DEVELOPMENT AND IMPLEMENTATION OF A COMPUTER-BASED LEARNING MODULE AS A VISUALIZATION TOOL FOR ENHANCING UNDERGRADUATE STUDENTS' LEARNING ACHIEVEMENT ON CRYSTAL STRUCTURES AND UNIT CELLS

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ABSTRACT

This study aimed to develop and implement a Computer-based Learning Module (CLM) as a visualization tool for enhancing undergraduate students' learning achievement on crystal structures and unit cells. The CLM in the pilot study, called pilot-CLM, consists of two components: the Virtual Unit Cell (VUC) and the Unit Cell Hunter game (UCH). The VUC is a 3D-model in virtual reality for the students to actively explore the unit cells. The UCH, implemented after the VUC, is a unit cell puzzle game with students competing to assemble the atomic pieces for two types of unit cell (cubic and hexagonal) framework. The module was tested on a small group of volunteer students as two separate studies, and the outcomes were assessed by two-group pretest-posttest in one trial and by one-group pretest-posttest in the other trial. The two studies were used to verify the effectiveness of the pilot-CLM on learning achievement in small groups. Then a final-CLM for mass lecture was developed and implemented on a target group, first year undergraduate students, by one-group pretest-posttest experiment. In the implementation study, the VUC was modified and transformed to the Interactive Multimedia PowerPoint (IMP) in order to implement it in the mass lecture.

Students' learning achievement after having benefited from working with the CLM and participating in the debriefing, in the two pilot studies was evaluated, by identical pretest and posttest at the beginning and end of the activities, and then also by their responses to the questionnaire.

The results from the pilot studies indicate that the CLM was very helpful for learning about crystal structures and unit cells.

The research results in the implementation study indicated that:

1.) the CLM as a visualization tool enhances students' learning achievement on the crystal structures and unit cells in the mass lecture.

2.) there is a positive correlation between visual-spatial ability and learning achievement in the topic.

3.) all students with different visual-spatial ability benefit from the CLM visualization tool.

KEY WORDS: CRYSTAL STRUCTURES / CRYSTALLINE SOLID / COMPUTER - BASE LEARNING MODULE / 3D COMPUTER MODEL / COMPUTER GAMES / DEBRIEFING / INSTRUCTIONAL GAMES / UNIT CELLS / UNDERGRADUATE STUDENT / VISUALIZATION TOOL/ VISUAL - SPATIAL ABILITY

111 pages

การพัฒนาชุดสื่อการสอนคอมพิวเตอร์สำหรับใช้เป็นเครื่องมือช่วยสร้างจินตภาพโครงสร้างสามมิติ เพื่อเพิ่มผลสัมฤทธิ์การเรียน เรื่อง โครงสร้างผลึกและหน่วยเซล ของนักศึกษาระดับปริญญาตรี

DEVELOPMENT AND IMPLEMENTATION OF A COMPUTER-BASED LEARNING MODULE AS A VISUALIZATION TOOL FOR ENHANCING UNDERGRADUATE STUDENTS' LEARNING ACHIEVEMENT ON CRYSTAL STRUCTURES AND UNIT CELLS

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บทคัดย่อ

การศึกษานี้ เป็นการวิจัยและพัฒนาสื่อการสอนคอมพิวเตอร์(Computer-based Learning Module:CLM) สำหรับใช้เป็นเครื่องมือช่วยสร้างจินตภาพโครงสร้างสามมิติ เพื่อเพิ่มผลสัมฤทธิ์การเรียน เรื่อง โครงสร้างผลึกและหน่วยเซล ของนักศึกษาระดับปริญญาตรี การศึกษาประกอบด้วยสองส่วนคือการพัฒนาสื่อ CLM และการวิจัยเพื่อตรวจสอบว่าสื่อ CLM ช่วยเพิ่มผลสัมฤทธิ์การเรียนเรื่องโครงสร้างผลึกและหน่วยเซลในฐานะที่เป็นเครื่องมือช่วยสร้างจินตภาพหรือไม่ และเพื่อศึกษาความสัมพันธ์ระหว่างผลสัมฤทธิ์การเรียนกับทักษะความสามารถในการจินตภาพของผู้เรียน

สื่อ CLM ขั้นทดลอง (pilot-CLM) มีองค์ประกอบ 2 ส่วน คือ ส่วนที่เป็นแบบจำลองสามมิติเสมือนจริง (Virtual Unit Cell: VUC) และส่วนที่เป็นเกมคอมพิวเตอร์กึ่งสามมิติ (Unit Cell Hunter game: UCH game) VUC ประกอบด้วยแบบจำลองโครงสร้างสามมิติของผลึกและหน่วยเซลที่ผู้เรียนสามารถสำรวจ หมุน/พลิกโครงสร้างดูได้ทุกมุมมอง เกม UCH เป็นเกมการศึกษากึ่งสามมิติสำหรับฝึกทักษะการมองโครงสร้างสามมิติ ประกอบด้วยการค้นหาชิ้นส่วนของหน่วยเซลแล้วนำไปประกอบเป็นโครงสร้างของหน่วยเซล

ได้นำสื่อ pilot-CLM ไปทดลองใช้สองครั้งกับกลุ่มตัวอย่างขนาดเล็กเพื่อประเมินประสิทธิภาพ ครั้งแรกเป็นการทดลองแบบสองกลุ่มเปรียบเทียบและมีการทดสอบความรู้ก่อนและหลังใช้สื่อ ครั้งที่สองเป็นการทดลองแบบกลุ่มเดียว ทดสอบก่อนและหลังใช้สื่อ และในการศึกษาทั้งสองครั้งมีการวัดความพึงพอใจของผู้เรียนที่มีต่อสื่อ CLM ผลการศึกษาที่ได้บ่งชี้ว่าสื่อ CLM มีประโยชน์มากสำหรับการเรียนเรื่องโครงสร้างผลึกและหน่วยเซล ได้นำข้อมูลนี้ไปใช้เป็นฐานในการพัฒนาสื่อสำหรับกลุ่มเป้าหมายซึ่งเป็นการเรียนรวมของนักศึกษาจำนวนมาก โดย VUC ได้ถูกปรับเปลี่ยนเป็นโปรแกรม PowerPoint แบบมัลติมีเดียชื่อ IMP (Interactive Multimedia PowerPoint: IMP) โดยเพิ่มเติมเนื้อหาจนครอบคลุม IMP ประกอบด้วยแบบจำลองสามมิติที่สามารถควบคุมการแสดงผลได้ง่าย สะดวกอย่างยิ่งในการใช้สอน

CLM ขั้นสุดท้าย (final-CLM) ประกอบด้วย IMP และ UCH ได้ถูกนำไปใช้กับกลุ่มเป้าหมายโดยการทดลองแบบกลุ่มเดียวทดสอบก่อน-หลัง และวัดความคิดเห็นด้วยแบบสอบถาม ผลการศึกษาพบว่า CLM มีประสิทธิภาพสำหรับใช้เป็นเครื่องมือช่วยสร้างจินตภาพและเพิ่มผลสัมฤทธิ์การเรียนได้ และพบว่าผลสัมฤทธิ์การเรียนมีแนวโน้มความสัมพันธ์ทางบวกกับความสามารถในการจินตภาพของผู้เรียน อย่างไรก็ดีผู้เรียนที่มีความสามารถในการจินตภาพต่างกันได้รับประโยชน์จากการใช้สื่อ CLM นี้ไม่แตกต่างกัน

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LIST OF ABBREVIATIONS

CLM	Computer-based Learning Module
final-CLM	Computer-based Learning Module used in implementation study
pilot-CLM	Computer-based Learning Module used in the pilot study
IMP	Interactive Multimedia PowerPoint
UCH	Unit Cell Hunter (the name of the simulation game)
VUC	Virtual Unit Cell (the name of 3D model component of CLM)

CHAPTER I
INTRODUCTION

Crystalline solid is one of the important topics in General Chemistry I, for the first year science students. It explains crystalline solids' properties through their crystal structures. In Thailand, students from many faculties, such as science, pharmacy, and engineering have to learn General Chemistry I, that is, they have to learn about crystalline solid.

Basic crystalline solid topic in General Chemistry I, contains many essential sub-topics, for example, crystal lattice, crystal system, cubic unit cells, metallic crystal structures, ionic crystal structures, holes in unit cells, coordination number, and calculation of solid properties using unit cell parameters etc,. In other words it concerns mainly on crystal structures that are built up from their smallest unit called unit cell.

The unit cell of a crystal is conventionally introduced as the smallest and representative unit of the crystalline material which, by translation along the three principal orthogonal planes, can generate the whole crystal lattice. The usual two-dimensional (2D) illustrations of the unit cell are inadequate in giving students an insight into how the unit cell represents all the essential physical features of the crystal. Foley (1996) reported that many undergraduate students find the unit cell content and symmetry too complicated and highly abstract; one of the reasons is the use of 2D representations on papers or chalkboards makes it difficult for students to visualize the 3D structure. Cros and co-workers (1986) found that crystals "remained a mystery for most": "When asked about the interactions in a crystal 42% of the students did not reply, and 15% gave incorrect or completely inadequate information. Only 27% of the students referred to a clearly defined arrangement of atoms or ions". This situation is also true in mineralogy where some students have initial difficulties with certain visualization of 3D crystal models, their rotation and so on (Ozdemir, 2009).

Since learning about this topic involves the visual-spatial ability, students' existing abilities would have a strong influence in facilitating mineralogy learning.

