THE EFFECTS OF 4C/ID-BASED ADAPTIVE PROCEDURAL SIMULATION ON SAFETY AWARENESS IN UNDERGRADUATE STUDENTS MAJORING IN GEMS AND JEWELRY*

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Abstract: Researchers had developed 4C/ID-based Adaptive Procedural Simulation (4C/APS) Learning System, which was an adaptive learning system based on van Merriënboer's four-component instructional design with procedural simulation in jewelry production. The goal of the system was to promote learner's safety awareness, which comprises of three aspects: 1) awareness of hazardous environment, 2) awareness of responsibility, and 3) awareness of rules and regulations. To test the effects of the learning system on learner's safety awareness, an experiment was conducted on 26 undergraduate students majoring in gems and jewelry at Poh-Chang Academy of Arts. The 4C/APS learning system was implemented in "Metalware and Jewelry Making 2" course for the duration of 8 weeks. The result found that even though the average pretest score had been as high as 4.289 out of 5.000, the posttest mean score increased to 4.761. Paired samples t-test confirmed significant increases from pretest to posttest in safety awareness with $p<.001$.

Keywords: Safety Awareness; Adaptive Learning; Procedural Simulation; 4C/ID, Instructional Design

Introduction

Despite the fact that gems and jewelry industry contributes to the growth of Thailand's economy eminently, the occupational health and safety of the workers in the industry are rather under par. Based on official records alone, as high as 1,892 work-related injuries in gems and jewelry industry were reported in the year 2013-2017 (Social Security Office, 2017). Yet unfortunately, there has never been any concrete attempt from the cooperation

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of government and private sectors to recuperate the situation (The Gems and Jewelry Institute of Thailand (Public Organization), 2014). The process of jewelry making involves all types of safety risks including fire, machinery, and chemical hazards. Accidents in gems and jewelry industry are very serious if not at all fatal, and therefore should be prevented with more earnestness.

Researches have found that the major cause of work-related accidents are from human errors (Garrett & Teizer, 2009; Rasmussen, 1997; Sole, Musu, Boi, Giusto, & Popescu, 2013). Jewelry manufacturing workers often overlook safety precautions and ignore safety rules and regulations due to lack of safety awareness (Arubol Chotipong, 2015; Office Workers Chanthaburi Province, 2006). Consequently, one of the most effective and appropriate approaches to prevent accidents would be to educate the workers about work safety (Guastello, 1993). When the workers understand and appreciate the importance of work safety and related risks, they will develop necessary safety awareness. Analyzing from previous researches on safety awareness (Dayuth Ruanghiran, 2013; Nawawit Jittworrakrai, 2011; Pramot Orkweha, 2005; Preenuht Panumonvatee, 2009; Sompop Wongprasarn, 2003), safety awareness can be categorized into three aspects which are 1) awareness of hazardous environment, 2) awareness of responsibility, and 3) awareness of rules and regulations.

Safety awareness can be enhanced through appropriate and well-designed learning system. To elaborate, the more engaging the instructional methods, the greater knowledge the workers would acquire, and the fewer accidents would occur. Simulation learning, being an instructional strategy that involve behavioral modeling with substantial amount of practice, is generally more effective in training for safety awareness (Burke et al., 2006). Even though researches indicated that simulation learning results in improved knowledge and skills, yet most current studies on simulation learning focuses on short-term gains in knowledge and skills, while the topic of transfer of learning from simulation still can appreciate further investigation (Nestel, Groom, Eikeland-Husebø, & O'Donnell, 2011). One of the most compelling approach for transfer of learning is van Merriënboer’s four-component instructional design (2002), which entails learning tasks, supportive information, procedural information, and part-task practice. The instruction within the learning system would be even more effective when it is not delivered as one-size-fit-all instruction for the whole group of learners, but rather adaptive for individual leaner (Aleven, McLaughlin, Glenn, Koedinger, & Routledge, 2016; Park & Lee, 2008). Adaptive learning system can combine educational models customized to the individual learner’s needs and goals, and attempt to adapt the learning tasks to suit the requirements of the learners and yield higher rate in transfer of learning (Salden, Paas, & van Merriënboer, 2006)

Based on literature reviews and preliminary needs assessment research (Charnkiat Mahantakhun, Prakob Koraneekij, & Jintavee Khlaisang, in press), we have developed 4C/ID-based Adaptive Procedural Simulation (4C/APS) Learning System, which is an adaptive learning system based on van Merriënboer's four-component instructional design with procedural simulation in jewelry production, to promote safety awareness in undergraduate students majoring in gems and jewelry.

