by Scherer and Wabner [20] presented a new visualization approach to physical parameters in an immersive workspace. The technique permits the visualization of constraints which underlie the FEA results pertaining to temperature, stress and deformation using virtual or augmented reality applications.

FEA Integrated with VR Technology in Package Design Learning

The use of FEA integrated with VR technology in package design learning allows the development of an interactive setting where designers can observe and adjust the plastic package shape and check for interference of the new plastic package shape, to evaluate the resulting stresses, and to evaluate the top-load value. This approach can use the FEA software license at a distance via the network system

from other educational institutions which have FEA software.

This approach differs from traditional desktop VR and VR linked with FEA because users are permitted to interact directly with objects in the VR setting with real test results. This interaction contrasts with the regular desktop VR which has no real test results and involves users interacting indirectly by manipulating on-screen characters (avatars) instead. Moreover, users in a new VR linked with FEA need no understanding of the specific engineering knowledge for FEA software applications and there is also no need to purchase an expensive FEA software license. The use of both desktop VR and VR linked with FEA has increased, including cases of applications for package design learning. These systems do not, however, automatically integrate package design learning activities, nor is it possible to incorporate such materials within the systems.

Furthermore, the traditional method for top-load testing using real instruments has the advantage of using tangible objects (e.g. the instruments and bottle) but the disadvantage of a higher cost of goods manufactured (e.g. cost of maintenance, cost of purchase). The proposed method uses the VR system to simulate the use of real instruments from turning on the instrument at the start to getting the final results. The VR system offers an advantage in the steps of pressing the VR buttons of the VR Tester because an alarm can sound when an error is made; with real instruments, such errors might cause damage to the instruments or injury to users.

The Development of the VR System and Learning Activities Design

Development of the VR System

Three stages were involved in developing the VR system for student practice learning on plastic bottle design and top-load testing: definition, design and construction.

Definition Stage

Initially, information was gathered through a review of the literature, analysis of the problem, and a questionnaire using both a 5-point Likert-type scale and a selection of open questions to survey the requirements of the sample participants. The data collected was then used to develop the composition of the learning system design. The participants comprised 30 third-year students in the Product and Package Design Department of the Faculty of Architecture at a Thai University. The outcome revealed that these students were interested in using a VR system to practice testing the quality of their package designs. The answers provided to the open questions revealed further student problems: 1) Poor levels of knowledge of material selection for plastics; 2) Insufficient instruments and materials for constructing and testing plastic packages; 3) Communication limitations between package designers and manufacturers leading to misunderstandings; 4) Inadequate understanding of the limitations in testing designs and packaging.

Design Stage

The second stage sets out all the components of the virtual environment, including the design of the conceptual framework, the course objectives, the design of the learning activities, the structure of the project the students will carry out, and the level of authenticity provided by the VR system. Design of the VR environment was carried out in accordance with the definitions, videos, images, manuals and ASTM D2659 standards [21]. The importance of this stage lies in ensuring that all students are able to demonstrate learning achievement in testing designs and packaging. All of the elements required for the testing process (instruments, laboratory and plastic bottle) were modeled to scale. The virtual laboratory environment was modeled from the 3D perspective to provide a higher degree of realism. All objects were modeled using Adobe Flash Professional CS6 software. The virtual environment is shown in Figure 1.



Figure 1: Virtual environment of the VR system.

Construction Stage

The final stage involves the construction of the virtual application itself. This includes the creation of virtual scenes which incorporate animations, audio and interactivity. The interface must also be developed and a link constructed to the FEA program. The accuracy of the VR tester results must then be checked via comparison with test results obtained from real instruments. This is also when the ability of the system to interact with the user and produce sounds must be developed, with a script used to depict the user's interaction with the virtual environment. This interactivity was produced using Adobe Flash Professional CS6, Adobe Dreamweaver Professional CS6 and Microsoft Visual Studio 2013.

Development of the VR system interface was completed to meet the requirement of the course to offer authentic learning scenarios, to incorporate learning activity designs and to meet ASTM D2659 standards. The interface of the VR system shown in Figure 2(a) can be subdivided into five parts, dependent on the user. Parts 1-4 are allocated to the student, while part 5 is for the teacher, as follows: 1) Adjustment menu, for making bottle thickness alterations and material selections; 2) Help, which demonstrates the use of the controls for

the test program; 3) Virtual environment; 4) Test results; and 5) Process error report.

This interface is therefore the site of the users' interaction with the learning system. The testing program is operated using a keyboard and digital mouse in accordance with the demonstration, and can be used in most classrooms.

Figure 2(b) shows the screenshot of the VR system download. Teachers and students could access the VR system by downloading the software from e-learning lessons and learn by themselves using an avatar to enter the laboratory. We used e-learning and social media to support the VR system in the Package Design IV course. The moodle was used as the e-learning platform, and is not only designed to help instructors create quality online content along social constructivist lines but also provides a platform for students to understand information relevant to the Design of Sustainable Plastic Bottles within the e-learning lessons prepared by the instructor. These lessons can be subdivided into five categories, as shown Table 1. Furthermore, social media (e.g. Facebook and Line) offer a means to enhance the educational experience and learning which supports the VR system, especially for younger users. For example, after registering to use Facebook, the instructor creates groups for the



(a)

(b)

Figure 2: (a) The VR system interface and (b) the screenshot of the VR system download.