In the last few decades, concrete hand-held models have been used for demonstrating mainly the unit cell (Cady, 1997; Mattson, 2000; Birk & Yezierski, 2003; Orlov, Schoeni, & Chapuis, 2006). Even when the hand-held unit cell models are made available, students still find it difficult to generate a good 3D crystal lattice because the unit cell pieces are usually opaque and insufficient in number. Cady (1997) employed Pom Pons, wool-balls, which can be assembled to make the unit cells in cubic system. Eggert (2000) cut and stuck together wooden balls to generate packing of atoms and the unit cell. A construction kit of spherical balls inserted through rods placed on a square plate to generate the cubic unit cell was constructed by Mattson (2000). Other models were certain computer-print outs on paper that were cut, folded and then glued together to generate various types of unit cell (Birk, et al., 2003). These physical models were exploited during formal teaching in chemistry classroom. However, most models can only be used for teaching certain topics because of their physical limitations, e.g., the nature of materials used, number of units, moldability. In addition, the empty spaces (holes between atoms) cannot be seen well in some models. Apart from physical models, instructors often use 2D still images embedded in the slide show. This makes 3D mental models generated by learners static due to the fact that there is only one viewpoint of the image they seen.

Due to insufficient of 3D visualization tools on the crystal structures and unit cells and the difficulties of studying three dimensional structures at sub-micro scale, students have a difficult time visualizing them or solving problems related to them.

1.1 Statement of the Problem

"Difficulty in learning crystal structures results from the cognitive load on visualization and inadequate instructional media that could help creating accurate mental models of the complex three dimensional structures"

In most chemistry classrooms, 2D still images are often used as an instructional media for chemistry concepts because theirs convenient and low cost. Therefore, in order to understand those concepts, e.g., chemical bonding, molecular structure, etc., students generally have to employ the visual-spatial ability for imagining 3D structures from 2D still images. Furthermore, this is a difficult task especially if there is overlapping part in the 2D image. Seddon and their colleages (1985) found that in order to perform task of rotating 3D structure form 2D structure to visualize the effects of rotation, students needed to respond correctly to the four depth cues including the foreshortening of lines, the relative sizes of different parts of the structure, the representations of angles, and the extent to which different parts of the diagram overlap. Additionally, students at the secondary school level have difficulties comprehending and translating symbolic representations and most of them are unable to form 3D mental images by visualizing 2D structures (Tuckey, & et al. 1991).

Learning structural chemistry needs students' visualization ability. Many researchers (Wu & Shah, 2004; Tasker & Dalton, 2006) found that visualization the 3D-mental model from 2D-image takes a lot of time and leads to the cognitive load problem.

In addition, interviews with many instructors, who have been teaching about crystal structures and unit cells indicate some helpful background problems as follows:

1. 2D-illustrations in textbooks make it difficult for learners to construct their own mental model, especially, in case of some parts blocking each other.

2. Using physical models is inconvenient and difficult to manipulate in the lecture room.

3. The computer-based learning module could enhance the learning achievement while it is convenient to manipulate.

From instructors' views and the research findings mentioned above, it implies that there are difficulties on learning about crystal structures and unit cells that arise from cognitive load on visualizing the 3D structure from the 2D still image.

Furthermore, using physical models is inconvenient for demonstrating in the lecture room.

This gave the researcher useful guides to develop the computer-based learning module as a visualization tool for reducing the cognitive load on learning, thus, enhance learners' achievement on crystal structures and unit cells. The computer module such as 3D virtual model, 3D simulation and games might help. The vivid models of the 3D virtual model and simulation should encourage learners to construct the accurate mental models without misconception. In addition, learning in the enjoyable context using computer games could extend the cognitive capacity.

1.2 Research Objectives

The objectives of this study are:

1. To develop a suitable **C**omputer-based **L**earning **M**odule (**CLM**) on Crystal Structures and Unit Cells for mass lecture.
2. To study the effectiveness of the CLM as a visualization tool on Crystal Structures and Unit Cells topic.

1.3 Research Questions

The research questions in this study are:

1. Can the CLM enhance students' learning achievement on the crystal structures and unit cells in the mass lecture as a visualization tool? And to what extend?
2. Is there any significant relationship between the learning achievement and the visual-spatial ability?
3. Who benefit from the CLM visualization tool: in case of different visual-spatial ability?

1.4 Significance of the Study

Learning chemistry at microscopic level such as crystalline solid always generates misconceptions in the learners. The topic consists of various abstract sub-topics concerning mainly on three dimensional crystal structures and unit cells. Learners usually have to visualize and create their own mental structural models, using imagination, from available material such as 2D still images. Imagination from inadequate materials leads to the cognitive load problem and misconception. In addition, traditional teaching approach cannot motivate learners to pay attention to the topic.

The computer-based learning module (CLM) can be utilized as a powerful tool to solve such problems. The CLM developed in this study employs 3D-virtual simulation and games, which are comprehensible and easy to employ, as a visualization tool for students in creating an accurate mental model. Teaching and learning by using the CLM should enhance students' learning achievement on the topic.

CHAPTER II
LITERATURE REVIEW

This chapter reviews the literature in five relevant issues including *learning difficulty in chemistry*, *the role of the visual-spatial ability*, *computer-based visualization tools*, *computer games as an educational tool*, and *theoretical framework*. The first concerns problems occurred in learning chemistry. The second concerns the role of the visual-spatial ability on the learning achievement in chemistry. The third concerns about computer-based visualization tools used for enhancing students' achievement in chemistry. The forth is about using computer games as an educational tool. The fifth section describes theoretical framework applied in this study. The chapter ends with *definition of terms* used in this study.

2.1 Learning Difficulty in Chemistry

Chemistry is the science of materials that make up our physical world. It deals with the composition, structure, properties of matter, changes in matter and the laws or the principles which govern these changes. Chemists have developed a variety of representations, such as molecular model, chemical structures, formulas, equations, and symbols to investigate natural phenomena through ideas of molecules, atoms, and subatomic particles, and the relationship amongst them (Hoffmann & Laszlo, 1991 as referred in Wu & Shah, 2004). Visual representations allow chemists to think, communicate and convey information efficiently. Accordingly, visualization plays a major role in chemists' daily practices and, in other words, we might say that chemistry is a visual science.

Johnstone (1982) distinguished three levels of chemical representation of matter including macroscopic level, sub-microscopic level, and symbolic level. The macroscopic level concerns visible and tangible things in chemistry, which always is the part of students' everyday life. The sub-microscopic level concerns things that cannot be seen by naked eyes: electron, atom, molecule, etc. Dealing with the sub-microscopic level needs model. The symbolic level composes of various representations such as pictures, formula, mathematics, etc. Learning chemistry concept is studying nature of matter in sub-microscopic level and phenomenon in macroscopic level using models in symbolic level to relate and explain. The key concept of learning chemistry is the ability to think of the same phenomenon in form of each three levels and relate among them. However, Gabel (1998) found that many secondary school and college students, and even some teachers, have difficulty transferring from one level to another. Tasker (2006) stated that chemistry involves interpreting observable changes in matter at the macroscopic or laboratory level in terms of imperceptible changes in structure and processes at the imaginary sub-micro or molecular level. At such sub-micro level which is an abstract symbolic level, imperceptible changes are then represented using specialized notation, language, diagrams, and symbolism.

The main problem of transferring between three levels is the “gap” among them. Models including images or physical models are always used to engage students to develop their own mental model. However, there is no any single model suited for all requirements. Using ball and stick model designed for teaching chemical bonding as a model for crystal structure may cause the misconception that the sticks in the crystal structure are also chemical bonds (Haluk Ozmen, 2004).

Difficulties not only come from the nature of chemical structure representations but also relevant abilities to comprehend the structure. Many researchers (Wu, & Shah, 2004; Tasker, & Dalton, 2006; Ozdemir, 2009) reported that the visual-spatial ability took dominant role in learning chemistry concepts concerning structures in sub-microscopic level.

2.2 The Role of the Visual-Spatial Ability

In chemistry education, teachers and educational researchers have recognized the importance of visualization in chemistry learning. Visualizations have been used for communicating concepts to students of chemistry. Secondary school and college chemistry curricula and textbooks use a variety of visual representations to introduce fundamental chemical concepts (Noh & Scharmann, 1997 as referred in Wu & Shah, 2004). For example, in order to identify geometric isomers, students are required to visualize the possible three-dimensional configurations, and compare the configurations. Thus, visual representations indeed facilitate students to understand concepts and by using multiple visual representations, students could achieve a deeper understanding of phenomena and concepts (Ainsworth, 1999; Kozma, et al., 1996 as referred in Wu & Shah, 2004).

One of the reasons visuospatial abilities play an important role in chemistry is that people need the ability to actively maintain and manipulate visual representations in many chemistry contexts. This skill is highly demanding of working memory resources for spatial information (Shah & Miyake, 1996 as referred in Tasker, 2006). Unfortunately, visualizations benefit learners having high spatial abilities more than those who have low visuospatial abilities (Gyselinck, et al., 2002 as referred in Wu & Shah, 2004). Factors that reduce cognitive load are fundamental to help students who need the most help. When tools are specifically designed to reduce cognitive load, they support learning for low spatial students (Wu & Shah, 2004).

The role of visuospatial cognition in chemistry learning was examined thoroughly from many relevant papers reviewed by Wu and Shah (2004). On the basis of their review, they concluded that visuospatial abilities and more general reasoning skills are relevant to chemistry learning, some of students' conceptual errors in chemistry were due to difficulties in operating on the internal and external visuospatial representations, and some visualization tools have been effective in helping students overcome the kinds of conceptual errors that may arise through difficulties in using visuospatial representations. They also suggested five principles for designing chemistry visualization tools to help students understand chemistry concepts and develop representational skills through supporting students' visuospatial thinking.

The five principles are as follows:

1) providing multiple representations and descriptions,
2) making linked referential connections visible,
3) presenting the dynamic and interactive nature of chemistry,
4) promoting the transformation between 2D and 3D, and

5) reducing cognitive load by making information explicit and integrating information for students.

In this work, three out of these five principles including item 1, 4 and 5 are applied in software designing. The researcher attempts to provide multiple explicit representations for each crystal structure in the cubic system and the close-packed structure. 2D still images and their corresponding rotatable 3D structure models are provided on the same screen to promote transformation between 2D image and 3D structure. In addition, relevant information are also integrated and presented on the same screen. All attempts aim to reduce students' cognitive load on learning the topic.