Objective

The purpose of this research was to study the effects of the 4C/ID-based Adaptive Procedural Simulation (4C/APS) Learning System on safety awareness in undergraduate students majoring in gems and jewelry.

Conceptual Framework

Four-component Instructional Design (4C/ID)

Instructional design (ID) principles can provide frameworks for developing efficient educational training programs (Merrill, Drake, Lacy, & Pratt, 1996). Van Merriënboer's four-component instructional design (4C/ID) (2002) offers design framework for complex learning. Complex learning involves integration sets of learning goals that include knowledge, skills, and attitudes, in a single interconnected knowledge base. 4C/ID can be described as four interrelated blueprint components: 1) learning tasks, which is whole-tasks that resembled real-life tasks aiming towards the integration of skills, knowledge, and attitudes. The learning tasks should be grouped into task classes and arranged from simple to complex with high degree of variability and with diminishing support given to learners throughout each class task; 2) Supportive information, which is the "theory" helpful for the learner to perform the problem-solving and reasoning aspects of the learning tasks. This information acts as a bridge that links between what the learners already know and what they need to know to work on the learning tasks; 3) procedural information, which is the how-to step-by-step information that is a needed for performing routine aspects of learning tasks. This information should be given to the learner in the just-in-time manner when it is needed; and 4) part-task practice, which is the optional practice items for the learners to help them reach a very high level of automaticity for selected routine aspects of a task. 4C/ID has been proven effective in various researches (Melo, 2018; Sarfo & Elen, 2007; Susilo, van Merriënboer, van Dalen, Claramita, & Scherpbier, 2013; Vandewaetere et al., 2015).

Simulation Learning

Simulation learning represents learning within an environment that was constructed to resemble real world situations. Learners are required to perform simulation of real-life complex tasks within the environment. Simulation learning is an experiential learning that could integrate cognitive, motivational, affective, psychomotor, and social facets of learning with high degree of authenticity (Breckwoldt, Gruber, & Wittmann, 2014). It also promotes active learning, allowing the learners to manipulate parameters and instantly observe the resulting changes, which helps the process of higher-level reasoning (Gallagher, 1986). Simulation learning was proven with improved knowledge and skills, and high levels of satisfaction from learners and instructors (Nestel et al., 2011).

Components of simulation learning (Kindley, 2002; Pareek, 1978) are 1) Objectives of the simulation, 2) Cognitive framework, 3) Storyline, 4) Failure staging for learners to learn from mistakes, 5) Learner's roles within simulation, 6) Variables simulated, 7) Rules for behavior and interaction, and 8) Interaction with simulation mentor. The learning process in simulation (Alessi & Trollip, 1991; Clapper, 2014; Forcier, 1996; Kunnaree Niyomthai, 2013) can be designated into 11 steps, which are 1) Present overall concept, 2) Explain rules and directions, 3) Motivate suspension of disbelief, 4) Present situation, 5) Demonstrate new skills, 6) Call for hands-on practice opportunities, 7) Evaluate performance, 8) Present results, 9) Present new or modified situation, 10) Call for reflection, and 11) Conclude and debrief.

Adaptive Learning System

Adaptive learning system means the learning system that can monitor the activities of its users, interprets these on the basis of domain-specific models, infers user requirements and preferences out of the interpreted activities, represents these in associated models, and acts upon the available knowledge on its users and the subject matter at hand to dynamically facilitate the learning process (Paramythis & Loidl-Reisinger, 2003). Historically, three different approaches had been taken into developing adaptive learning systems (Park & Lee, 2008). The approaches are macroadaptive, aptitude-treatment interaction (ATI), and microadaptive. Macroadaptive systems are systems that provide more individualized instruction on student's learning needs and abilities which were determined prior to instruction. The ATI adaptive learning systems are those that adapt instructional methods, procedures, or strategies to the student's aptitude information. Microadaptive systems were developed to diagnose the student's needs and provide appropriate instructional treatments during the process of instruction. Despite the different approaches to developing an adaptive learning system, a learning system can certainly benefit from multiple approaches. Especially for content adaptation, micro-adaptative decision can help identify what to present, while macro-adaptive decision can help how to present it (Mavroudi & Hadzilacos, 2016)