Table 1: Learning activities design and procedures.

Stage name	Learning objective	Duration	Learning method (in e-learning lessons)	Procedure	Learning outcome
Stage 1: Introduction	To learn the use of the VR system correctly and to activate students' prior knowledge about the design of plastic bottles	1 week	Download the VR system software, the VR system manual, the e-learning manual, the instruction manual for using social media, the design problem and the knowledge sheet	(a) Students download the VR system software (b) Students register as members and login to e-learning (c) Students learn about the use of the system (d) Students learn about the design problem (e) Students brainstorm about the design problem (f) Students write their existing knowledge	(a) Use of the VR system correctly (b) Prior knowledge
Stage 2: Search and Learning	To search for information and to inspire the creation of a new package design with peer students, teachers and experts	1 week	Studying the document about the influence of shape upon the strength of plastic bottles, sustainable packaging, testing standards, portfolio of bottle images, and tutorial video clips about the principles of package design	(a) Students write a question and share with each other (b) Students search for information about design problem (c) Students share knowledge and write their newly gained knowledge and final concept conclusion	(a) Information technology skills (b) Social interaction skills (c) The best design concept
		1 week			
Stage 3: Design and Conclusion	To design and share knowledge about their design sketches with peer students, teachers and experts	1 week	Discussing and uploading to share their design sketches via web board and chat room	(a) Students sketch 4-5 shapes of plastic bottles (b) Students upload and share their design sketches (c) Final sketch will be obtained from collaborative learning	(a) Design sketch skills (b) Information Technology skills (c) Social interaction skills (d) The best of design sketches
		1 week			
Stage 4: Practice and Testing	To practice design skills, development, strength evaluation of plastic bottles and top-load testing with VR tester	1 week	Learning CAD manual, tutorial video clips showing tips for using CAD software for forming bottles, tutorial video clips about the use of top-load tester	(a) Students create 3D bottle model using CAD software (b) Students practice top-load testing with VR tester (c) Students learn through e-learning lessons for redesign	(a) Design skills with CAD software (b) Knowledge about limits of plastic bottles design (c) The optimal strength of plastic bottles and cost saving (d) Testing skills with VR tester
		1 week			
Stage 5: Evaluation	To assess the design project, top-load testing skills with real tester, and level of satisfaction	1 week 15min/person 15min/person 10min	Submit images of design project for presentation and CAD file for production	(a) Students upload their design project (b) Students present their work (c) Students test their skills with real tester (d) Students evaluate their level of satisfaction	(a) Skills of design project evaluation (b) Testing skills with real tester (c) The optimal plastic bottle design

Package Design IV course, and then adds other students, experts in package design and the package design course teachers as “friends”. The group can then exchange messages about the design problem, post status updates and images of the design project, share tutorial video clips, and receive notifications when others update their design issues.

The VR system enables the presentation of learning materials that receive testing results from the FEA software (ANSYS) via a network system, as shown in Figure 3. This study uses a student group with a teacher on the network system to communicate with the Apache Server (caifea.com) and the FEA Server. The network system of (Student group of University B) can originate from other educational institutions (Student group of University A) which have FEA software. For example, the student group of University B can upload their 3D bottle file via the graphical user interface (GUI) on the web browser. The 3D bottle file is then sent for processing with FEA software (University A) and the results are sent back to the GUI on the computers and also to the students’ e-mail. Consequently, this system can avoid the cost of

additional FEA software licenses and can also build a network of learning communities throughout the system both in educational institutions and in industries.

Figure 4 shows the steps of pressing VR buttons in the VR Tester through which students will practice their skills in order to achieve the skill level of a real tester. Test results will then be obtained to evaluate the design project work.

When the VR test results are compared with real test results, the average error recorded is around 11.16%, as shown in Figure 5. The data reveal that in general, the VR test results are slightly higher than real test results. Furthermore, the VR system was validated by a panel of six experts, including specialists in educational technology, programming, and package design. To evaluate the system in three specific areas, a questionnaire was used which contained both open questions and items which applied a 5-point Likert-type scale. The feedback revealed that the screen design was good, the content and instructional design was very good and the technique was also very good.

