Advance Access publication on 1 April 2014
doi:10.1093/iwc/iwu010

A Virtual Experiential Learning and Students' Ill-Structured Problem-Solving Ability

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In order to provide students with an experiential learning experience and understand the effect of a three-dimensional (3D) virtual learning environment in students' ill-structured problem-solving ability, the study designed a 3D virtual company (3DVC) for the participants to be a general manager to solve several complex problems for different departments. The study selected one class of business students to participate in the experiment. The entire procedure comprised pretest, 3DVC training and posttest. The results were analyzed through a paired sample *t*-test to understand if there is any significant difference between pretest and 3DVC, and pretest and posttest. The results showed that the participants made a significant improvement in ill-structured problem-solving ability after the 3DVC training. The results provide important references for educators that a 3D situational learning environment is beneficial in improving students' ill-structured problem-solving ability.

RESEARCH HIGHLIGHTS

- The study firstly combined situational problem-solving learning and virtual reality.
- The study provides a real-like environment for students to learn problem solving.
- The designed system highly motivated students' problem-solving learning.
- The results proved that the system is helpful in students' problem-solving ability.

Keywords: computer-assisted instruction; E-learning; scenario-based design; virtual reality

Received 21 August 2013; Revised 10 February 2014; Accepted 19 February 2014

1. INTRODUCTION

Students have to practically face numerous hard and ill-structured problems when they go to work. As most of these problems are complex and difficult, they usually need to pay a lot of cost (for example: time or money) to acquire the related experiences. Therefore, how to enhance students' problem-solving ability and reduce the above-stated cost is probably one of the most important concerns of educators.

Ill-structured problems are usually very complicated, with vague objectives, difficult to handle, and the related information that is required to solve the problem is usually insufficient (Chi and Glaser, 1985); in order to help students to be well experienced to deal with the related problems, educators have been trying different ways to address the issue.

Fortunately, the application of virtual reality (VR) technology in the recent decade has greatly changed learners' role and provided students with active learning opportunities, which made them be more effective in facing their future career (Bridge *et al*., 2007; Engum *et al*., 2003). With features like immersion, interactivity and presence (Bhatt, 2004; Walsh and Pawlowski, 2002), a virtual learning environment (VLE), constructed from VR technology, provides learners with hands-on experiences and a three-dimensional (3D) real-like environment, where learners can immerse themselves to get real-like experiences. In the past decade, researchers have employed a VLE as a facilitator to enhance students' professional ability or notion construction (see section 'Experiential learning and situated learning' for reference), which were hard to understand in the usual learning context. However, the VLE's role was still mainly limited to clarifying learners' concepts, rather than guiding them to learn problem solving.

In a traditional classroom, students mostly rely on note-taking or lecture-listening to acquire knowledge. However, the study argues that experiential learning would be a more effective way (Jarmon *et al*., 2009; Kolb, 1984; Mills and Araujo, 1999) for students to accumulate personal experiences so that they would pay less to be experienced in ill-structured problem solving. As the problems in the real world are really complex, it is not enough to have students merely make paper decisions or deliver knowledge by one-way communication (such as lecturing). Educators have been trying to facilitate students' problem-solving ability through case study (Ballantine and McCourt Larres, 2004; Shulman, 1986; Wood and Anderson, 2001) or role-play (Van-Ments, 1989); however, past researchers have criticized that some cases provide too much information and make it had for students to make a decision (Gloeckler, 2008) and, on the other hand, role-play is complex and difficult to evaluate because 'novices may also fail to develop and practice the intended skills due to a lack of repeated exposures' (Holsbrink-Engels, 2001, p.54). In other words, the above-stated two ways still leave room for improvement. Accordingly, the key point would be how to construct a repeatable and relative economic environment to help students embed the experiences in their mind.

In addition, there has been no research that combined the technique of VR and ill-structured problem solving; it is worth understanding the effect of a VLE on students' ill-structured problem-solving ability, and this drove the researcher to conduct the study.

To understand the effect of a 3D VLE in helping students' ill-structured problem-solving ability, the study designed a 3D virtual company (3DVC) with three different departments for students to experience ill-structured problem solving. The participants were requested to be a general manager to solve ill-structured problems for different departments when they go to work in the VLE. The instruments utilized to collect data and analyze the results will be described in detail in the following sections.

Based on the above, the purpose of the study is therefore to explore: (i) whether a 3D VLE is helpful in facilitating students' ill-structured problem-solving ability; that is, whether a 3D VLE drives participants to perform better; (ii) the participants' attitudes, thoughts or opinions about the learning. It is anticipated that the study would provide critical references for improving ill-structured problem solving.

2. THEORETICAL CONTEXT

2.1. The rationale to use VR

The authenticity of the learning environment is supposed to be closely related to knowledge transference because the learning process or the learning environment plays a pivotal role in learning (Huerta-Wong and Schoech, 2010). Constructivists (Vygotsky, 1978) also stressed that providing learners with a hands-on experiential environment would be the key point in helping students transfer classroom knowledge to the real world. The reason why the experience is important and valuable is because once the learner gets an experiential learning opportunity, the experience would embed in his/her mind and the transference of the experience would become more possible in the future (Chittaro and Ranon, 2007).

Based on Dewey's interest theory of learning (1913), a learning environment with more multi-modal sensory feedback will supply learners with a stronger perception of presence and immersion, which thereby makes the learning experience more transferable to the real world. In the researcher's opinion, paper knowledge remains as just words on paper unless it can be applied to the real world; therefore, the study is trying to construct a real-like environment to make students engage in the environment and, hopefully, it would be much easier for the students to adapt the very different ill-structured cases in the real world.