Adaptive learning systems (Livergood, 1991; O. Park & Seidel, 1991; Recker & Pirolli, 1992; Wallach, 1987) usually composes of 1) domain knowledge module, 2) analysis module, 3) interface module, 4) student model module, and 5) teaching module, white the process of adaptation cycle (Shute & Zapata-Rivera, 2012) consists of 1) capture learner's information as the learner interacts with the system, 2) analyze the learner's performance in the learning domain, 3) select suitable approach, and 4) present appropriate content.

Methodology

Participants

26 undergraduate students who enrolled in "Metalware and Jewelry Making 2" course from Poh-Chang Academy of Arts, Rajamangala University of Technology Rattanakosin were recruited as the sample group of this study, deriving from the following criteria: 1) The institution was equipped with computer lab and was ready for educational technology experiments, 2) The course structure was procedures oriented and related to jewelry making, 3) The course was enrolled by at least 25 students, and 4) The course was held during research's timeline of experimentation.

Procedures

The study employed a quasi-experimental with one-group pretest-posttest design. The participants were given pretest at the beginning of the experiment and posttest at the end. The 4C/ID-based Adaptive Procedural Simulation (4C/APS) learning system was developed, validated by experts, and implemented for 8 weeks in "Metalware and Jewelry Making 2" course at Poh-Chang Academy of Arts, Rajamangala University of Technology Rattanakosin. The 4C/APS is an adaptive learning system based on van Merriënboer's four-component instructional design with procedural simulation in jewelry production. The goal of the system is to promote learner's safety awareness which comprises of three aspects: 1) awareness of hazardous environment, 2) awareness of responsibility, and 3) awareness of rules and regulations. The learning process of 4C/APS learning system can be described in 6 stages as followed.

Stage 1) Introduction to the learning system

The introduction to the learning system is the first and essential step in 4C/APS learning system. Since most learners are not familiar with computer-based procedural simulation learning, it is therefore necessary to ensure that the learners clearly understand the learning objectives from the beginning. The introduction stage is important because it draws learners' attention to the lesson and inspires them to take further steps into their studies. The introduction stage is conducted by a simulation mentor, an artificial character in the learning system. The simulation mentor explains the learners the scenario, rules, and directions of the lesson, and informs the learner that they are about to enter the process of jewelry production that takes place in the simulation of jewelry production workshop. The jewelry mentor also informs the learners that the simulation mentor will be guiding them throughout the lesson until the learners could successfully finish making a piece of jewelry at the end of the lesson. This introduction could be considered as suspension of disbelief briefing which would prompt the learners to accept the otherwise unrealistic aspects of simulation and fully believe or immerse themselves in the simulation.

Stage 2) Safety awareness simulation screening test

The screening test aims to analyze the learners' safety awareness when performing in real task. Simulation mentor informs the learners that they are now in the first process of jewelry production, and their learning task is to prepare metal amalgam. The simulation mentor provides the learner with procedural information pertaining to steps of jewelry production, without any guidance about work safety in order to capture and analyze whether the learners lack any aspects of safety awareness according to the following evaluation details,

"Awareness of hazardous environment" analysis by 4 behavioral indicators

- The learners perform pre-operational check for machine and equipment.
- The learners appropriately organize the working area before operation.
- The learners are mindful with the machine and equipment during an operation.
- The learners store chemicals appropriately.

"Awareness of responsibility" analysis by 3 following indicators

- The learners use proper equipment according to the type of the work.
- The learners wear personal safety device during operation.
- The learners clean and organize the working area after an operation.

"Awareness of rules and regulations" analysis by 4 following indicators

- The learners study rules and regulations before operation.
- The learners abide by the rules and regulations during operation.

- The learners study instruction of tools, machines, or equipment before operation.
- The learners study chemical labels before operation.