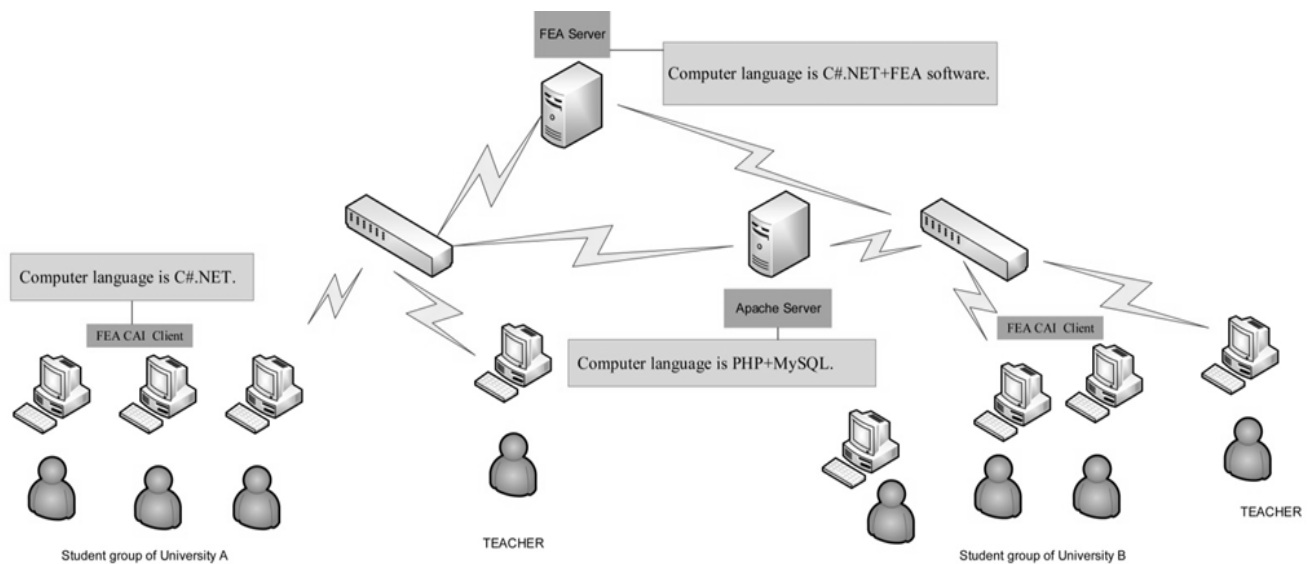


Figure 3: System architectural diagrams of establishing a link with the FEA software.

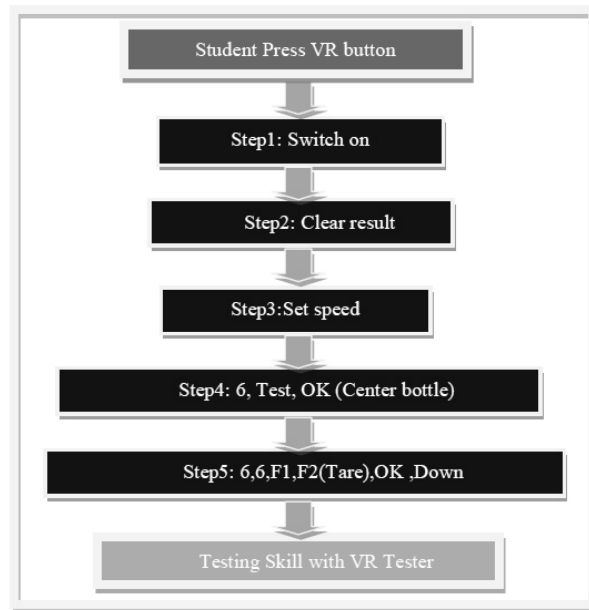


Figure 4: Steps of pressing the VR buttons in the VR tester.

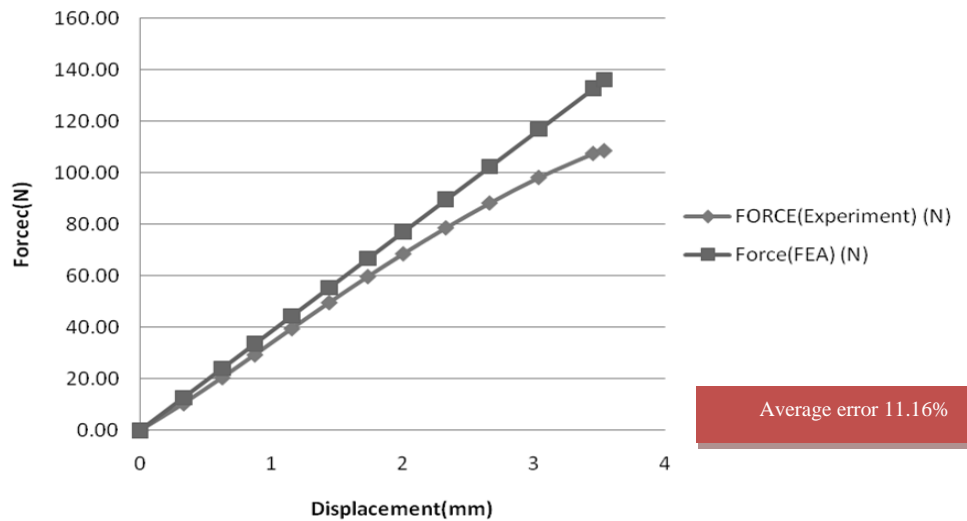


Figure 5: Comparison of the results between the real tester and the VR tester.

Learning Activities Design

The Package Design IV course required practice in package design project management, including experimentation and testing, and the ability to analyze packages in terms of meeting physical requirements and also the psychological or aesthetic requirements which might confer marketing benefits. Additionally, this course covers both architecture and engineering; the primary concern in architecture lies in designing the development work while

the engineering responsibility is for ensuring that the design can be implemented in a safe and reliable manner. In this research, we provide a project involving the design of sustainable plastic water bottles. Students gain experience about packaging design and testing in the VR system with learning activities and can also interact with the virtual objects. The real test results are revealed directly on the computer screen.