Moreover, learning is not merely the communicative process between learners and instructors of the classroom but the meaningful process about how to make knowledge be more transferable (Moreno and Mayer, 2000). The instruction media thus become pivotal to implement the objective. Moreover, past research also suggests that a digital-based learning environment might be effective to enhance motivation (Johnson and Huang, 2008; Kebritchi and Hirumi, 2008) and learning performance (Gee, 2003; Prensky, 2003). In the researchers' opinion, learning is not merely memorizing, but, from today's viewpoint, a meaningful knowledge construction process supported by personal experiential experiences. Therefore, a motivational learning environment could address the reasons to drive learning motivation and why the learning performances are improved (Astleitner and Wiesner, 2004). From another viewpoint, how to make learning be more applicable and helpful would also be a critical issue.

Recently, modern computer technology has transformed learners' role from being passive to being active with learner-initiated and learner-controlled functions by engaging learners in an active, constructive, intentional, authentic and cooperative learning environment (Jonassen *et al*., 2008). In this regard, VR would be a promising tool to achieve the tasks. Notably, the 'presence' of the objects in the VLE often makes it hard for learners to tell virtuality from reality (Steuer, 1992); this not only highly motivates learners' interests in the learning process but also makes the VLE be more advantageous than any other learning tools. Therefore, a VLE that is constructed by

VR technology would be the most proper alternative to support learning.

2.2. Experiential learning and situated learning

An experiential learning theorist defined the term as: 'the process whereby knowledge is created through the transformation of experience. Knowledge results from the combination of grasping and transforming experience' (Kolb, 1984, p.41). Based on the theory, experience would be a key point impacting on students' knowledge transfer. In addition, past study also noted that applying technological know-how to build an experiential learning environment is one way to achieve the transference (Turney *et al*., 2009); this implies that when students are exposed to a real-life environment, it becomes more possible to apply the experiences they learned to reality. In addition, experiential learning theory has also stressed that learning could be enhanced through the reflection of substantial experience and feedback (Kolb, 1984) because 'one of the most important and powerful aspects of experiential learning is that the images in our brains come from the experience itself' (Zull, 2002, p.145). Therefore, based on the theory, one can infer that modern computer technology could achieve the transition because highly developed computer technology has the potential to reach learners' needs and enhance their learning (Turney *et al*., 2009). Students can be trained in a closed and safe environment, which enables them to shorten the time of the experience and reduce the visible or invisible costs they have to pay.

In the meantime, situated learning theory (Lave and Wenger, 1991) has attracted more attention in the past (Bell and Morris, 2009; Glahn *et al*., 2008; Herrington and Oliver, 2000); the theory stressed that learners should be considered as participants in a community of practice; they are performers of their own learning in the process. Very importantly, studies reported that a situated learning environment is effective in facilitating students' learning motivation and performance (Clark *et al*., 2006; Sierra *et al*., 2012; Yasar and Adiguzel, 2010). Specifically, a situated learning environment that is built with 3D technology 'can be used to facilitate experiential learning tasks that lead to increased intrinsic motivation and engagement' (Dalgarno and Lee, 2010, p.20) because learners can enjoy the sense of immersion that comes from their physical sensation or psychological perception and which triggers their higher engagement in the learning process (Hedberg and Alexander, 1994). Notably, learner engagement is of foremost importance to learning success (Herrington *et al*., 2003).

Based on the above, one can infer that a situated learning environment that integrates with VR technology would still be promising in our predictable future when compared with a 2D alternative (Dalgarno and Lee, 2010) because 'problem situations that closely resemble real situations in their richness and complexity so that the experience that students gain in the classroom will be transferable' (Schoenfeld, 1992, p.365).

Notably, in the past years, researchers from different areas have utilized VR technology to build various learning interfaces to facilitate students' learning. For example, in terms of school education, a game-based learning environment can be developed by VR to improve students' learning motivation and engagement, and their learning performance was then improved (Merchant *et al*., 2014; Virvou and Katsionis, 2008; Yang *et al*., 2010). Meanwhile, educators also utilized VR to build an all-dimensional learning environment to enhance students' understanding and learning performances from the standpoint of various professional areas (Dodd and Antonenko, 2012; Heid and Kretschmer, 2009; Hwang and Hu, 2013; Kartiko *et al*., 2010; Lee *et al*., 2010; Merchant *et al*., 2013); the results all proved to be very positive or effective. Moreover, the immersive feature of VR education makes it be so attractive, which leads to the students' higher engagement and better performance (Di Blas and Poggi, 2007; Limniou *et al*., 2008; Shih and Yang, 2008). Generally, the key point of the above research is to utilize VR's promising features (such as interactivity, engagement, immersion and interest) to make learning be more interesting and different so that the results would be more applicable to real life.

However, regretfully, VR was still kept to be in the role of a learning interface. From the perspective of business education, the researcher believes that VR surely can do more in learning; it could be integrated with part of our daily life; then it would be more possible to transfer classroom learning to the real world. Therefore, the study employs VR to build a VLE to provide students with a real-like learning experience.

2.3. Ill-structured problems

The problems or situations that we confront every day are mostly ill structured. Namely, ill-structured problems actually exist in our daily lives. People may have to face different situations in various contexts in their human experiences; this leads to different cognitive process and mental organization for children or adults, experts or novices to develop their problem-solving ability (Chi and Glaser, 1985). However, one remarkable thing is that ill-structured problems are usually vaguely defined and with insufficient information; this makes it more difficult and complex for people to solve problems. Additionally, solving ill-structured problems requires domain knowledge and justification skills (Shin *et al*., 2003). On the other hand, notably, ill-structured problems usually have multiple solving alternatives (Chi and Glaser, 1985). That is, unlike well-structured problems, ill-structured problems are open-ended and practically have no fixed answers, which require solvers' higher order thinking and all-dimensional consideration when solving the problems.