After the learners have successfully completed the learning task in this stage, the system will analyze their awareness in each aspect according to above indicators. The learner would pass the criteria for that aspect of safety awareness, if he could perform the learning task with all of the indicator in that particular aspect. The system will then divide the learners into 8 groups, namely,

Table 1: *Learner groups and criteria of evaluation.*

Learner group	Awareness of hazardous environment	Awareness of responsibility	Awareness of rules and regulations
1	fail	fail	fail
2	fail	fail	pass
3	fail	pass	fail
4	fail	pass	pass
5	pass	fail	fail
6	pass	fail	pass
7	pass	pass	fail
8	pass	pass	pass

The failure of safety awareness evaluation in any aspects indicates that the learner is lack of awareness in that particular aspect. The system would then adapt itself to accommodate the learner by selecting an appropriate learning path for the learner.

Stage 3) Adapted procedural simulation with guidance

The simulation mentor informs the learners that the learning task of this stage is to operate the sequel sub-steps of jewelry production and that the main focus of the task is to perform it with safety.

In this stage, the structure of each step in jewelry making simulation contains “normal situation” as the lesson’s storyline, as well as three types of additional situations, namely, 1) situations that emphasis on working in hazardous environment, 2) situations that emphasis on performing expected responsibility, 3) situations that emphasis on the importance of rules and regulations. These additional situations provide the learners the opportunity to learn about safety according to their evaluation from stage one. Each additional situation begins with failure staging that exposes the learner to an accident caused by lack of safety awareness. The learners can learn from such mistake with the help of simulation mentor who provides supportive information about the cause and solution of the accident. The learning paths are divided into 8 paths according to the group classification of the learners as follow,

Table 2*: Learning paths and situation selection*.

Learning path	Situations that emphasis on working in hazardous environment	Situations that emphasis on performing expected responsibility	Situations that emphasis on the importance of rules and regulations	Normal Situation
1	✓	✓	✓	✓
2	✓	✓	-	✓
3	✓	-	✓	✓
4	✓	-	-	✓
5	-	✓	✓	✓
6	-	✓	-	✓
7	-	-	✓	✓
8	-	-	-	✓

The learners who passes every aspect of evaluation are the ones who are not lack in any aspect of safety awareness. They would not require additional learning situation. Their learning path only consists of “normal situation” of jewelry production simulation without any additional situation. However, if the learners are considered lack of safety awareness in certain aspect, the system will adapt to the learner by selecting the learning path that contains additional situations to promote that particular aspect of safety awareness before leading the learner back to “normal situation”. An example of the differences between situations in learning paths is illustrated below.