The learning setting was designed to be applied both inside and outside the classroom; the instructor had to be able to adhere to all the standards outlined in the curriculum and also able to edit the learning materials freely and conveniently at any time. After several consultations with the Package Design teacher, manufacturers of plastic bottles and manufacturers of drinking water, learning activities which fit the curricular requirements were created. The design of the learning activities encompassed five stages: Introduction, Search and Learning, Design and Conclusion, Practice and Testing, and Evaluation, as shown in Table 1.

Stage 1: Introduction

In the orientation stage of using the VR system, the students will first learn from the VR system manual, the e-learning manual and the instruction manual for using social media on the course within the e-learning lessons. Only then will they begin to study the design problem through the e-learning lessons and social media for greater accessibility. The problem will stimulate the activation of students' prior knowledge, critical thinking, analysis and problem solving. Brainstorming will help them to explain and write their existing knowledge (K = Know) into the knowledge sheet, as illustrated in Figure 6.

Stage 2: Search and Learning

Students write a question that they want to know (W = Want to know) into the knowledge sheet and share with each other both face-to-face and via social media, then they search for the information to inspire the creation of a new packaging design through the e-learning lessons, or from external sources such as using search tools (e.g. Google and Yahoo), communication tools (e.g. Facebook and Line), or receiving additional coaching from expert advisors who are on hand to assist, in order to find the solutions together and write the new knowledge into the knowledge sheet (L = Learned) as well as a final concept conclusion using mind maps with the instructor monitoring, as illustrated in Figure 7.

Stage 3: Design and Conclusion

Each student sketches 4-5 shapes of plastic bottles with details of the dimensions, then they upload their design sketches on both the e-learning system and social media to share with other students, teachers and experts, in order to select the best of the design sketches from each person, as illustrated in Figure 8.

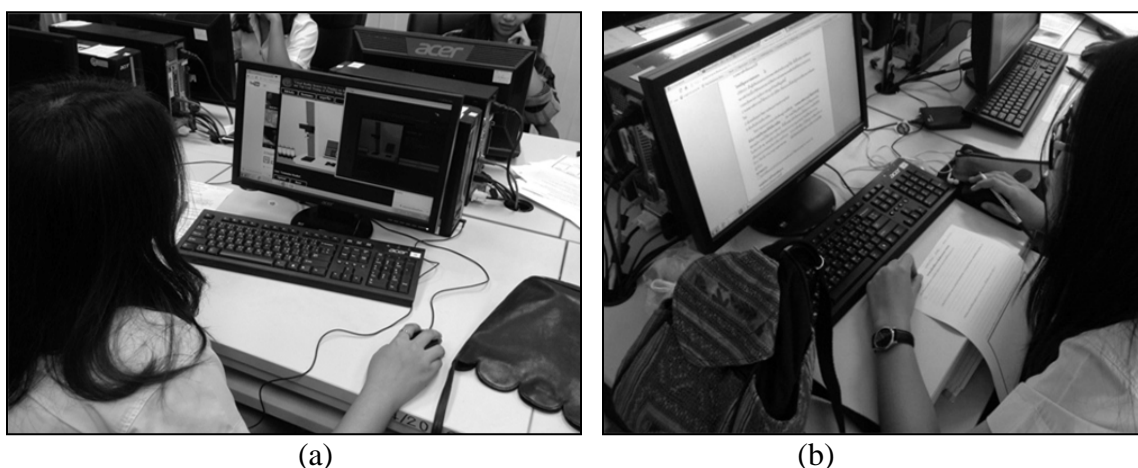


Figure 6: (a) Students learn how to use the VR system and (b) begin to study the design problem.

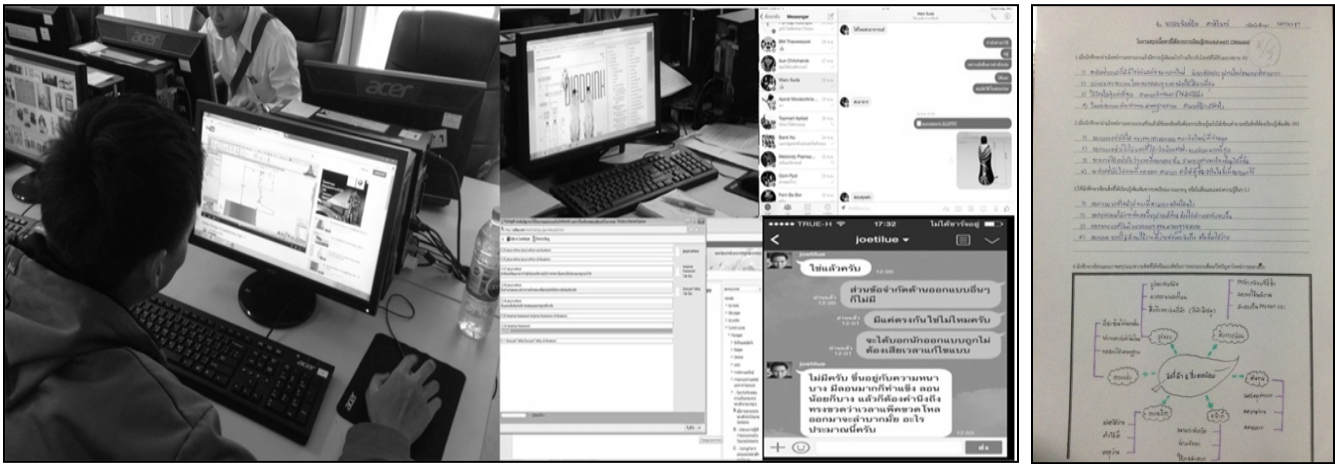


Figure 7: (a) Students brainstorming, searching for information and (b) a final concept conclusion.