Based on the above, one can understand that problem solving is actually a situation or a status that requires solvers' cognitive skills to reach a goal. Accordingly, the present study defines ill-structured problem-solving ability as: the competence or skill to reach a goal or improve the situation in a context that is not well defined.

In the world of business, people often run into problems that are with no specific scope or definition but with multiple solutions, which makes them become more difficult or complex, for example: developing a new market (with insufficient information about how to reach the goal), the quick decrease of a firm's sales volume (the causes are vaguely defined) or the decision of entry into a new business (with multiple solution alternatives). Solving problems like the above requires clear thinking, taking of a quick decision and integration of knowledge from all perspectives by the solver. It is notable that the items we developed in the experiment are similar to the above ones, which mainly centered on the area of our daily business life and tested our problem-solving ability.

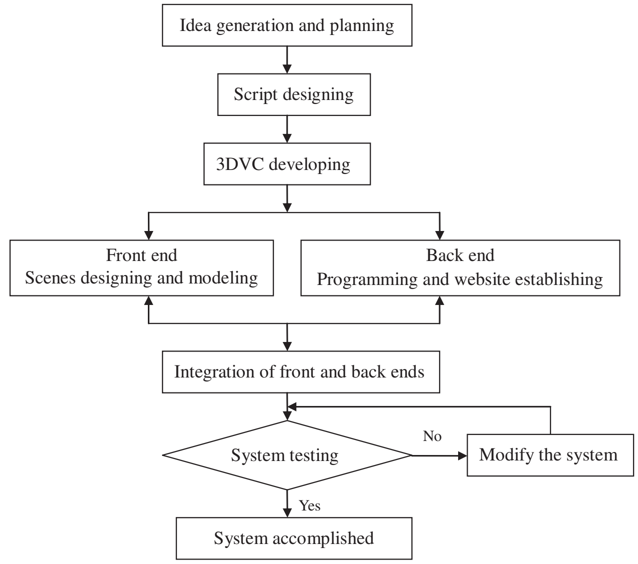

Figure 1. Flow chart of system development.

Figure 2. Registration screen.

3. METHODOLOGY

3.1. System design

At the frontend: The 3DVC designed in the study specifically refers to a computer-simulated 3D learning environment, which provided users with a real-like scene to practice ill-structured problem-solving ability.

The virtual objects in the 3DVC were created by a professional modeling software—3Ds Max. The background of the 3DVC (like the furniture, aisle, ceiling, floor, door, wall and lighting) is designed through 3Ds Max to make them as lifelike as possible.

At the backend: The actions (such as walking, turning head or playing gestures) and expressions of the virtual characters are controlled through Javascript programming. Meanwhile, the answers input by the participants during the experiment are stored in the database at the backend of the system; this is run by MySql. In addition, the system is linked with the Internet through PHP so that it is accessible elsewhere (see Fig. 1 for reference).

3.2. System content

In the beginning, a participant can log into the system by inputting his/her username and password. When the lens is being zoomed in, the glass door, with the big words of 'Da Fa Food Company, Ltd' on it, of the 3DVC opens automatically, depicting noisy and stepping sound effects to represent the busy situation of the 3DVC. Meanwhile, in order to reflect the authentic situation in real life, the study selects some of the departments that we can see in reality (for example, finance, marketing and production departments) to be presented in the 3DVC.

To simulate the pressing situation of the real world, the display of each item was limited to 30 min by a timer shown at the upper left corner of the screen. Before logging out, the participants have to read the 'Expert model' file to understand the organized way of fixing the problems. Moreover, to make the problem-solving procedure be more realistic, when the participant is answering the question, s/he has to deal with minor reports or inquires sent from the subordinates occasionally (see Figs. 2–5 and Table 1 for reference).

3.3. Question development and grading

As ill-structured problems are open-ended and complex, to objectively evaluate the participant's performance, the study invited two management professionals, who have rich experiences in both teaching and practice, to develop the items (including pretest, 3DVC treatment and posttest) and process the grading, so that the items' content validity is ensured.

Additionally, to confirm whether the grading is processed under similar criteria, the study conducted inter-rater reliability

Figure 3. Log-in screen.

to examine the results; if the coefficient is acceptable (for example, above 0.7), it implies that the grading outcome is trustable.

Notably, in order to avoid grading bias caused by the graders during the process (for example, if the grader knows the status of the answer sheets, s/he may make the outcomes purposefully higher or lower), the status of the tests and the participants' personal information were all hidden.

3.4. Participants

The study selected one class of freshmen with management background, a total of 46 students, to participate in the experiment. The purpose is to cultivate their problem-solving ability as early as possible so that it would be more helpful in their future lives.

The reasons for the present study to adopt a one-group design are described as follows: The effect of VR in education had been proved by many prior researchers (Bailenson *et al.*, 2008; Barnett *et al.*, 2005; Chen *et al.*, 2007; Di Blas and Poggi, 2007; Dodd and Antonenko, 2012; Heid and Kretschmer, 2009; Hwang and Hu, 2013; Kartiko *et al.*, 2010; Lee *et al.*, 2010; Lim *et al.*, 2006; Limniou *et al.*, 2008; Merchant *et al.*, 2013, 2014; Shih and Yang, 2008; Virvou and Katsionis, 2008; Yang *et al.*, 2010). The real objective of the study is not to focus on proving once again whether VR is better in improving learning performance when compared with those who did not have VLE experience, but on understanding if the learning situation we provided is beneficial in improving students' ill-structured problem solving ability. Accordingly, we finally employed a one-group design.