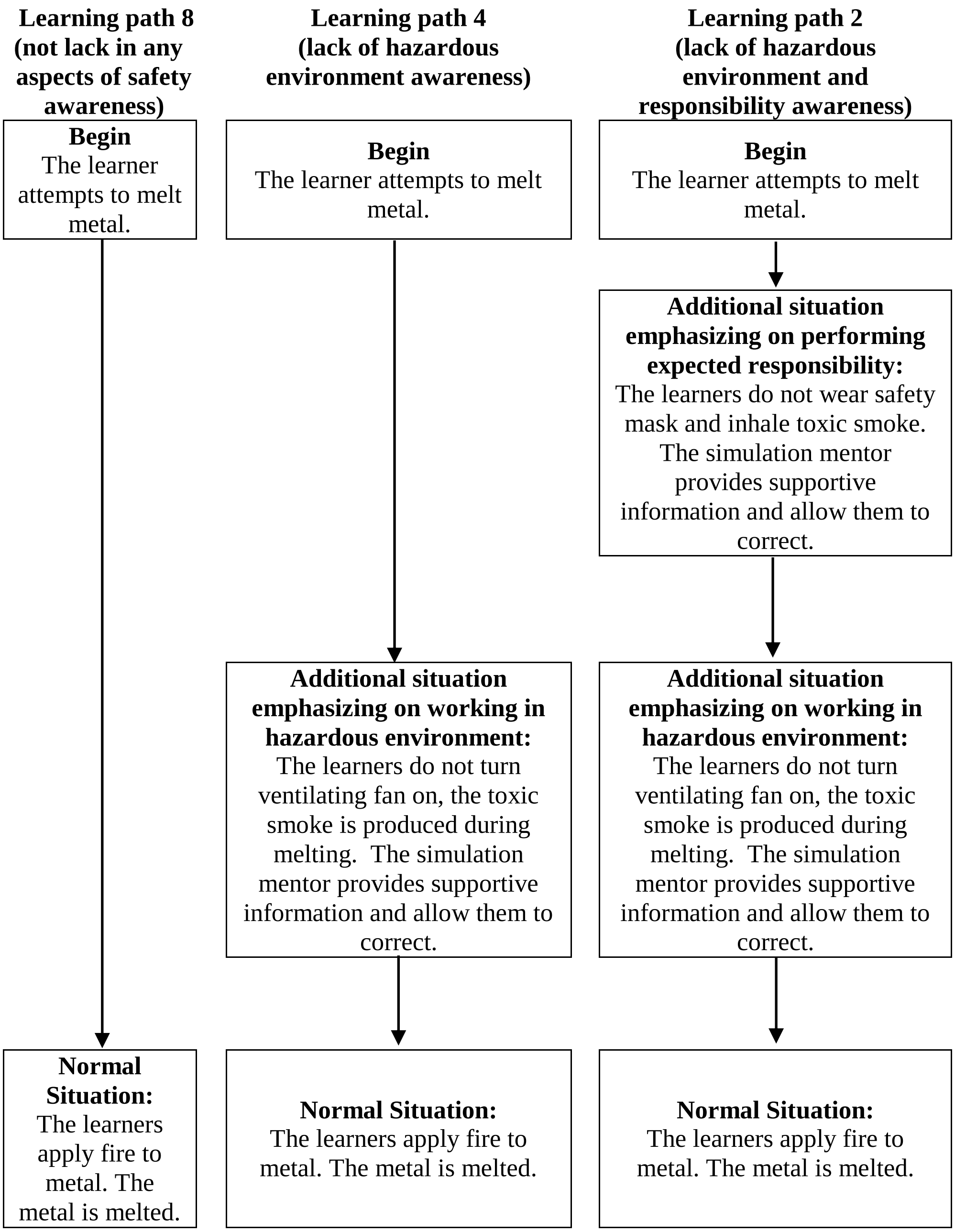

Figure1: ***Example of different situation combinations among learning paths.***

In each sub-step of jewelry production, the system would adapt additional situations according to the result of learners' evaluation throughout the learning path. By exposing the learners with various dangerous situations, the learners can create a mental model from induction. The simulation mentor would give advice and support the using scaffolding technique. In the early phase of this learning task, when the learners do not have experience in solving dangerous simulation situation, the simulation mentor would support the learner by demonstrating any necessary skills and provide them with knowledge for solving the particular problem. In the middle phase of this learning task, the simulation mentor would decreasingly change its support into advice in solving problem. And at the late phase of the learning task, when the learners have gained experience and have been proficient in problem solving, the level of support will be decreased until it becomes just stimulating question.

In every learning path throughout the learning task, part-task practice sessions are introduced at semi-random time. Because certain hazardous situations should be dealt with at a timely manner, these sessions allow the learners to repeatedly practice necessary skills to solve the problems until they have mastered them and could do it automatically when the situation arises.

Stage 4) Learning Journal Entry

To write a learning journal is a task for learners to reflect, connect and apply their learning, which stimulates critical thinking in the learners and connect their knowledge, skill and attitude from procedural simulation operation to their experience in real life. In doing so, the learners can recognize the relation of events occurred in real life, which lead to new knowledge stored in long-term memory. This stage has three steps as follow,

4.1. The system asks the learners to answer an open-ended question for reflection, “In the previous simulation of jewelry production, there were several accidents occurred, which accident do you think was the most dangerous and why?” This question allows the learners to reflect their feelings or perspective on the safety of the procedural simulation operation.

4.2. The system asks the learners to answer an open-ended question for connection, “In your real-life experience of jewelry production, which situation do you think had been hazard and what the detail of that situation was?” This question allows the learners to connect the relation between what they have learned in the learning system to their actual working experience

4.3. The system asks the learners to answer an open-ended question for connection, “In the future, how will you conduct yourself in order to produce jewelry with more safety?” This question allows the learning to apply what they have learned to future situation.