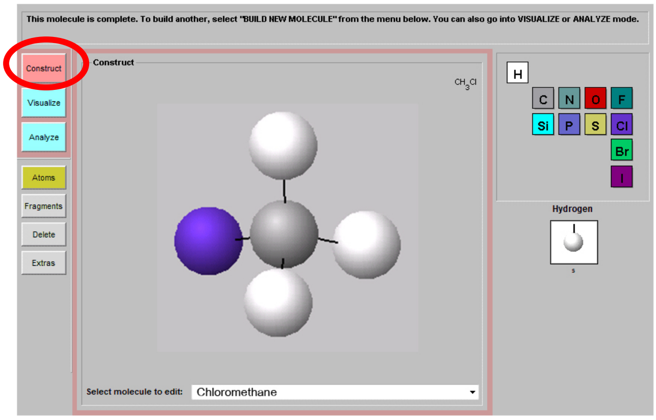
2.3 Computer-Based Visualization Tools

The main purpose of computer-based visualization software is to provide the comprehensive illustrations of chemical structures in the way that promotes the learners to construct the correct mental model. Many computer-based visualization tools have been developed. In this section, the researcher explores a number of molecular visualization educational software used to describe the important concepts of molecular structure. The software, including eChem (Wu, Krajcik & Soloway, 2001), VisChem (Tasker, et al., 1996), and CrystalVis (Foley, 1996), are mentioned as follows.

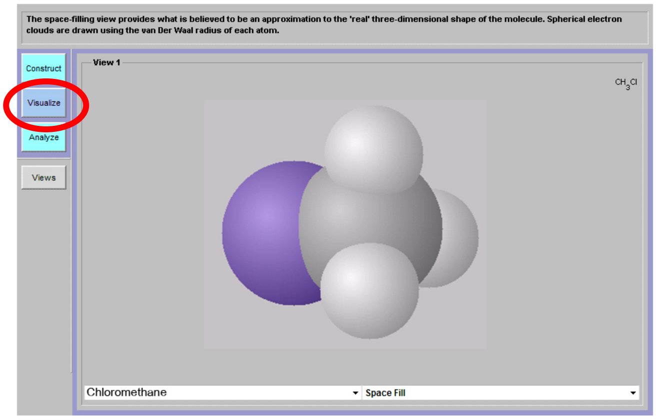
2.3.1 eChem

The eChem is a chemistry software package to construct virtual 3D-models of molecules, visualize multiple views of molecules, and compare/analyze properties of molecules. The eChem composes of three main actions: Construct, Visualize, and Analyze. Figure 2-3 shows the screen of the three main actions.

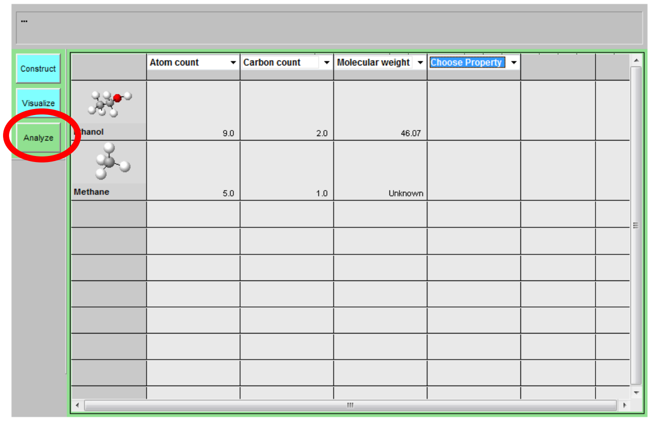
The eChem lets learners select compound they would like to construct and then gradually create bonding between each atomic pair in the compound. The types of bonding are also provided in this step and the resulting compound can be explored in 3D space in order to enhance students' visualization. However, the software does not deal with the crystal structures and unit cells.



(a) Construct



(b) Visualize



(c) Analyze

Figure 2-1 The screenshots of three main actions in eChem program.

2.3.2 VisChem

VisChem is an Australian project which produces multimedia resources illustrating the three levels of chemistry: laboratory, molecular, and symbolic. Figure 2-2 shows three levels of chemistry of ice melting. The equation depicts symbolic level, the photograph of ice melting in beaker depicts macroscopic level, and 3D molecular model depicts sub-microscopic level.

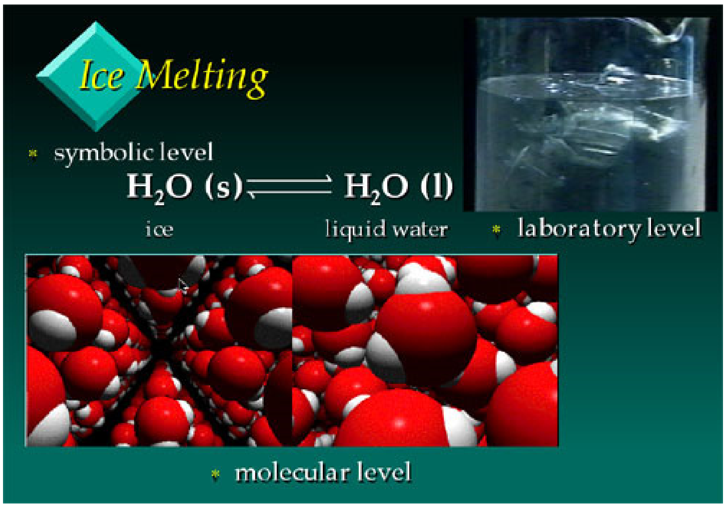


Figure 2-2 VisChem interface shows the relationship of three levels representation in Chemistry

Although its illustrations are comprehensive for learners to relate the three levels of chemistry, it is not designed for crystal structures. It has a very useful feature for demonstrating the dynamic concept of chemical phenomenon such as acid/base hydrolysis, redox reaction, etc..

2.3.3 CrystalVis

CrystalVis is a visualization tool for crystal structures. The program provides various ways to display crystal structures and allows learners to rotate the 3D-structure. However, most contents such as point group, symmetry, and plane are too advanced for general chemistry course.

In addition, CrystalVis is developed for Macintosh computers. Hence, it has a slight advantage for some learners who use such computer. Figure 2-4 shows the screenshot of CrystalVis program.

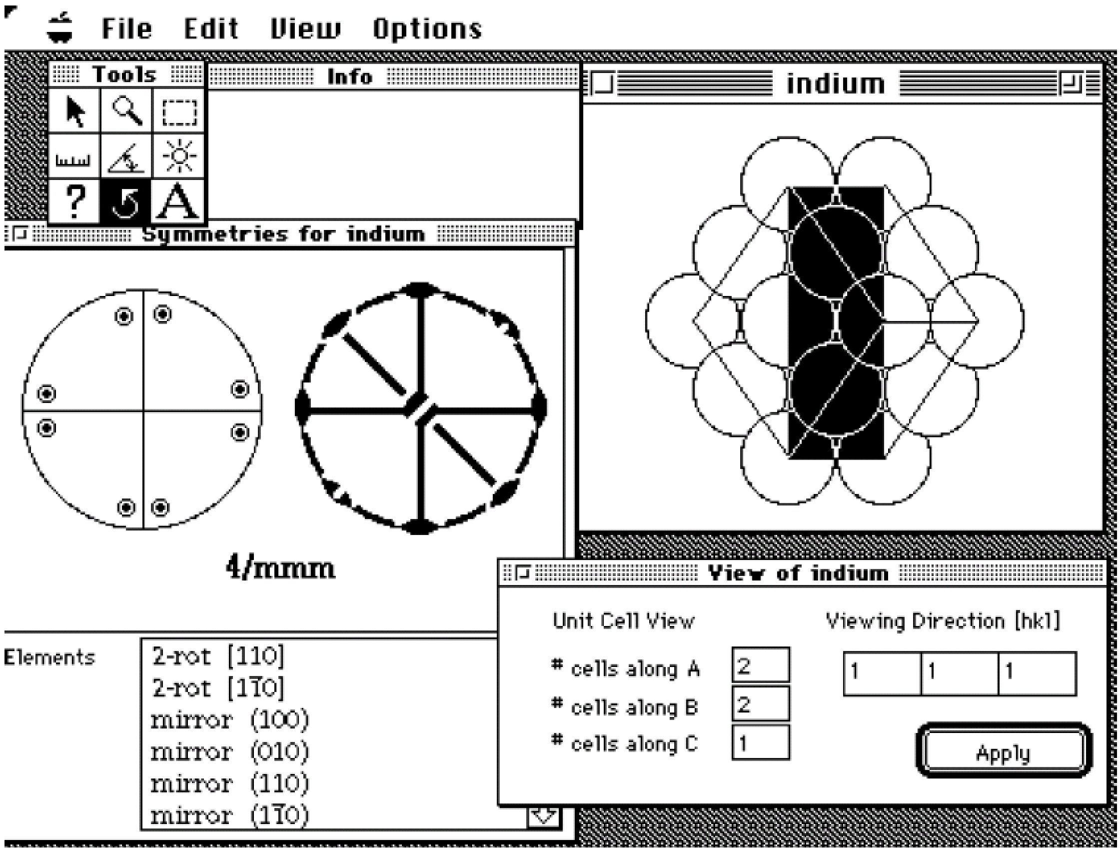


Figure 2-3 The screenshots of CrystalVis Program.

2.4 Computer Games as an Educational Tool

Computer games also play an important role to any fields of education. The games encourage learning within enjoy environment. A lot of game providers such as Davison, pay attention to educational games development, e.g., Math Blaster, Reader Rabbit. Dondlinger (2007) reviewed publications addressing educational game design in order to identify elements of game design that promote learning. He found that motivation and narrative context are essential elements in game design. Many researchers (Amory, Naicker, Vincent, & Adam, 1999; Dickey, 2005; Fisch, 2005) found that motivation to play is a significant characteristic of educational video games.