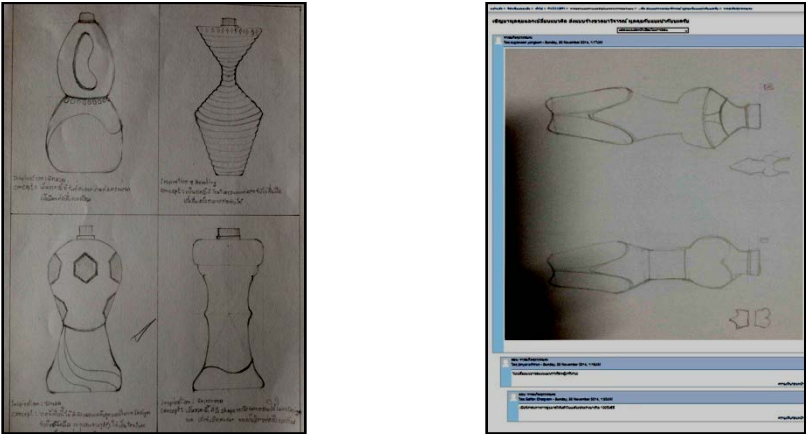


Figure 8: (a) Design sketches of plastic bottles and (b) sharing their design sketches through e-learning.

Stage 4: Practice and Testing

Students take a selected plastic bottle shape and form the shape as a 3D model of the final sketch using CAD software (Solidworks), then keep their own CAD files. Next, in the context of packaging quality control and learning the limits of package design, the students practice top-load testing with the VR tester to evaluate the strength of the plastic bottles. Different materials can be selected and the thickness of the bottles adjusted before bottles are uploaded via the button that appears of the VR tester screen. Thus, they can upload their CAD files to

the server and then receive FEA results (FEA simulation video clips and top-load test results). If the design does not pass the quality standard, the design will be reprocessed using the learning resources and communication via e-learning or social media (For example, they study the documents about the influence of shape upon the strength of plastic bottles and share their knowledge via e-learning or social media) to solve the model problems, before re-testing until a design is found to pass the standard, as illustrated in Figure 9.



(a)



(b)

Figure 9: (a) Forming the shape of the bottle using CAD software and (b) practice testing with the VR tester.

Stage 5: Evaluation

Students upload their design project through the e-learning system or Facebook for peer-assessment to improve their project one week before the presentation of design project. They also present their work in front of the class for their instructor and three external evaluators to assess using the scoring rubric. Then, students' testing skills are assessed using a real tester in

front of one external evaluator using the checklist. The details explaining this evaluation are outlined in the method section. The scoring results of the evaluation will be relayed to the students via the e-learning system and social media. Finally, students evaluate their level of satisfaction with the system using the questionnaire, as illustrated in Figure 10. Figure 11 shows some examples of the completed design work in the experimental group.



(a)



(b)



(c)

Figure 10: (a) Presentation of the design work, (b) skill test with the real tester and (c) evaluating the level of satisfaction.



Figure 11: Some examples of design project work.

Methods

To achieve the study objectives outlined previously, an empirical study was performed in order to investigate the effects of using the VR system by comparing two groups using different package design learning methods. Both groups were taught by the same instructor. 40 students participated in the study in total, and quantitative techniques were used to analyze the resulting data.

Participants

- Students:** The participants involved in this study were 40 fourth-year undergraduate students in the Package Design IV class for the first semester of 2014, majoring in Product and Package

Design at the Faculty of Architecture at a Thai University. Participants were divided into two groups using Kelly's Technique of 27 percent (two groups post-test only design), then the lottery method (simple random sampling) was used to select the experimental group. The VR system was used with the experimental group while the other group acted as the control group, and was trained using PowerPoint slides, images and videos (teacher-centered). There were 20 students (9 males and 11 females) in the experimental group and 20 students (7 males and 13 females) in the control group. These students had already completed foundation coursework in design fundamentals and CAD software.

- *External evaluators:* Three external evaluators used the scoring rubric to evaluate the achievement of students in the design project for three aspects. The three evaluators held master's degrees and had more than 5 years of experience in teaching. Their individual areas of expertise were package design, packaging technology, and production engineering. Additionally, one external evaluator used the checklist to evaluate the students' skill achievements in top-load testing. This evaluator was a technical teacher who had more than 5 years of experience of teaching in the Civil Engineering Department of the Faculty of Engineering at a Thai University.

Procedures

The study was carried out over a period of eight weeks in five stages, two groups per week, as shown in Table 1.

Instruments

Numerous instruments were used in this study, including the VR system, design project, scoring rubric, checklist, top-load tester and questionnaire, as follows:

- VR system: For the experimental group, the VR system was first introduced by the

teacher. Students learned how to interact with the system through learning activities for each stage via e-learning. For the control group, the learning materials were presented via PowerPoint slides, images and videos. Figure 12 shows both the experimental and control groups during the study.