To ensure the validity of the experiment, the participants have to be qualified as follows:

(1) The participants all had taken the prerequisite course, management, this ensures experiment validity and confirmed that all of the participants have equivalent prior knowledge.

(a)
(b)
(c)


Figure 4. Different snapshots of the departments. (**a**) The Marketing Department of the 3DVC: two marketing staffs are busy on the phone and one department manager is walking toward the lens to report to the general manager about their problems. The sales chart is displayed at the back. The lighting and layouts simulates the real scene of an office. (**b**) The Finance Department of the 3DVC: the other staffs are out for official business; only two female members are in the office. One of the two is busy on the computer; the other is walking toward the door to report to the general manager. The settings and sound effects present a real condition of the office. (**c**) The Production Department of the 3DVC: two bakers in professional suits are busy producing bread and confectionery; one department manager is walking toward the lens when the general manager knocks on the door. The facilitation and layouts fully address the scene of a production department. Meanwhile, some of the finished bakery products are on the workbench.

Figure 5. A snapshot of the answering screen. While the department manager is reporting the problem, the wordings are presented on the screen simultaneously. After that, each button like 'step 1'/'step 2' and the contents of question prompt bounce onto the screen; then the participant has to input answers in the text input area. Once the text is keyed in, the timer at the upper left corner starts to perform time counting; the participant has to press 'Save' button to save his/her answers, and the time limitation for each problem is 30 min. In addition, to simulating the real-life situation, different sound effects are played while the general manager is solving the problems; to keep the problem-solving procedure going, the participant can stop the disturbance by pressing the buttons (e.g. 'I'm not available'; 'come again later').

Table 1. System content of the 3DVC.

Q1	Q2	Q3
General manager, our key client suddenly confronted cash flow problems, they informed and requested us to agree to their delay payment, but our capital is insufficient, this will make influences on all of our future payment, so what should we do?	General manager, based on our internal information, our sales greatly dropped and the rate of returned purchase significantly increased after head Lin resigned, so what can we do?	General manager, it is really terrible! The big order we received last week was canceled by the client, this will bring us a great trouble on the raw material in stock, what should we do to fix the problem?
Question prompt (1) How would you do to clarify the problem? (2) Now please list at least three alternatives to solve the problem. (3) Which one is the best (or the most feasible) alternative? (4) Why do you think the alternative is effective?		
Theory of the above prompt (Sinnott, 1989; Voss and Post, 1988)		
When the final step solution is entered, the virtual manager comes to bow to the lens and said: 'Thanks for your great help, general manager!'		

(2) The participants' academic performance in the previous semester was distributed normally.

3.5. Procedures and measurement

Table 2 reports the procedures and measurements of the experiment. Additionally, to sense the sound effect of the system and not to bother the others, the participants were requested to wear earphones to operate the 3DVC system. Furthermore, all of the participants were not allowed to talk or discuss during the procedure in order to ensure experiment validity.

After finishing the experiment, the participants had to fill out a self-reported questionnaire for the researcher to understand their attitudes and satisfaction toward the system. This is because whenever a new instructional instrument is employed practically, success is evaluated from the dimensions like students' performance and satisfaction (Alavi and Gallupe, 2003).

With regard to the questionnaire contents, the items of the questionnaire were adapted from a technology acceptance model (Davis, 1989); we refer the reader to Table 3 for questionnaire item contents and source. Notably, the questionnaire was originally in Chinese and then was translated into English by a bilingual professional. Moreover, a five-point Likert-type scale was employed to measure the respondents' attitude toward the questions (5 = Strongly Agree; 1 = Strongly Disagree).

Table 2. Procedures and measurement of the experiment.

Procedures	Measurement	Context	Time limitation (min)
Pretest	Three ill-structured problems with prompt	Traditional classroom	90
3DVC	Three ill-structured problems with prompt	Computer laboratory	90
Posttest	Three ill-structured problems with prompt	Traditional classroom	90

Very importantly, in order to avoid the so-called 'maturation effect' (the memorizing effects that students gained from the last exam) (Bryman, 2004), the study intentionally arranged the items in the entire procedure to be totally different because the situations in management are diversified; the participants have no way to receive any memorizing effect from the previous exam. Therefore, the experiment is free from the 'maturation effect', and the study conducted the different tests every other week after careful discussion with educational professionals.

3.6. Questionnaire reliability analysis

To understand if the questionnaire items are stable and reliable, the present study conducted questionnaire reliability analysis through testing the coefficients of Cronbach α for each item. The questionnaires were sent to 20 freshmen with a business background. It is notable that the participants of the pilot study were isolated from those of the formal experiment so that the validity of the experiment was ensured.

In the reliability analysis, if the item coefficient is greater than the construct coefficient, this reflects that the construct reliability will be better when the item is eliminated, and then the item should be removed. Fortunately, the α value of each item is lower than that of the construct (Construct 1: Cronbach α value is 0.9075; Construct 2: Cronbach α value is 0.8555); this implies that the items are with good internal consistency. In addition, it is generally accepted that the item is with high reliability if the α value is >0.8 (Bryman and Cramer, 1997) or 0.7 (DeVellis, 1991). The results indicate that the items are all with internal consistency. Accordingly, all of the items were kept for the following formal investigation.