Motivation by game can promote the learning achievement even in the complex concept. Squire, Barnett, and Higginbotham (2004) and other studies (Aguilera, & Mendiz, 2003; Gee, 2003; Lunce, 2006; Prensky, 2006) found concerning mastery of abstract and conceptual knowledge through game play.

Moreover Kelly (2005) argued that technologies including video games promote mastery of complex concept.

According to Aguilera and Mendiz (2003), playing complex video games situated in 2D/3D environments improve visual spatial processing. Klopfer and Yoon (2005) reported that StarLogo, the game-like computer-modeling environment can enhance learners' comprehensive in complex system. This implies that educational games-based application can be employed to promote learning in complex content.

Cai, Lu, Zheng and Li (2006) developed new edutainment technology for learning of 3D structural protein. The fundamental concepts, including protein primary structure and secondary structure were selected for the development. The content was conducted in an immersive 3D environment using virtual reality (VR) technology, so learners can explore protein structures as if they travel through the helix structure. Although learning by situation in VR can motivate students' attention, it requires a VR high-performance laboratory that is not available in all universities.

2.5 Theoretical Framework

There are several theories that suggest the ways to reduce cognitive load arise from cognitive resources. For example, the cognitive theory of multimedia learning proposed by Mayer (2005), the cognitive load theory by J. Sweller (1988), the information processing theory by Miller (1956), and motivation theories by Malone (1981).

The *cognitive theory of multimedia learning* states that people learn more deeply from words and pictures than from words alone. This theory based on three main assumptions:

1) there are two separate channels (auditory and visual) for processing of information;

2) there is limited channel capacity; and

3) learning is an active process of filtering, selecting, organizing, and integrating information based upon prior knowledge.

These assumptions imply that humans can only process a finite amount of information in a channel at a time; they make sense of incoming information by actively creating mental representation. Design principles include providing coherent verbal, pictorial information, guiding the learners to select relevant words and images, and reducing the load for a single processing channel.

George A. Miller (1956) has provided the concept of chunking and the capacity of short term memory in his *information processing theory*. He presented the idea that short-term memory could only hold 5-9 chunks of information, where a chunk is any meaningful unit. A chunk could refer to digits, words, chess positions, or people's faces. Moreover, from the modern brain study, 4 is the new maximum chunks that short term memory could hold (Scholl & Xu, 2000). These indicate that short term memory is limited in the number of elements it can contain simultaneously. Hence, when faced with new, high element interactivity material, we cannot process it adequately. We invariably fail to understand new material if it is sufficiently complex (Sweller, 2002).

The cognitive load theory proposed by Sweller, suggests that learning happens best under conditions that are aligned with human cognitive architecture (Sweller, 1988). Sweller builds a theory that treats schemas, or combinations of elements, as the cognitive structures that make up an individual's knowledge base. Sweller's theory is best applied in the area of instructional design of cognitively complex or technically challenging material. In the design of effective learning materials, this theory suggests that we must keep cognitive load of learners at a minimum during the learning process. For example, if the text data which unnecessarily increases working memory load is replaced with numbered arrows in the labeled illustration, the learner would concentrate better on learning from the illustration alone. Alternatively, if the text is essential, placing it on the diagram rather than separated will reduce cognitive load associated with searching for relations between the text and the diagram (Sweller, 1988).

In this work, the CLM is designed on the basis of minimizing text illustrations to reduce the load on reading an explanation text. The researcher provides numerous graphics especially the 3D models instead of text. In addition, narration by the instructor is given while using the CLM to reduce the cognitive load on visual channels. In some complicate sub-topics, simulations are designed to reduce the load on studying. As a result of these designs, the CLM should help students reduce the cognitive load on learning the topic.

Beside, there is the other way to help students increase working memory capacity for studying. Such way is motivation. Motivation is closely related to arousal, attention, anxiety, and feedback/reinforcement. For example, a person needs to be motivated enough to pay attention while learning; anxiety can decrease motivation to learn, but receiving a reward or feedback usually increases motivation. Weiner (1990) pointed out that behavioral theories tend to focus on extrinsic motivation (i.e., rewards) while cognitive theories deal with intrinsic motivation (i.e., goals). In cognitive theory, motivation serves to create intentions and goal-seeking acts (Ames & Ames, 1989). One well-developed research area that highly relevant to learning is achievement motivation (Atkinson & Raynor, 1974). Motivation to achieve is a function of the individual's desire for success, the expectancy of success, and the incentives provided. Studies show that in general people prefer tasks of intermediate difficulty. Malone (1981) presented a theoretical framework for intrinsic motivation in the context of designing computer games for instruction. Malone argued that intrinsic motivation is created by three qualities: challenge, fantasy, and curiosity. Challenge depends upon activities that involve uncertain outcomes due to variable levels, hidden information or randomness. Fantasy generation depends upon the skills in the construction of the module. Curiosity can be aroused when learners believe their knowledge structures are incomplete, inconsistent. According to Malone, intrinsically motivating activities provide learners with a broad range of challenge, concrete feedback, and clear-cut criteria of performance. From these reviews, it can be seen that computer games can motivate learning. However, the educational game must be designed in the way that could keep the learning objectives.

In this study, the computer game is developed to motivate learning on the topic. It is designed by integrating appropriate level of challenge, fantasy, and curiosity.

2.6 Definition of Terms

Important terms used in this research are defined as follows.

Cognitive load is the load on working memory during learning.

Computer-based learning module (CLM) is the computer-based learning module developed by the researcher for use in this study. Its components were adjusted progressively from pilot-CLM till an appropriate final-CLM for implementation study was obtained.

Debriefing is an important phase in using simulation games. Participants are invited to discuss experiences gained from playing the game and those from their life. Thus, debriefing is the phase meant to encourage learning from the simulation game.

Effectiveness of Computer-based learning module is a software efficiency that can be verified through students' learning achievement using an examination scores, pretest and posttest.

Effect Size is simply a way of quantifying the size of the difference between two groups. It is particularly valuable for quantifying the effectiveness of a particular intervention, relative to some comparison. It tells us on 'How well does it work in a range of contexts?'.

Final-CLM is computer-based learning module used in the implementation of this study.

Interactive Multimedia PowerPoint (IMP) is one component of the final-CLM which was developed by integrating of various 3D models and simulation into a multimedia PowerPoint format.

Mental model is a kind of internal symbol or representation of external reality, hypothesized to play a major role in cognition, reasoning and decision-making.

Pilot-CLM is computer-based learning module used in the pilot studies. It comprises two components including the VUC and the UCH.

p-value (the significance level) is a probability that a difference of at least the same size would have arisen by chance, even if there really were no difference between the two populations. For differences between the means of two groups, this p-value would normally be calculated from t-test. For example, at a desired significant level of 0.01, if $p<0.01$ (i.e. below 1%), the difference is taken to be large enough to be 'significant'; if not, then it is 'not significant'.

Spatial ability is a category of reasoning skills that refers to the capacity to think about objects in three dimensions and to draw conclusions about those objects from limited information. For example, someone with good spatial abilities might be good at thinking about how an object will look when rotated. These skills are valuable in many real-world situations and can be improved with practice.

Virtual Unit Cell (VUC) is made in the virtual reality context. The models are presented using Virtual Reality Modeling Language.

Visualization is the imagination what it is like by forming a mental picture of it. If you visualize something, you imagine what it is like by forming a mental picture of it.

Visual-spatial ability is the ability to mentally manipulate 2-dimensional and 3-dimensional figures. It is typically measured with simple cognitive tests and is predictive of user performance with some kinds of user interfaces. The cognitive tests used to measure spatial visualization ability include mental rotation tasks and cognitive tests like Paper Folding, and Surface Development tests. Though the descriptions of spatial visualization and mental rotation sound similar, mental rotation is a particular task that can be accomplished using spatial visualization. The visual-spatial ability is also not completely static; it can be improved with practice. In this study, this ability was measured by using the aptitude test.

Unit Cell Hunter game (UCH) is a computer simulation game developed for practicing on the unit cell sub-topic.

Working memory is the ability to actively hold information in the mind needed to do complex tasks such as reasoning, comprehension and learning.

CHAPTER III
METHODOLOGY

This study aimed to research and develop computer-based learning module (CLM) as a visualization tool for enhancing the learning achievement on crystal structures and unit cells for implementation in mass lecture of undergraduate students. Software was developed concurrently with evaluation till an appropriate CLM as a visualization tool for mass lecture was obtained.

The researcher performed two pilot studies to verify an effectiveness of pilot-CLM components including 3D virtual models (VUC) and the simulation game (UCH) on the learning achievement in small groups. Then the final-CLM for mass lecture was developed and implemented in a target group, the first year undergraduate students, to answer the research questions.

3.1 Development of the CLM

The CLM was developed under the theoretical framework described in section 2.5 and the guides suggested by Wu & Shah (2004). Their suggestions are employed as the basis of the development.

3.1.1 The Pilot-CLM

The pilot-CLM comprises two components: 3D-virtual model of crystal structures and unit cells named VUC and a simulation games named UCH.

3.1.1.1 The VUC (Virtual Unit Cell)

The VUC is 3D-virtual model that simulates the crystal structures and the unit cells. It was developed for use as a visualization tool. All virtual 3D structure within VUC can be rotated and explored in any viewpoints. VRML language was used to develop VUC. The VUC consists of three parts as shown in Figure 3-1.