- Design project: The design problem under the title of "Love Sports and Eco-Friendly" was given in the project. The students were given seven weeks to complete the project. Solving the problems required students to design as follows:
 - a. A new structure for plastic drinking water bottles of 600 ml.
 - b. Reducing the amount of plastic material.
 - c. The top-load values must fall between 8-12 kg.
 - d. Reducing space for storage and distribution.
 - e. Ergonomic non-slip handling.
 - f. The bottle design could be formed in a commercial manufacturing process.
 - g. Details of complete presentation consistent with the design title.
- Scoring rubric: The assessment of students' achievement in the design project for three aspects using the scoring rubric (analytic rubrics) as shown in Table 2.



(a)



(b)

Figure 12: (a) The experimental group using the VR system and (b) the control group using PowerPoint slides.

Table 2: Scoring rubric for the design project covering three aspects.

Aspect	Items	Weighted score (100)
1. Innovation (40 points)	1.1) Innovation implies the creation of new and original works that are created for the first time.	10
	1.2) Adaptation implies improvement from the original works to achieve beauty, strength, reasonable costs and environmental friendliness.	10
	1.3) Synthetic implies synthesis and the use of different techniques (more than three techniques) to design the bottle.	10
	1.4) Beauty implies works which are both beautiful and exquisite.	10
2. The function of the packaging (40 points)	2.1) The strength of the drinking water bottle must have a top-load value between 8-12 kg which is the industry standard.	10
	2.2) The environmental performance must reduce the amount of plastic material which makes plastic bottles lighter and thinner.	10
	2.3) The functionality and convenience must reduce space for storage and distribution as well as allow ergonomic non-slip handling.	10
	2.4) The efficiency and commercial manufacturing criteria required that the bottle design could be formed in a commercial manufacturing process.	10
3. The complete presentation of the design and consistency with design problems (20 points)	3.1) Details of information presentation included design concept, process, orthographic view, detail, dimensions, thickness and top-load value, perspective view and scale/unit.	10
	3.2) The content of the design must be consistent with the design title.	10

- Checklist: The checklist provides a list of top-load testing skills and encompasses 6 major items according to ASTM D2659, as follows:
 - a. Turn on the tester.
 - b. Set the speed of testing.
 - c. Place the test specimen in the testing machine at the center line.
 - d. Press tare to reset the scale to zero.
 - e. Read the test results.
 - f. Maneuverability of testing.
- Top-load tester: A top-load tester is a tensile testing machine: The Hounsfield H5ks (0442) model was used for skill testing with the real tester.
- Questionnaires: A ten-item technical program and learning motivation questionnaire was designed using a five-point Likert scale and open-ended questions. According to Kizony et al., [22] the Short

Feedback Questionnaire (SFQ) can be used to obtain the subjective responses of participants towards the VR learning experience. The SFQ measures participants' experiences and perceptions in the following categories: realism of the learning environment, sense of immersion, levels of comfort and enjoyment during the process, accomplishment, feeling of being in control, ease of interpreting the on-screen feedback, and the difficulty of the task. Some aspects of the SFQ were integrated in certain items of the questionnaire assessing students' satisfaction toward the VR system, as shown in Table 3. The open-ended question is as follows: What additions to the system would improve your learning experience?

Table 3: Items of the questionnaire on the technical program and learning motivation.

Item
1. Demonstration about how to use the tools in the learning system is easy to understand and appropriate for use in the practice prior to using the real tester.
2. Media or learning system is easy to control.
3. The learning system stimulates and motivates you to study and search for more information for solving problems about design.
4. Techniques of the learning system make the lessons much more interesting.
5. Techniques of the learning system allow you to recognize the experience of learning in the environment as being realistic.
6. Interactive techniques of the learning system are appropriate and easy to understand.
7. You feel success about your learning when you have finished the learning activities.
8. You can learn from the learning system by yourself.
9. You can review the lessons at any time.
10. Login and log out of the system or the lesson are convenient.

Data Analysis

Since the sample was normally distributed, parametric tests were applied to conduct the data analysis. The 2 independent sample t-test was carried out in order to compare students' design project learning achievement between the post-tests of the two groups. For the checklist covering skill achievements in top-load testing, the data were calculated and represented as percentages of passing the skills test.

For the information from the questionnaire about students' satisfaction with system, the data were calculated and represented as an arithmetic mean score (\bar{x}) and standard deviation (SD). The five-point Likert scale used to assess quality was as follows:

- Excellent: 4.50–5.00.
- Very good: 3.50–4.49.
- Good: 2.50–3.49.
- Fair: 1.50–2.49.
- Poor: 0.00–1.49.

Results and Discussion

The following section presents the results as follows: 1) results of design project learning achievement; 2) results of skill achievements in

top-load testing; and 3) results of questionnaires on students' satisfaction.

Results of Design Project Learning Achievement

Table 4 summarizes the descriptive statistical analysis in terms of the mean (\bar{x}) and standard deviation (SD) of the design project learning achievement scores. The results indicate that a significant difference existed between the experimental group and the control group in the post-test ($p = 0.001 < 0.05$). Additionally, the results show that in comparison with the control group, the experimental group made significant progress in design project learning achievement.