3.7. Grading and data analysis

The participants' answers were firstly graded by two invited professionals; then the study conducted inter-rater reliability to examine if the coefficients between the two graders are acceptable. If the coefficients are within the acceptable level (for example, above 0.7), then the participant's final score will be divided by the total of the two graders' grading outcomes.

Table 3. The questionnaire contents.

Constructs	Item	Objective	Source
Demographics	A: 1–5	Understanding the profile of the participants	—
System design	B: 1–17	Understanding the participants' attitude about the system	Davis (1989)
Ease and use of the system	B: 18–21	Understanding the participants' attitude about the ease and use of the system	Davis (1989)
Open-ended questions	C: 1–2	Understanding the participants' thoughts or opinions about the learning from a qualitative viewpoint	Developed by management and qualitative professionals

The grading criteria are developed by the researcher and the graders based onprevious research (Jonassen, 1997; Voss and Post, 1988) after careful discussion.

(1) If the student has clearly defined the problem: 30%.
(2) The feasibility of the solutions developed by the student: 40%.
(3) If the student has well justified and evaluated the alternatives or solutions: 30%.

Notably, the feasibility specified in criteria (2) was viewed by the two graders from the perspective of management functions, which contain: feasibility, marketing feasibility, manpower feasibility, technical feasibility and financial feasibility.

4. RESULTS AND DISCUSSION

Before discussing the results, the study has to explain that the participants' performances are actually due to the VLE so that the following analyses would be meaningful:

First, when developing the items, we had careful discussion about how to prevent the participants from being experienced. Because problems in the real world are always changing, if one can fix a complex problem no matter how different the situation is, then such a person would be regarded as one with problem-solving ability.

Secondly, based on the researcher's observation, traditional teaching does not mean it is no good, but it seemed hard to motivate students with a paper-and-pencil test. On the other hand, a lot of prior research (Bailenson *et al*., 2008; Barnett *et al*., 2005; Chen *et al*., 2007; Di Blas and Poggi, 2007; Lee *et al*., 2010; Lim *et al*., 2006; Limniou *et al*., 2008; Shih and Yang, 2008) had proved that students' learning engagement and performance can be improved by the instruments that are constructed through VR technology. It would be rational to infer that students who did have the VLE experience would predictably outperform students who did not have the VLE experience. Moreover, when the 3DVC training was ongoing, the researcher found that the participants were highly motivated, presented very good attitude and achieved good results. This helped us understand that the participants' better performance actually resulted from the VLE.

Thirdly, the most powerful evidence that led us to conclude that the results are actually due to the VLE came from the participants' comments; we refer the readers to 'Questionnaire results—Part C: Open-ended questions'. Moreover, the researcher also randomly and informally interviewed several participants right after the VR training finished; they answered that the learning environment was beneficial in improving their ill-structured problem-solving ability. It is mainly because the situation successfully motivated their performance.

Based on the reasons stated above, we finally recognized that the results actually came from the VLE.

4.1. Grading results

The grading was carefully performed by the above-stated two professionals. The inter-rater reliability coefficients obtained from each stage (include pretest, 3DVC training and posttest) were all above 0.8, which reflects that the two graders reached high consistency in grading. The results confirm that the grading outcome is acceptable; therefore, each participant's final score is derived from the average of the two graders' totals.

4.2. Data fit test for normality

Before analyzing the results, the study had performed a χ^2 test to ensure whether the data collected from the experiment distributed normally; if yes, the t-test analysis would be meaningful. The study hypothesized as follows:

H_0: the data collected from the experiment distributed normally.
H_1: the data collected from the experiment does not distribute normally.

In the process of the experiment, including pretest, 3DVC and posttest, the results of the tests all indicated that the data distribution approached normality. Therefore, the study did not reject H_0. This indicates that the data obtained from the experiment distributed normally.

Accordingly, the study conducted a t-test to analyze the results sequentially.

4.3. Paired sample *t*-test

Before explaining the results, the study has to explain why we recognized that the results reported in Table 4 are due to different teaching environments. Because the intervals between every two nearer tests were only 2 weeks, things went exactly as usual and nothing changed except the instructional environment during the period of time. Rationally, we recognized that the performance differences of the participants were due to the change in the instructional environment.

From Table 4, we can see that the mean scores of the participants improved from 41.76 (pretest) to 45.93 (3DVC);

Table 4. Paired sample t-test results.

Pretest vs. 3DVC							
Test	n	Mean	SD	F	t-Value	df	P-value[a]
Pretest	46	41.76	10.26	0.093	3.130	45	0.0015*
3DVC	46	45.93	10.66				
Pretest vs. posttest							
Test	n	Mean	SD	F	t-Value	df	P-value[a]
Pretest	46	41.76	10.26	0.579	2.672	45	0.005
Posttest	46	45.25	9.64				

[a] P-value is rounded off to the third decimal place.
*$P < 0.01$.

the standard deviation does not indicate much difference (10.26 pretest and 10.66 in 3DVC). Meanwhile, it is encouraging that the P-value, which represents the significance of the probability, does indicate significance ($P = 0.0015$; $t = 3.130$; df $= 45$).

Based on Table 4, it is important that the participants' mean score has generally improved. The 3DVC used in the study provides students with unique learning; though the ill-structured problems are complicated, the novice students did a good job to reach a statistical significance. The outcomes inspire educators that using 3D learning environment is a very good beginning, which deserves their lasting devotion in the foreseeable future to obtain a more brilliant outcome. Hence, it is proved that a learning environment plays a pivotal role in improving students' problem-solving ability.