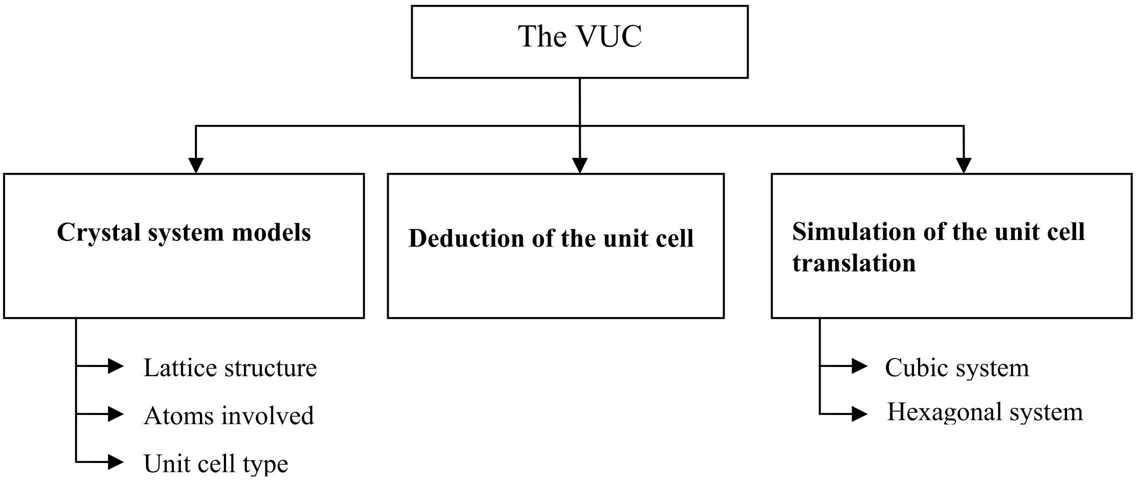


Figure 3-1 The VUC's structural diagram showing its three main parts and subtopics.

The first part involves models of *cubic crystal and hexagonal crystal*, both of which are composed of three components: lattice structure, atomic pieces involved in the unit cell, type of unit cell.

The second part, *deduction of the unit cell*, provides graphics showing how to deduce the unit cell from a lattice.

The last, *simulation of the unit cell translation*, simulates the way the unit cell translates along the three principal orthogonal planes to generate the crystal lattice.

3.1.1.2 The UCH (Unit Cell Hunter)

The UCH is an instructional game designed for practicing the unit cell structure. Macromedia Flash 8 Professional with actionscript2.0 was used to develop the game. Theme of the game is challenging students with gathering and constructing tasks. Students have to collect the unit cell's components to construct the accurate unit cell structure. After completing the tasks, students' performance based on the correctness of the tasks was evaluated.

At each level of the game, the user interface of the UCH consists of two scenes. In the first scene, the player collects atomic pieces of the unit cell in order to put them in their proper places on the cubic framework of the second scene. The UCH structural diagram is shown in Figure 3-2.

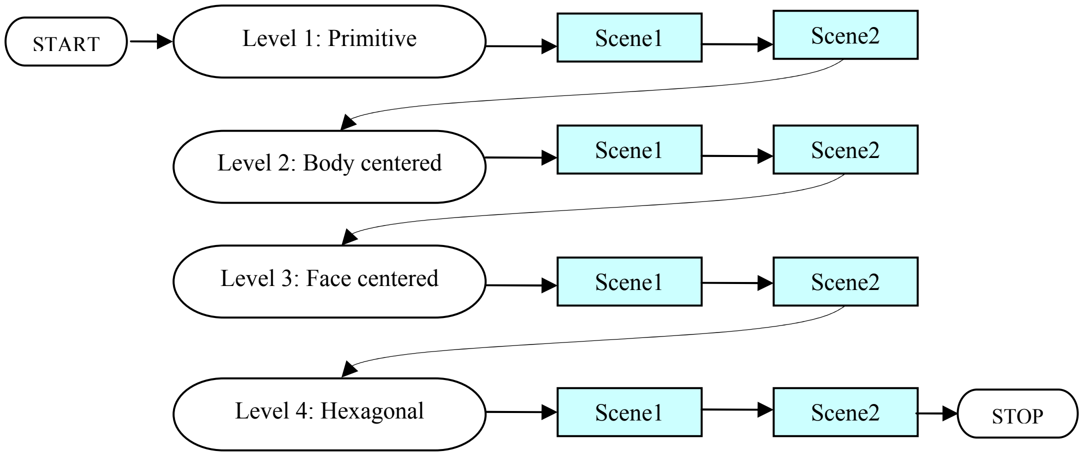


Figure 3-2 The UCH's structural diagram showing its structure and relationship between levels and scenes.

The UCH game has four difficulty levels starting with the easiest to the most difficult unit cell structures: simple cubic, body-centered cubic, face-centered cubic and hexagonal close-packed, respectively.

- level 1: Primitive cubic
- level 2: Body-centered cubic
- level 3: Face-centered cubic
- level 4: Hexagonal close packed

Each level has two scenes of the same type: Scene 1 involves collecting correct number and type of the atomic pieces of the unit cell. Scene 2 involves putting the collected pieces at their proper places in the unit cell to make a quasi-3D display.

3.1.2 The Final-CLM

The final-CLM was used in the implementation study. It comprises of two components including an Interactive Multimedia PowerPoint named **IMP** and the UCH. The IMP obtained by integrating suitable models selected and adapted from the VUC component in the pilot-CLM into the PowerPoint format. The reason for this adaptation is that there is no computer in a lecture hall for students and the lecture period is too short. Therefore, the software to be provided for the lecturer should have a very friendly user interface that easy to be used. One general program format we familiar with is Microsoft PowerPoint. Hence, the PowerPoint format was selected and the **IMP** was developed for this implementation study. In IMP development, the scope of the content has been extended to cover all sub-topics as described in chapter I.

The IMP was designed to help students visualize the crystal structure effectively while it is easily controlled by the lecturer. The UCH component was still employed in the implementation study. Thus, the final-CLM comprises two components, the IMP and the UCH. However, due to the mass lecture environment, participating in the UCH game must change from individual's playing into co-operative playing. Two groups of four students were invited to be competitor in playing the UCH games and the rest participated in game playing by cheering and giving a hint to the players.

3.2 Research Design

In the pilot studies, the researcher aimed to develop and investigate the effects of the pilot-CLM (VUC & UCH) on the unit cell sub-topic. The pilot-CLM was tried on a small group of participants in order to examine the feasibility of the pilot-CLM as a visualization tool. In the first pilot study (the pilot study I), the pilot-CLM was evaluated by using two-group pretest-posttest design. In the second pilot study (the pilot study II), the pilot-CLM was evaluated by using one-group pretest-posttest design.

For the implementation study at the mass lecture, the final-CLM (IMP & UCH) was implemented on a large group of target participants, to evaluate the effectiveness of the pilot-CLM as a visualization tool using one-group pretest-posttest design. The reasons for choosing this research design are the limitation of the first year university students' time schedule and the lecturer's intention on fairness.

3.3 Population and sampling

In pilot studies I and II, small group of 24 and 23 participants from a government university were selected by volunteer respectively. The different groups of participant in both pilot studies were the first year students from the faculty of Science who interested in computer simulations and games and volunteered to participate in the study.

The target population of this study is the first year undergraduate students who have to study the topic. Research participants, 170 pharmacy students in a government university in the central part of Thailand were selected for implementation study by using purposive sampling method.

3.4 Research Instruments

The research instruments used in this study were developed particularly for each phase.

3.4.1 Research Instruments Used in the Pilot Studies

Research instruments in pilot studies include the pilot-test, the pilot-questionnaire, and semi-structured interview.

3.4.1.1 The Pilot-Test

The pilot-test is a paper pencil test that was used to assess the learning achievement after using the pilot-CLM, in effect to verify the effectiveness of pilot-CLM as a visualization tool to enhance the learning achievement. Both pilot studies employed the same pilot- test. A copy of the pilot-test is shown in Appendix G.

3.4.1.2 The Pilot-Questionnaire

The questionnaire was used to measure students' attitude toward the pilot-CLM. The questionnaire has question statements relating to whether the pilot-CLM helps the students to visualize and get better understanding on the content. Both pilot studies employed a different version of pilot-questionnaire. In pilot II-questionnaire, additional statements were added to evaluate more aspects of students' attitude toward the UCH game. Copies of the pilot-questionnaires are shown in Appendix H and I for the pilot study I and II, respectively.

3.4.1.3 Semi-Structured Interview

The semi-structured interview aimed to investigate students' opinion toward supplementation of the pilot-CLM to their regular learning. It was conducted only in the pilot study I. Some students from the traditional and supplemented groups were randomly selected for the interview. They were asked for drawbacks and suggestions for improvement. For the pilot study II, the main purpose is to verify the UCH efficiency through a debriefing process, thus, participants participated in debriefing instead of interview.

Debriefing is an important process to encourage learning from the simulation game, it is done immediately after playing the game to guarantee the knowledge that students gain from the game. Normally, in general games, players always try to achieve the game objective such as pick up the weapon and fight to monster, etc. In case of instructional games, the learning objective(s) must be integrated to the role in games. While playing, the player may be distracted by any factors such as the difficulty of the games. Most of them recognize the game objective but usually miss the learning objective. In debriefing, participants are invited to discuss experiences gained from playing game and those from their life in order to guarantee that they achieve both objectives.

3.4.2 Research Instruments Used in the Implementation Study

Implementation study employed three research instruments: aptitude test, achievement test, and questionnaire.

3.4.2.1 Achievement Test

The achievement test is a multiple choice test (Appendix D) designed to examine students' learning achievement. At the same time, it is an implication of the final-CLM effectiveness. The test was used both in pretest and posttest. It was developed under the following learning objectives:

(1) Able to analyze crystal structures and unit cells in cubic system,

(2) Able to combine atomic pieces and indicate number of atoms within the unit cells,

(3) Can calculate the relationship between atomic radius (r) and unit cell edge's length (a),

(4) Can utilize the relationship of unit cell parameters to calculate atomic radius of the material crystallized in cubic structure,

(5) Able to identify the closest-packed structure,

(6) Able to identify holes in the closest-packed structure,

(7) Able to identify the co-ordination number in the crystal structures

3.4.2.2 Aptitude Test

An aptitude test was carried out to examine students' visual-spatial ability. It was composed of both multiple choices and one-word fill in the blank questions (see Appendix E). The test was developed based on Visual-Spatial Chemistry Specific Assessment test developed by Christian (2009) and the following two objectives:

(1) To what extent the students are able to visualize (creating a mental model) a complex three dimensional structures from two dimensional images and able to analyze the spatial relationship between the elements in the structure, and

(2) To what extent the students are able to rotate and compare three dimensional structures from two dimensional images.