Stage 5) Safety awareness simulation post-assessment

In this stage, the learners are required to perform the simulation of the final process of jewelry production, while trying to achieve maximum safety on their own, without supportive information from the simulation mentor. The situation consists of 1) situations with hazardous working environment, 2) situations which the learners have to demonstrate expected responsibilities, 3) situations which the learners have to follow the rules and regulations. During the performance, the learners will be awarded a point for each safety action they successfully perform. Total of 11 points, in accordance to the safety indicator, will be awarded. The learners can monitor whether or not they have accomplished any indicator. However, only the numeric representation of indicator will be displayed, while the details of each indicator are hidden from the learners, to encourage the learners to be mindful of all safety actions throughout the simulation.

Stage 6) Presentation of safety performance result and summary

The system presents the result from safety awareness simulation final assessment to the learners. The details of each safety indicators will also be displayed. The learners will be able to examine each and every safety indicator they successfully performed with details. After that the simulation mentor summarizes the instructions to the learners.

Instrumentations

Two self-assessment questionnaires on safety awareness for pretest and posttest were designed for data collection at the beginning of the experiment and at the end. Each questionnaire consisted total of 23 questions, divided into 3 parts covering the 3 aspects of safety awareness which were 1) awareness to hazardous environment, 2) awareness to responsibility, and 3) awareness to rules and regulations. The questionnaires were designed with both positive and negative question items to ensure that the respondents consider the questions carefully and provide a more meaningful response. The questionnaires were validated by experts and yielded 0.819 and 0.763 on reliability indexes through Cronbach's Alpha reliability technique for pretest and posttest questionnaire respectively.

Findings

The results are presented in Table 3 which shows the paired samples t-test results of the safety awareness pretest-posttest mean scores of the participants.

Table 3 *Safety awareness pretest-posttest mean scores of paired samples t-test result*

Safety Awareness Aspects	Variants	Mean	SD	Levene's test	sig	t	sig	Conclusion
Awareness to hazardous environment	pretest posttest	4.411 4.641	.473 .410	.476	.014	2.581	.016*	posttest> pretest
Awareness to responsibility	pretest posttest	4.083 4.861	.402 .194	.324	.107	10.286	.000***	posttest> pretest
Awareness to rules and regulations	pretest posttest	4.371 4.782	.568 .326	.379	.056	3.907	.001**	posttest> pretest
Overall	pretest posttest	4.289 4.761	.402 .245	.560	.003	7.214	.000***	posttest> pretest

*p<.05; **p<.005; ***p<.001

Significant differences were observed in favor of the posttest in all aspects and also in overall safety awareness. To elaborate in each aspect, the mean pretest score in the awareness of hazardous environment aspect was 4.411, and the posttest mean score was 4.641, and the difference was significant with p<.05. The mean of the pretest score in the awareness of responsibility aspect was 4.083, and the posttest mean score was 4.861, and there was a very significant difference in favor of the posttest with p<.001. The mean pretest score of the awareness of rules and regulations aspect was 4.371, and the posttest mean score was 4.782 and the difference was significant in favor of the posttest with p<.005. For overall safety awareness, paired samples t-test confirmed significant increases from pretest to posttest in safety awareness. The mean pretest score of overall safety awareness was 4.289, and the posttest mean score was 4.761 and the difference was very significant in favor of the posttest with p<.001.

Discussion and conclusion

Our findings suggest that the learners can attain more safety awareness after learning with 4C/APS learning system. We had further investigated the effects of different learning paths on safety awareness. A one-way between subjects ANOVA was conducted for comparison and there was not a significant effect of learning path on safety awareness at the p<.05 level. These results suggest that the different learning path does not have effect on safety awareness. In other words, when the learning path is appropriately selected for the learner by the system, every learning path can lead to increase in safety awareness. This finding would be consistent with the study by Salden et al. (2006) who found that selecting learning tasks based on the characteristics of the individual learner can yield higher transfer than non-adaptive training systems, which present a fixed sequence of tasks that is identical for all learners.

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