Also noteworthy is the fact that the standard deviation of the experimental group was lower than that of the control group, in particular showing less than half the difference in the post-test. However, the standard deviations of the two groups are high because the test measures aspects of the design work that require a variety of skills, resulting in the creation of individual differences, especially in the control group under the traditional learning approach in which students received information passively and did not have the opportunity to interact actively with the system.

Table 4: Comparisons of post-tests for design project learning achievement.

	N	\bar{x}	SD	t	p-value
Experimental group	20	81.7	6.13	5.928	<0.001
Control group	20	66.3	9.86		

* $p < 0.05$

Figure 13 shows the comparison of students' design project learning achievement between the experimental group and the control group in three aspects. These results indicate that the experimental group's score was found to be higher than that of the control group in all three aspects. Interestingly, in the second aspect (the function of the packaging), the data show that the learning achievement scores of the two groups were highly different because in the experimental group, all students could make adjustments to reduce the thickness of bottles to be eco-friendly and then re-test until a design was found to pass the standard. By contrast, students in the control group were not able to use these techniques and the strength evaluation of plastic bottles in top-load testing was tested using the same VR tester, but they could evaluate the test only one time after completing the design project. These techniques made the control group students' scores lower than those of the experimental group.

The problem in this research is that the students in the control group missed an opportunity to learn using the proposed method. However, we solved this problem after finishing the evaluation process; the control students were given the opportunity to learn with the proposed method but without an evaluation process for

the re-learning. Additionally, when students have asked questions via the social media but did not receive the right answer or any answer from social media. This problem can be solved in various ways, such as search engines, email and face-to-face discussion with experts.

Results of Skill Achievements in Top-Load Testing

Figure 14 shows the comparison of students' skill achievements in top-load testing between the experimental group and the control group in terms of 6 major items. In item 1, 100% of the students in both the experimental group and the control group showed that they can turn on the top-load tester. In items 2 and 3, 100% of the students in the experimental group showed that they can set the speed on the top-load tester and 90% of the students can place the test specimen correctly in the testing machine at the centre line. By contrast, only 35% and 10% of the students in the control group have these skill achievements respectively.

For items 4, 5 and 6, 100% of students in the experimental group showed that they can press tare to reset the scale to zero, 100% of students can read the results of testing correctly and 80% of the students have maneuverability in top-load

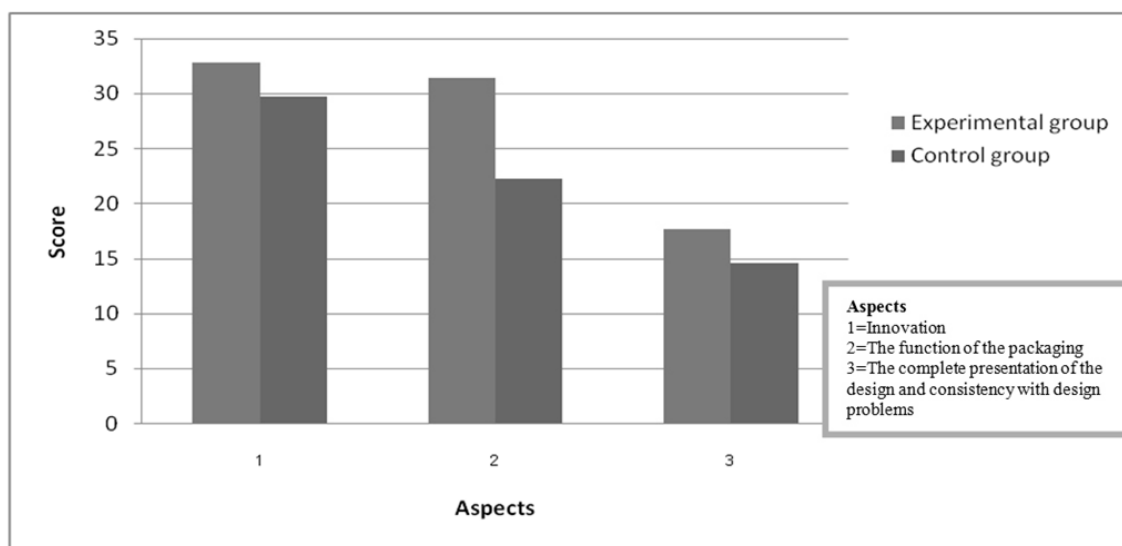


Figure 13: The comparison of design project learning achievement between groups (experimental and control).