3.4.2.3 Questionnaire

The questionnaire was made for measuring students' attitude toward the final-CLM. Students' attitude is also an important evidence for assessing the effectiveness of the CLM as a visualization tool. The questionnaire has eight question statements relating to whether the final-CLM helps students to get better visualization on crystal structures and unit cells. It was made based on a 5-point Likert scale. A copy of the questionnaire is shown in Appendix F.

3.5 Data Collection

Data collection in each study phase is presented separately as follows.

3.5.1 Data Collection in the Pilot Study I

Participants in the pilot study I were divided into two groups, a traditional group and the CLM-supplemented group.

The traditional group received traditional lecture using physical models made from folded papers and ping-pong balls. The students in the supplemented group were lectured using the pilot-CLM and, after lecture, they were also allowed to study with the physical models.

Students in both groups were asked to do the pilot-pretest (Appendix G) for 30 minutes before the learning. At the end of the activities, all students were asked to do the pilot-posttest using the same pilot-test; only students in the supplemented group were asked to respond to the questionnaire for their satisfaction toward the CLM. The data collection steps in the pilot study I are summarized in Table 3-1.

Table 3-1 data collection steps in the pilot study I
(1-week teaching unit: 1-2 periods/ day)

Time	Activities	
	Traditional group	**Supplemented group**
30 min	Students do the pretest.	
5 hours (in 3 days)	Lecture in classroom - Teacher uses physical models in lecturing. - Students study the physical models with the teacher guidance.	Lecture in computer room (one computer / student) - Teacher uses the CLM in lecturing. - Students study the CLM with the teacher guidance. - Students investigate the physical models (for comparison with the CLM).
30 min	Students do the posttest.	
15 min	-	Students fill in the questionnaire.
1 h	Some students are randomly selected for interview.	

3.5.2 Data Collection in the Pilot Study II

The students were given the pilot-pretest (Appendix G) for 30 minutes in the lecture room. Afterwards, students were invited to the computer laboratory room and manned a computer individually. The researcher started teaching with the VUC, followed by the UCH. Then students participated in the debriefing process. At the end of the process, all students were asked to do the pilot-posttest using an identical pilot-test and fill in the questionnaire (Appendix I). The data collection steps are summarized in Table 3-2.

Table 3-2 Data collection steps in the pilot study II
(1-day teaching unit – approximately 4 hours)

Time	Activities	Place
30 min.	Students do the pretest.	Lecture room
	Start teaching	
1 hour	Students participate with the VUC.	Computer room
1 hour	Students participate with the UCH.	Computer room
	Stop teaching	
30 hour	Students participate in debriefing.	lecture room
30 min.	Students do the posttest.	lecture room
15 min.	Students fill in the questionnaire.	lecture room

3.5.3 Data Collection in the Implementation Study

The students were asked to do the aptitude test (Appendix E) followed by achievement pretest (see Appendix D). Afterward, the lecturer starts lecturing using the IMP followed by the UCH game contest. At the end of the activities, all students were asked to do the posttest using an identical achievement test and then responded to the questionnaire. The data collection steps in the implementation study are summarized in Table 3-3.

Table 3-3 data collection steps in an implementation study (1-day teaching unit: approximately 4 hours)

Time	Activities at the lecture hall
5 mins	Inform students the research process approved from the Mahidol University Institutional Review Board (MU-IRB).
15 mins	Students do the aptitude test.
40 mins	Students do the achievement pretest.
90 mins	Lecture in the lecture hall (one computer for instructor). Instructor gives narration while demonstrating using IMP.
30 mins	Two groups of three students participate in UCH game contest at the podium (this competition was shown by two overhead projectors). The rest participate by cheering and giving a hint to players.
40 mins	Students do the achievement posttest.
10 mins	Students fill in the questionnaire.

3.6 Validity and Reliability of the Research Instruments

The content validity, reliability, and discrimination of the instruments used in the implementation study were determined with 40 first-year undergraduate science students to assure the quality of measurement results.

The content validity of the instruments was determined using IOC -- Index of Item Objective Congruence. The validation was established by three content experts. This determination was performed on all instruments except the questionnaire. IOC at 0.67 and above is judged acceptable (Rovinelli & Hambleton, 1977).

The reliability of all instruments was determined using Cronbach' alpha. The higher the Alpha, the more reliable the test is. There is not a generally agreed cut-off. Usually 0.7 and above is judged acceptable (Nunnally, 1978).

Discrimination of the instruments was determined using various methods depending on the type of data obtained from the test. For the aptitude test and achievement test which generate dichotomously-scored data, their discriminations were determined using the general formula. While the questionnaire which is a rating scale range from 1 to 5 points, the t-test was used instead. For the former method, item discrimination index of 0.3 and above is acceptable (Doran, 1980). For the latter, t_{cal} will be compared with t_{table} at the desired significance level, if t_{cal} is higher than t_{table} the discrimination is acceptable.

3.6.1 Achievement Test

IOC results of most items at 1.0 and two items at 0.67 show content validity of this test.

The Cronbach's alpha coefficient at 0.736 of this test means that its reliability is acceptable.

The item discrimination index of most items in this test are greater than 0.3, imply that these items did discriminate usefully. Although some items have discrimination index lower than this criteria, such items still be employed due to the aim of this study does not focus on performance discrimination but on the learning achievement of all student in all learning objectives.

3.6.2 Aptitude Test

IOC results at 1.0 for all test items indicate content validity of this test.

The Cronbach's alpha coefficient result at 0.706 indicates reliability of the test.

The item discrimination index of most items in this test are greater than 0.3. This implies that these test items did discriminate usefully. Two items that has discrimination index at a bit lower than 0.2 are still employed to measure the learning achievement in all learning objectives set out.

3.6.3 Questionnaire

The Cronbach's alpha at 0.763 of this questionnaire indicates its reliability. The item discrimination index (t) of most items in this test, except only statement 7, are greater than 2.55. This implies that the statements did discriminate usefully at α 0.01. However discrimination index (t) at 2.47 of statement 7 still has discrimination power at α 0.05.

3.7 Data Analysis

All statistical data analysis were performed by using SPSS program (version 17). Data analysis method used in each research studies are described in detail as following.

3.7.1 Data Analysis in the Pilot Studies

3.7.1.1 The Pilot Study I

The data from each group: traditional and CLM-supplemented group, are analyzed individually for the difference of mean between pretest and posttest score using paired t-test.

The mean pretest, posttest and percentage gain score of both groups were compared using independent t-test.

Percentage gain scores (Menlo & Johnson, 1971) show how much the students gained out of the total possible that they could have gained from pretest to posttest. The formula for percentage gain is:

$$\text{Percentage gain} = \frac{\text{Posttest score} - \text{Pretest score}}{\text{Maximum score} - \text{Pretest score}}$$

All statements in the questionnaire were analyzed separately as frequencies of students' attitudes on each rating scale.

The interviews were recorded and analyzed for students' opinion.

3.7.1.2 The Pilot Study II

The pretest and posttest scores of the pilot-test were analyzed for their difference using the paired-samples t-test. The learning achievement is verified through the posttest score in percentage compared with criterion referenced score. All statements in the questionnaire were analyzed separately as frequencies of students' attitudes on each rating scale.

3.7.2 Data Analysis in the Implementation Study

To verify the effect of the final-CLM on the learning achievement, the achievement pretest and posttest score of each learning objective were analyzed using paired t-test to examine their significant difference. Posttest score in percentage was used to assess students' achievement compared to criteria score. In addition, the mid-term examination data of two groups, students who learned with the traditional lecture in the year before (N=183) and the students who learned with the CLM in this year (N=169), were also obtained from the lecturer. Both groups are the first year Pharmacy students from the same university from academic year 2009 and 2010 respectively. They are in the same learning conditions; such as same lecturer, same topics, and same examination test; except only the latter were lectured with the CLM. The percentage test score of students in both groups were compared for the difference of mean using independent t-test. Then, the effect size was determined to measure the magnitude of the effect of the CLM on the learning achievement. The Cohen's formula (shown below) was used to estimate the effect size.

$$\text{Effect Size} = \frac{[\textit{Mean of Experimental group}] - [\textit{Mean of Control group}]}{SD_{pool}}$$

Where:

Mean of Experimental group is the mean test score of the CLM group.

Mean of Control group is the mean test score of the traditional group.

SD_{pool} is the pooled estimate of standard deviation. It is an average of the standard deviations of the experimental and control groups as shown below.

$$SD_{pool} = \sqrt{\frac{(\mathrm{N_E} - 1)\,\mathrm{SD_E^2} + (\mathrm{N_C} - 1)\,\mathrm{SD_C^2}}{\mathrm{N_E} + \mathrm{N_C} - 2}}$$

Where:

N_E is the number of participants in the experiment group (the CLM group).

N_C is the number of participants in the control group (traditional group).

SD_E is the standard deviation of the experiment group (the CLM group).

SD_C is the standard deviation of the control group (traditional group).

The efficiency of the final-CLM as a visualization tool was assessed through the relationship between the percentage gain score and the correlation level between the learning achievement and the visual-spatial ability at each learning objective. If the gain score among objectives concurred with the required level of the visual-spatial ability, it should reflect the effect of the CLM as a visualization tool. The correlation levels for each learning objective were determined between the means of achievement posttest scores that fell on the same aptitude scores and the corresponding aptitude scores using Pearson's Correlation. The efficiency of the final-CLM as a visualization tool was also confirmed by students' attitude obtained from the questionnaire. All statements of the questionnaire were analyzed individually as frequencies of students' attitudes at each rating scale.