As presented in Table 4, the results between pretest and posttest are improved and, very importantly, they have statistical significance (mean in pretest $= 41.76$; mean in posttest $= 45.25$; $t = 2.672$; df $= 45$; $P = 0.005$). The mean score of the participants was 41.76 pretest; 45.93 in 3DVC training; then it slightly decreased to be 45.25 posttest. The phenomenon perhaps resulted from the different situations of the test. As it is the participants' first experience with the 3D learning environment, they were highly motivated by the real-like situation; therefore, even though they are only novice problem solvers, their performance almost reached statistical significance ($P = 0.005$). When they went back to the traditional paper-and-pencil test (posttest), without the sensory stimulation provided by the real-life environment (3DVC), their average performance slightly went down to be 45.25 posttest. This proved that the learning environment is critical to students' learning performance. Namely, students' performance is dependent on the test situation; educators should keep up efforts at designing or improving the learning situation so that students' performance could always be improved.

4.4. Questionnaire results

After the questionnaires were collected, the researcher randomly coded the questionnaires from 1 to 46 for analysis. The section reveals and explains the results of the questionnaire by parts as follows:

4.4.1. Part A: Demographics

Table 5 reports the participants' demographics, which enables us to understand the profile of the participants.

Table 5. Demographics of the participants.

Items	Frequency	Percentage	Cumulated percentage
Gender			
Male	24	52.2	52.2
Female	22	47.8	100.0
Personal PC experiences/years: average 8.87 years			
Personal daily PC hours			
Less than 2 h	5	10.9	10.9
2–4 h	15	32.6	43.5
4–6 h	17	37.0	80.4
Above 6 h	9	19.6	100.0
Know about VR before			
Yes	35	76.1	76.1
No	11	23.9	100.0
Typing speed words/min[a]			
Average 46 words			

[a]Chinese words per minute.

4.4.2. Part B: Personal attitude toward the system

The reliability coefficient of the construct is 0.838 (Cronbach's $\alpha = 0.838$), which indicates that the construct reliability is quite acceptable.

Table 6 reports the participants' attitude toward the system. Based on the table, most of the participants commented positively on the system.

Construct 1: In general, the design of the system pertinently reflected the real-world situation and highly motivated them to devote their efforts to problem solving. This inspires business educators that a different learning environment could bring out students' potential and encourage them to bravely face the troublesome problems. The results advise us that a diversified or appealing pedagogy may brighten students' insight and then enhance their learning performance. Though the virtual objects' vividness was commented on as being low (Mean $= 3.15$), it is acceptable. One point that the study has to address is that the young participants possibly evaluated the item based on their other animation experiences; so the score of the item is not as high as those of the others. In terms of the background music, though the participants did not comment highly on the design, the outcome is acceptable (Mean $= 3.17$); maybe it is because the system used real persons' voices rather than a that of a professional broadcaster.

Based on the results, the participants agreed highly that the system is helpful in enhancing their ill-structured problem-solving ability. Though the participants are young, they realize that the learning is helpful for them.

With regard to the question prompt used in the system, most of the participants commented highly on the technique. They agreed that the prompt is beneficial in guiding them in solving the problems and helps them think in an organized way as well as simplifies the complex problems.

It is encouraging that the expert model in the system obtained the most applause from the participants. Some of the participants reported that the expert model broadened their thinking and revised some of their incorrect concepts; they commented that it is of great help to them. In the researcher's opinion, students can improve much more when they have an opportunity to observe how the others fix the problems, because no matter how smart they are, a novice's thinking would not be as extensive as that of an expert. The design is actually aimed at cultivating the participants' higher order thinking.

Table 6. The participants' attitude toward the system.

Items	Mean	SD[a]
1. The layouts of the VLE fully reflected the real world's situation	4.30	0.59
2. The virtual objects of the VLE presented vividly	3.15	0.97
3. The background sound effects of the VLE played naturally	3.17	0.95
4. The interaction of the VLE was interesting	3.50	1.07
5. The problems of the VLE mirrored the real life's condition	4.24	0.64
6. I think the VLE is helpful in enhancing me to solve the complex problems in the future	4.37	0.64
7. I think the VLE is helpful in enhancing my ill-structured problem-solving ability	4.37	0.64
8. I think the role-playing of the VLE gave me sense of achievements	3.52	0.81
9. I think the role-playing of the VLE provided me an important experience of solving ill-structured problems	4.33	0.70
10. I think the question prompt of the system is beneficial in helping me to judge the problems	4.11	0.57
11. I think the question prompt of the system helped me to systematically solve the ill-structured problems	3.87	0.78
12. I think the question prompt of the system helped me to simplify the complex problems	3.80	0.78
13. I think the expert model of the system helped me to clarify the logic of the ill-structured problems	4.17	0.68
14. I think the expert model of the system was helpful in my ill-structured problem-solving ability	4.30	0.55
15. I think my problem-solving ability has been improved after training by the system	4.07	0.71
16. I think my knowledge application ability could be enhanced through the related learning system	4.13	0.69
17. I think the VLE is helpful in shortening the gap between theory and practice	3.96	0.84

[a]SD, standard deviation; $n = 46$.

With regard to the last three questions of the construct, the participants answered that their problem-solving ability has been improved after the 3DVC training, and they mostly agreed that the training is helpful in enhancing their application ability and shortening the gap between class theory and practice. In

Table 7. The participants' attitude about the ease and use of the system.

Items	Mean	SD[a]
18. I think the VLE is easy to use	4.07	0.93
19. I think the VLE is interesting	3.70	0.94
20. I hope I can have another opportunity to use the similar system	3.93	0.90
21. I hope my teachers can teach us by the way that is different from the traditional one as possible as they can	4.28	0.72

[a]SD, standard deviation, $n = 46$.

the researcher's viewpoint, business education is different from the other professional areas; it requires learners to integrate classroom learning with daily life experiences. Sticking with paper and pencil would only make students dull and their learning not applicable to the society. More importantly, it is always the educators' responsibility to develop more diversified instruction to facilitate students' problem solving ability. Possessing better problem-solving ability certainly makes their lives easier.