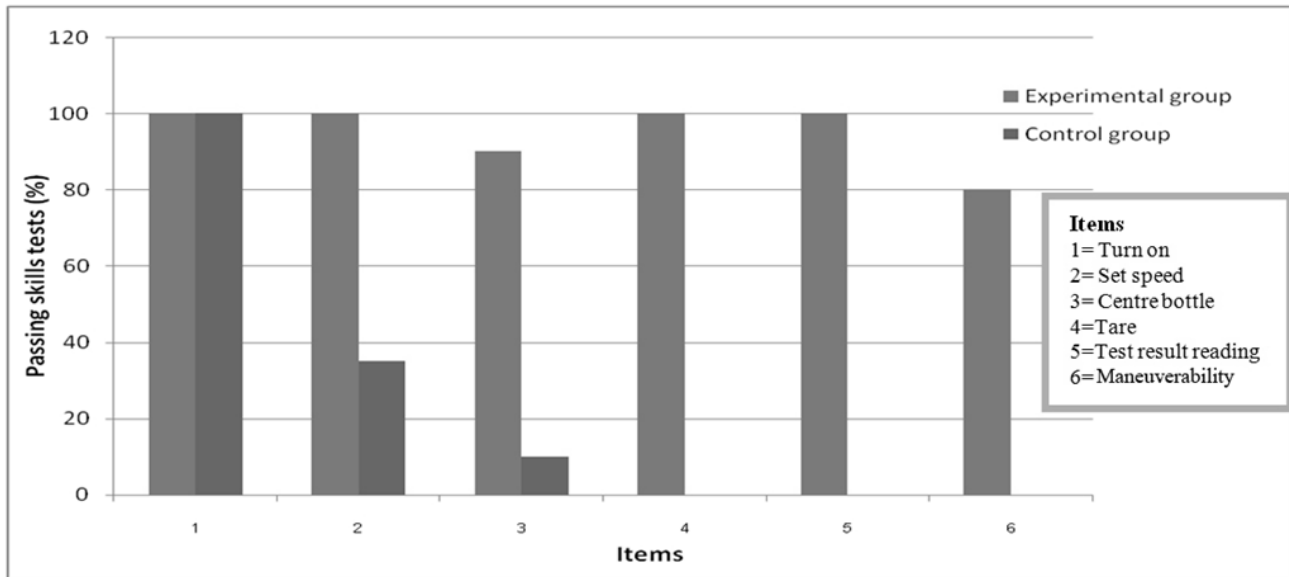


Figure 14: The comparison of skill achievements in top-load testing between groups (experimental and control).

testing with the real tester. By contrast, none of the students in the control group had these skill achievements. These findings show that the system has improved top-load testing skill with the real tester. Interestingly, items 4, 5 and 6 were three items for which none of the students in the control group could pass the evaluation criteria because they had only watched a testing demonstration by video and had no interaction with the VR tester, especially for complex skill practice, while the remaining students in the experimental group would have had a greater opportunity to interact with the VR system. These findings are consistent with research indicating that VR will help trained personnel to achieve knowledge, skills and expertise to perform tasks which would be too dangerous, inconvenient or expensive to practice in real-life situations [6-8].

Results of Questionnaires about Students' Satisfaction

The results show that students awarded high levels in all items (more than 4.50). This indicates that interactive techniques enhanced students' learning motivation in terms of packaging design learning. One of the important

details when considering the items of the SFQ section of the questionnaire was the explanation of 3 key aspects, as in the following paragraphs:

In terms of *ease of control of the learning system*, most students responded that they were able to manipulate the system deftly and easily. The students confirmed that control via the user interface with practice in top-load testing was easy and intuitive, which is consistent with research indicating that the new GUI can be analyzed and addressed conveniently and intuitively [18,19], and they had no need to understand the specific engineering knowledge for FEA software applications. However, one disadvantage of this system was the waiting time (on average 5 minutes) for the testing results to arrive after FEA software processing, which depends on the complexity of the model. The proposed solution was to introduce a queuing system for the tested bottles and to increase the number of computer processing servers. FEA software is the key factor that determines the accuracy of the testing results, which results in a verdict of passing or not passing the required quality standard for plastic bottles. In a previous study, FEA showed the

capability of evaluating the optimum design solution of aerosol cans [5].

In terms of *the learning system allowing students to recognize the experience of learning in the environment as being realistic*, most students expressed that they felt the learning environment provided a realistic setting. Additional methods were used to increase student engagement levels with the learning activities: for example, students controlled the cartoon character to walk into the laboratory for testing the bottles via mouse and keyboard. Accompanying students' realistic results in plastic bottle testing, these techniques helped students to feel that they were engaged in a realistic interactive learning challenge.

In terms of *students feeling success about their learning upon completion of the learning activities*, most students confirmed that they felt a certain level of satisfaction after completing the activities. This matches the results from the design project learning achievements and skill achievements in top-load testing. The results showed that experimental group students had outperformed the control group students, and a vast majority of the students in the experimental group stated that their confidence in design skills and top-load testing had been increased. Therefore it can be concluded that students' confidence levels can be a factor in encouraging active participation in learning activities, which can ultimately lead to successful learning outcomes [23].

Conclusions

In this paper, the empirical results revealed that using the VR system has significantly improved students' design project learning achievement as well as skill achievements in top-load testing with the real tester, especially for complex skills. The experimental group performed better than the control group both in design project learning achievement and skill achievements in top-load testing. Students actively participated with the VR system which represented an improvement over the

participation levels arising in the traditional classrooms using PowerPoint display slides, images and videos. These results demonstrated how the use of the VR system in Package Design IV classes can benefit students in terms of participation and learning outcomes. Additionally, the results of the technical program and learning motivation questionnaire show that most students were motivated by the VR system to learn Package Design, and they encountered few difficulties in using this learning system.

This paper clearly demonstrates the significant benefits of integrating VR technology linked with FEA using e-learning and social media to support an interactive learning environment for Package Design learning. However, the study was limited to top-load testing. Therefore, it will be useful to conduct further studies to examine the drop testing of drinking water bottles in order to further develop and expand upon the results described in this paper.

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