To verify the correlation between the visual-spatial ability and the learning achievement, the aptitude test score and the achievement posttest score of all participants were analyzed using Pearson's Correlation. In addition, in attempt to interpret the data more clearly, the total achievement posttest scores fell on the same aptitude score were averaged, then, the mean scores were analyzed for the correlation with their corresponding aptitude scores using Pearson's Correlation. The mean plot between the aptitude scores and the mean achievement posttest scores was shown with their correlation.

To verify a benefit of the CLM on students with different visual-spatial abilities, students were graded into five groups of abilities according to their aptitude test score in percentage: grade 0, 1, 2, 3, and 4 at ≤50%, 50-59%, 60-69%, 70-79%, and ≥80%, respectively. Then, the significant difference of the mean posttest scores between groups were analyzed using one-way ANOVA.

Relationship between the implementation study issues and the data analysis method are summarized in Table 3-4.

Table 3-4 Relationship between the implementation study issues and the data analysis.

Implementation study issues	**research instrument**	**collected data**	**data analysis method**
Effect of the CLM on the learning achievement	Achievement test	pretest-posttest scores (N=133)	• paired sample t-test
		posttest score (N=170)	• posttest score in percentage
	Mid-term test (by the lecturer)	test scores of traditional group (year 2009; N=183) and the CLM group (year 2010; N=169)	• independent t-test • effect size
Efficiency of the final-CLM as a visualization tool	Achievement test	pretest-posttest scores (N=133)	• percentage gain score *(for each learning objective)*
	1. Aptitude test *(visual-spatial ability test)*	test score (11 groups of the score: range from 0,1,2,3,4,… to 10 points)	• Pearson's correlation *(for each learning objective)*
	2. Achievement test	the mean posttest scores of students who have the same aptitude score (11 mean scores)	
	Questionnaire	response (N=100)	• frequencies of students' attitude
Correlation between the visual-spatial ability and the learning achievement	1. Aptitude test	test score (N=170)	• Pearson's Correlation
	2. Achievement test	posttest score (N=170)	
Beneficial of the final-CLM on students with different visual-spatial abilities	1. Aptitude test	test score (as grade) (5 grades : 0, 1, 2, 3, 4)	• one-way ANOVA
	2. Achievement test	the mean posttest scores of students in the same aptitude grade (5 mean scores)	

3.8 Research Overview Diagram

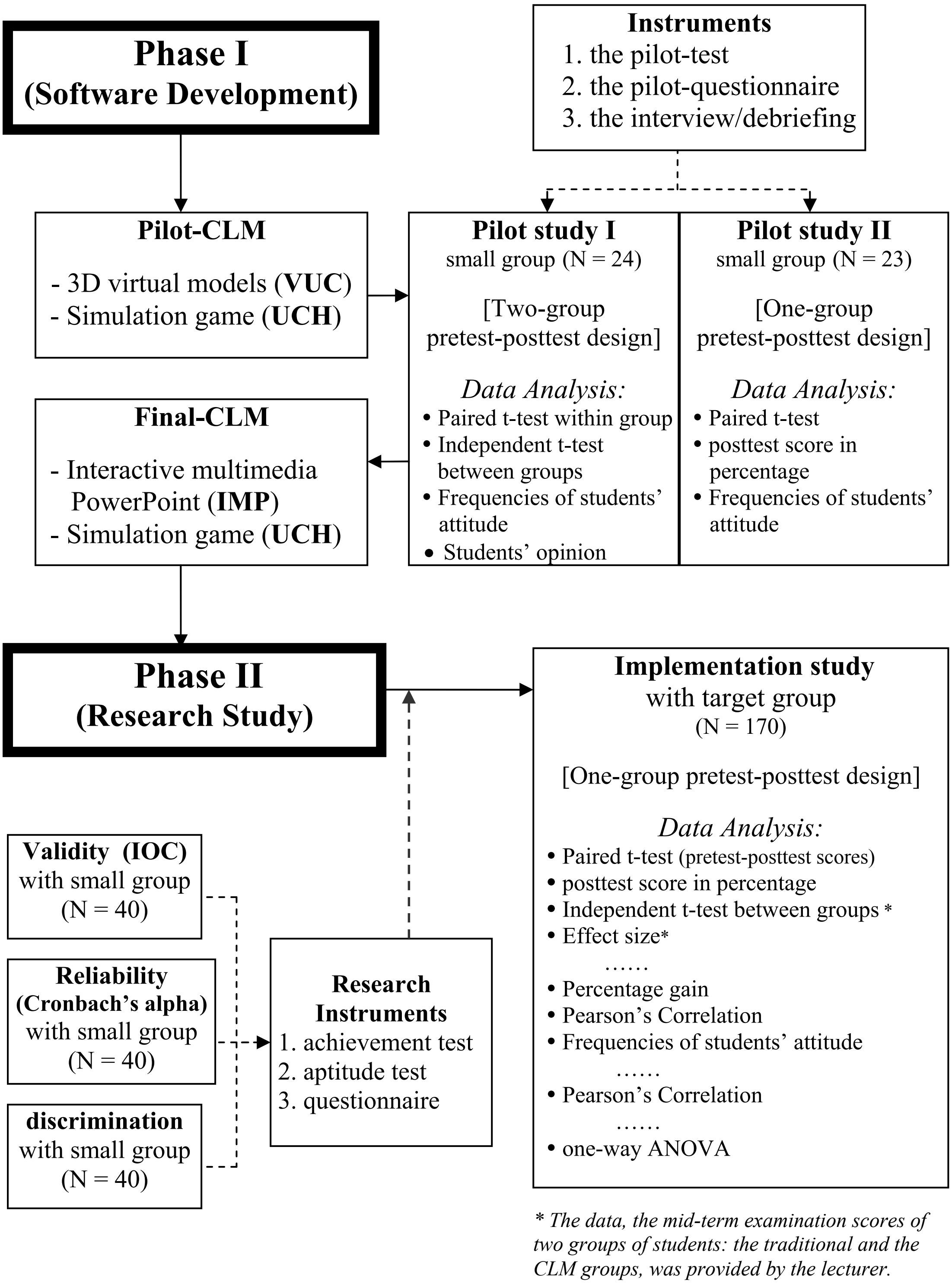


Figure 3-3 The Research Overview Diagram

CHAPTER IV
RESULTS

All results obtained from each study were reported in this chapter, starting with the software that has been developed, the CLM. Its beneficial features are presented. Then the results obtained from two pilot and the implementation studies are reported, respectively.

4.1 The CLM

The CLM has been developed in 2 versions, the pilot-CLM, and the final-CLM. The pilot-CLM (the VUC & the UCH) was conducted to two pilot studies. The final-CLM (the IMP & the UCH) was conducted to the implementation study. Note that in the final-CLM, the VUC was modified to be the IMP as described in section 3.1.2. Figure 4-1 shows structure and components of the CLM at each study phase.

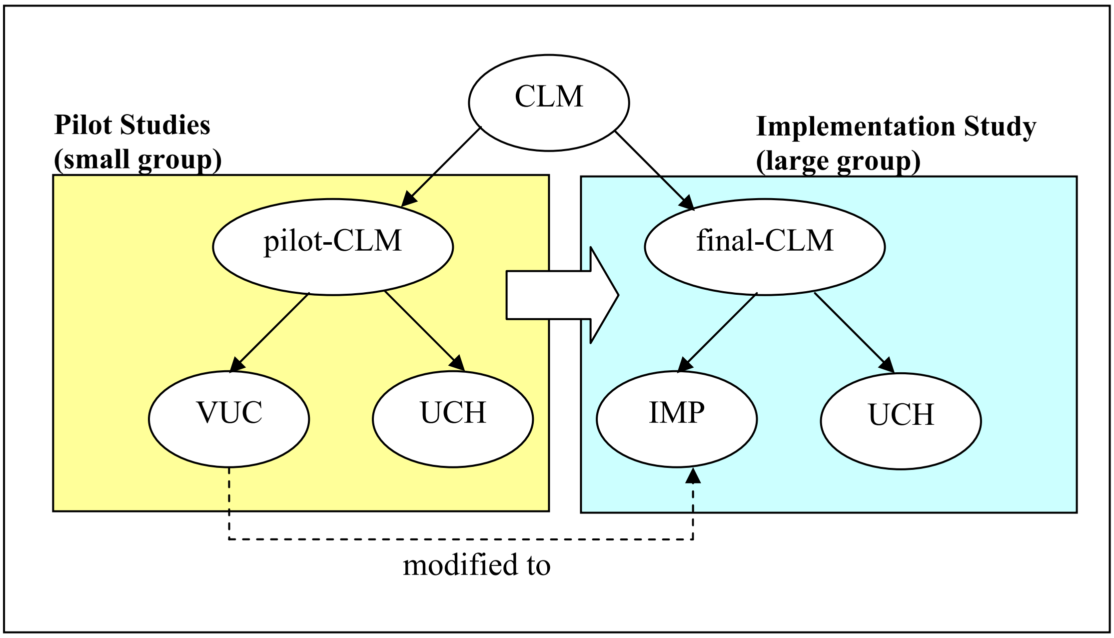
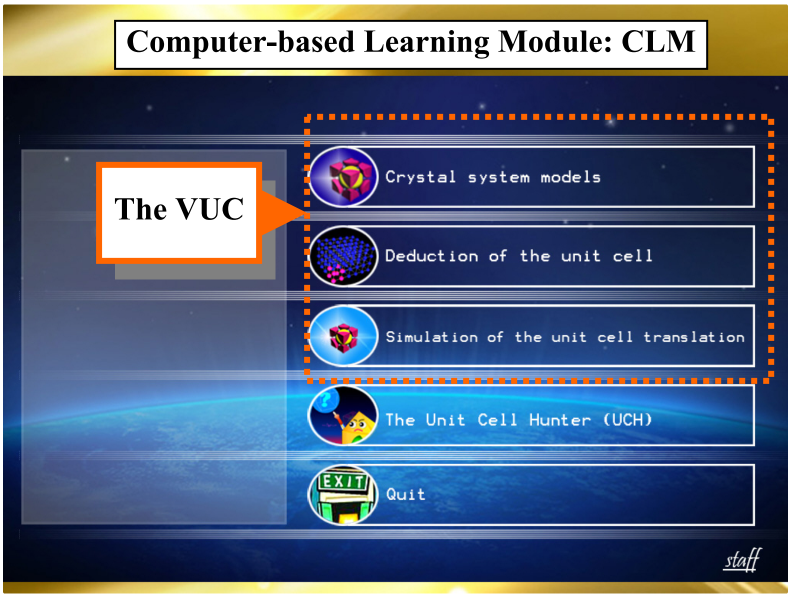


Figure 4-1 The components of CLM at each study phase.