Table 7 reports the participants' attitude on the ease and use of the system. The Cronbach α coefficient of the construct is analyzed by SPSS to ensure item reliability, and the outcome is 0.715, which implies that the reliability of the construct is acceptable.

Construct 2: Based on Table 7, one can understand that the system is user friendly from the participants' standpoint. One very important thing is that no matter how valuable the notion is, things will be all in vain if the system is not designed for easy use. Meanwhile, how to drive the participants' motivation and make them be attentive to learn problem solving is another important point. The study's trial has been proved to be acceptable and friendly, which has successfully encouraged the participants and led them to practice ill-structured problem solving.

It is noteworthy that the majority of the participants replied that they hoped to be trained by similar systems in the future and they expected that learning could skip over the traditional instruction as much as possible. The phenomenon reflects that the youth are looking forward to different types of learning. One very impressive thing is that a participant self-marked '6' and noted 'super agree' at item 21, which stated 'I hope my teachers can teach us by the way that is different from the traditional one as possible as they can', though we only used five-point Likert-type scale. Pertinently speaking, the instruction used in the study is to facilitate student's problem-solving ability rather than replace the traditional instruction because 'tradition' does not mean obsolete or no good. What the study is trying is to transform the conventional learning to be brand new to motivate young students to improve their learning. The results above prove that the study is contributive in terms of students' problem-solving ability to some extent.

4.4.3. Part C: Open-ended questions

After thoroughly reviewing the results, the researcher selected and listed several participants who have described the questions clearly. The contents are listed and discussed as follows (see Table 8 for reference):

Some key points emerged from the results of open-ended questions are discussed as follows to answer whether 3DVC is helpful:

Open-ended question 1: First, the participants are confident that their problem-solving ability is improved: 'I've learned a lot from the system, which was not possible from textbooks—Student 39'; 'I've learned how to fix the similar problems and how to improve my problem-solving ability. I think it's very helpful…—Student 34'. As noted previously, ill-structured problem solving is with high complexity and difficulty, and the degree of confidence is only a psychological perception of the participants. However, past research (Lent *et al.*, 1987; Pintrich and De Groot, 1990) has proved that high self-efficacy is significantly correlated to learning achievements. Therefore, it is not easy for the study to improve the students' problem-solving confidence. The results are encouraging!

Secondly, the participants reported that they have learned to be organized and clear in thinking when facing a complex situation. For example: 'I've learned how to be unflustered in a disturbing environment, you have to be organized to firstly understand the situation and then take right steps to solve the problems from different department's standpoint…—Student 35'; 'So I know a decision maker has always to keep calm and take decisive steps for the company's survival. Student 39'. This would be of great help because most people are in a puzzle when facing a hard and complex circumstance (Chi and Glaser, 1985). Holding a clear and calm head and making a correct and instant decision would be the key point to successfully solve problems. In this regard, the study provides a good contribution.

Thirdly, the 3D learning system used in the study simulates reality and exposes students to a real-life environment, which provides them with fidelity and guides them to be experienced in ill-structured problem solving. For example: 'I think it's very helpful for me because the problems will possibly happen in our daily life.—Student 34'. 'I've directly experienced the practice rather than the dull context of the textbooks—Student 39'. The effect would not be easily achieved by the traditional lecture-based instruction. Therefore, the outcomes reported by the participants inspire and encourage educators to be devote their lasting efforts in improving students' problem-solving ability by use of related computer technology.

Open-ended question 2: First, a great part of the participants commented positively on the system. They reported that the learning experience is unique and valuable ('The learning experience is unique,—Student 21'; 'Truly speaking, the teaching way is good…; it is of great help for our future!—Student 24'), which is not replaceable by any other instruction in their learning career. In addition, they did not realize that learning could be conducted in such a unique way. In this regard, the study is contributive in forming their correct learning concepts. Because learning does not necessarily happen in classrooms, the instruments that allow for repeated learning and provide learners with sense of reality would be advantageous.

Table 8. Selected participants' answers of the open-ended questions.

Question 1: What have you learned from the system in terms of ill-structured problem solving?

Student 34: I've learned how to fix the similar problems and how to improve my problem-solving ability. I think it's very helpful for me because the problems will possibly happen in our daily life. Though the problems are hard for me, I still tried hard to answer them. The problems are somewhat like playing games; I do enjoy the test way. It's my first time to experience this way, it's really fresh!

Student 35: I've learned how to be unflustered in a disturbing environment, you have to be organized to firstly understand the situation and then take right steps to solve the problems from different department's standpoint. The system enables me to realize that we have to solve problems in an ordered and arranged way rather than a flurry manner. Moreover, as a manager, you have to take the most effective, organized and speedy ways to achieve the problems, so it's really hard to be a manager!

Student 39: I've learned a lot from the system, which was not possible from textbooks. The scenes are vivid. I've never thought to have the opportunity to fix big problems for the company. I know it's not so easy to be a manager because being a decision maker; you have to find out solution alternatives for the company in a limited time. So I know a decision maker has always to keep calm and take decisive steps for the company's survival. It's really with pressures! I've directly experienced the practice rather than the dull context of the textbooks.

Question 2: State your comments about the system and the most important experiences you've learned in the way.

Student 21: I personally think the system is not bad! But if some of the objects can be improved, it will be better. The learning experience is unique, it's not like the traditional paper-and-pencil test, it's really impressive! The VR learning makes me foresee the future and helps me understand that one has to be very responsible and decisive to be a manager.

Student 24: The system enhanced our learning in the way of personification; it's easier for us to understand! In addition, the reality is transformed to be the scenes of the system, so we can learn how to respond to different departments under the circumstances of complexity. Truly speaking, the teaching way is good. We are requested to be a manager to deal with complex cases for the departments; it is of great help for our future!

Student 39: It's not only interesting but also really impressive! The instruction gave us more space and joy in learning. I could sense the pressure when the problem is in front of you. I had higher intention to learn and breakthrough the point in the environment. I've learned a lot from the expert model. I think I still have to improve!

In contrast, some of the participants mentioned that the virtual figures are not beautiful enough, the sound effects are with a little noise and the stability of the system should be improved. Actually, due to the limitation of the campus Internet, some of the system's shortcomings commented on by the participants do exist but has no impact on their training. In addition, the sound effects problem somewhat disturbed several participants, but it resolved quickly and the participants' performance were not impacted eventually. As to the beauty of the virtual figures, no matter how the modeling technique is improved, 3D animation is different from a real figures. The researcher has explained this to the participants after the training finished. In addition, one participant commented that the input contents were not revisable; it is for the students to understand that many decisions in real life are unable to be modified once decided. The researcher had clearly explained this point before the training was conducted.

Secondly, the participants described that the system simulates the situation in the real world; this method motivates their learning interest highly and drives them to seriously face problems. 'It's not only interesting but also really impressive!—Student 39'; '…helps me understand that one has to be very responsible and decisive to be a manager.—Student 21'. In addition, they have also realized that one has to make a correct decision at the very first time under very urgent circumstances in order to survive in an intensively competitive environment. 'I've learned how to be unflustered in a disturbing environment,—Student 35'. Moreover, it is very important to obtain an organized solution because the problems are really complicated. Regarding this point, the system is helpful in training the participants' logical thinking, which the participants think is more effective than textbooks. Actually, from learners' standpoint, the sense of 'walking into' the environment provides them with engagement and their devotion to problem solving is thereby enhanced. This is in accordance with the prior research (Lim *et al*., 2006) that a 3D learning environment is effective in increasing learners' engagement. Meanwhile, the results also enlightens business educators that the contents of the learning environment should always be integrated with daily life so that the ability obtained by the learners could be transferred to practice (Schoenfeld, 1992).

5. CONCLUSION

To support our findings and make them be more referential, the issue whether there is a direct effect from a 3D environment on ill-structured problem-solving is addressed as follows:

First, no prior research had proved that there is a direct effect between a 3D environment and ill-structured problem solving; very importantly, we did not assume that a 3D learning environment has positive and direct effects on ill-structured problem solving.

Actually, to be experienced in ill-structured problem solving, one may need to pay decades for cost. Practically, a better way for the youth to learn problem solving is to be an intern; however, exposing students to an open environment not only makes the following performance evaluation very hard but also costs a lot. Therefore, we figured out a way to put students in a closed and safe environment for learning. Theoretically speaking, the environment allows learners experience repeated learning; its relative low-cost feature and multimodal sensory feedback sometimes make the 'virtual' appear real. This is why the 3D technique has been pervasively applied to education recently.

In addition, the original reason for us to conduct the research was to understand whether a 3D learning situation is effective in driving students' problem-solving motivation. The goal is to understand if the students' potential could be maximized by a different learning situation; the results provided evidence that the participants were successfully motivated by their different experience and their performances were then improved.

Moreover, the study employed a 3D VLE to facilitate students' ill-structured problem-solving ability; the results are in line with those of prior research (Bailenson *et al*., 2008; Chen *et al*., 2007; Di Blas and Poggi, 2007; Dodd and Antonenko, 2012; Heid and Kretschmer, 2009; Hwang and Hu, 2013; Kartiko *et al*., 2010; Lee *et al*., 2010; Limniou *et al*., 2008; Merchant *et al*., 2013, 2014; Shih and Yang, 2008; Virvou and Katsionis, 2008; Yang *et al*., 2010), which affirmed the function of a 3D learning environment in education. The contribution of the study is that students' problem-solving ability was skillfully enhanced through a different learning design. The students expressed that they were surprised that learning could be conducted in such a brand new way, which highly motivated them to be mature in their learning attitude and trained them to make a logical and responsible decision the very first time when confronted with a complicated and difficult problem.

Though the study has tried to design the system as lifelike as possible, the researcher has to acknowledge the following limitations: First, peoples' ill-structured problem-solving ability in the real world is subjected to many unpredictable factors; the results derived from a lab may be different from that in the field. Secondly, due to the constraints of campus Internet, the scenes were simplified to make the system run smoothly; this may have reduced the abundance of the background. Finally, the study employed only one class as the experiment sample; this probably hinders readers from knowing the comparison effect used in a two-group design. However, despite the above limitations, the study is contributive in facilitating student's problem-solving ability. A following qualitative research will be extended from the present study to understand students' thoughts or comments toward virtual learning (such as VR) so that the reference we provide would be more extensive and critical to computer learning. Meanwhile, it is suggested that future study may classify students into different levels based on their academic performance and go further to explore the function of a 3D VLE among different-level students.

ACKNOWLEDGEMENTS

The authors gratefully acknowledge the insightful comments provided by the three anonymous reviewers. The authors are also very thankful for the very important contribution supplied by the two system developers: Mr. Jie-Qi Huang and Mr. Shi-Shu Wang.

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