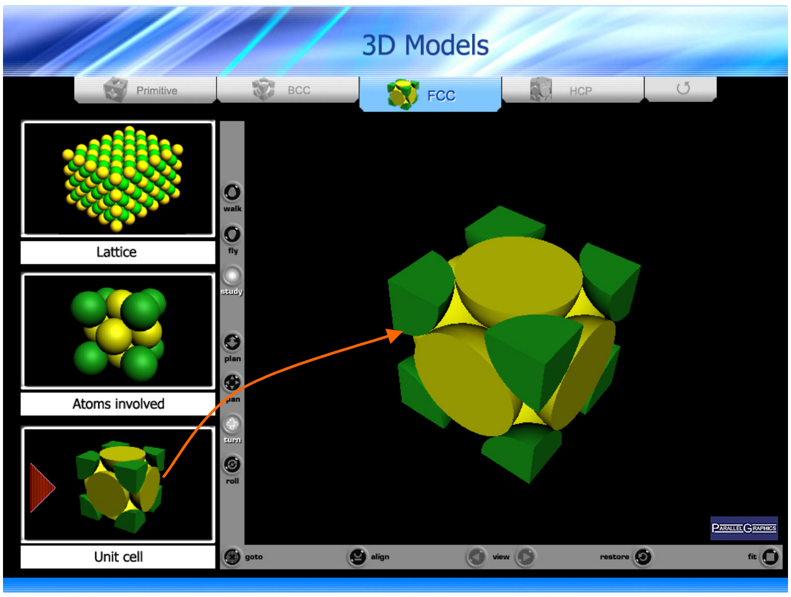
The VUC, the UCH, and the IMP are reported separately as following.

4.1.1 The VUC

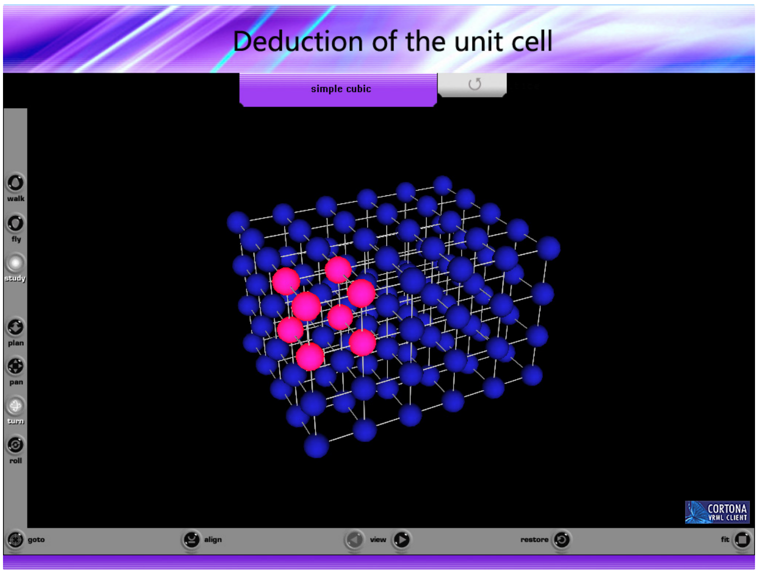
The VUC is an application software containing 3D-models of crystal structures and unit cells in the cubic system. The models were developed using Virtual Reality Modeling Language (VRML). Some main screens of the VUC are shown in Figure 4-2 (a)-(d) (see also Appendix A).



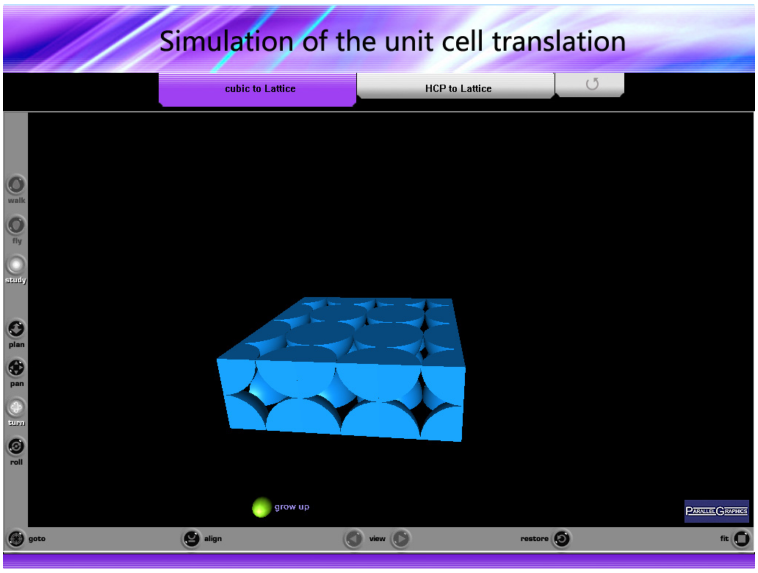
(a) The pilot-CLM main menu.



(b) An example of 3D model in VUC, face centered cubic unit cell



(c) The screen shot of unit cell deduction function in VUC.



(d) The screen shot shows simulation of the unit cell translation**.**

Figure 4-2 Some main screens of the VUC.

The main advantages of the VUC are the ability to display the crystal structures and unit cells as virtual 3D models with contrasting colored atoms and rotatability of the models to make them appear "real". In the process of deducing the unit cell, the color of the atoms and pieces thereof can be changed by a click, as shown in Figure 4-3. The latter feature helps facilitating the gradual deduction of the unit cell from a crystal structure as the students gradually narrow the number of unit cells down to the irreducible one eventually (Figure 4-3).

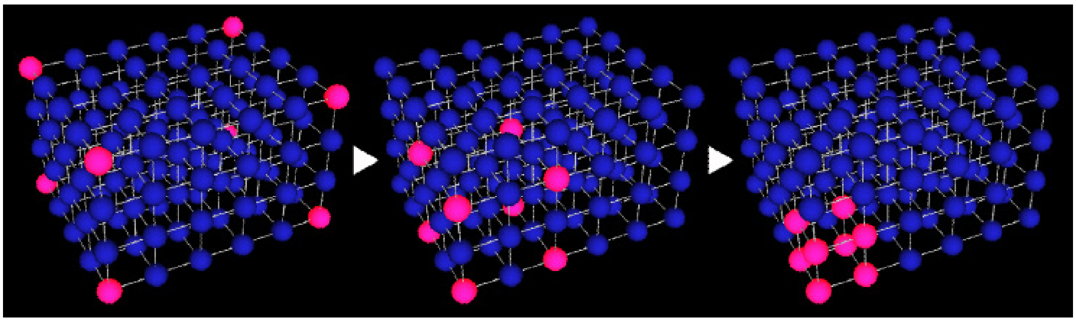


Figure 4-3 The color of the atoms can be changed by a click during the narrowing down to an irreducible unit representing the unit cell.

In the simulation of the unit cell translation to generate the crystal structure, the previous steps are reversed now by expanding of the unit cell along the xy, yz and zx planes to generate a larger structure (Figure 4-4).

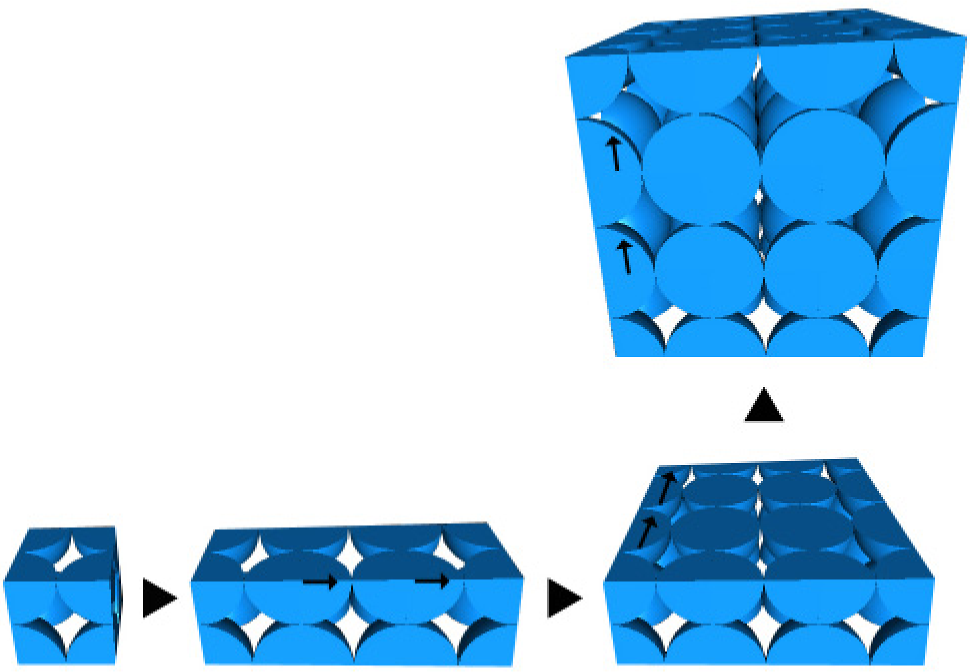
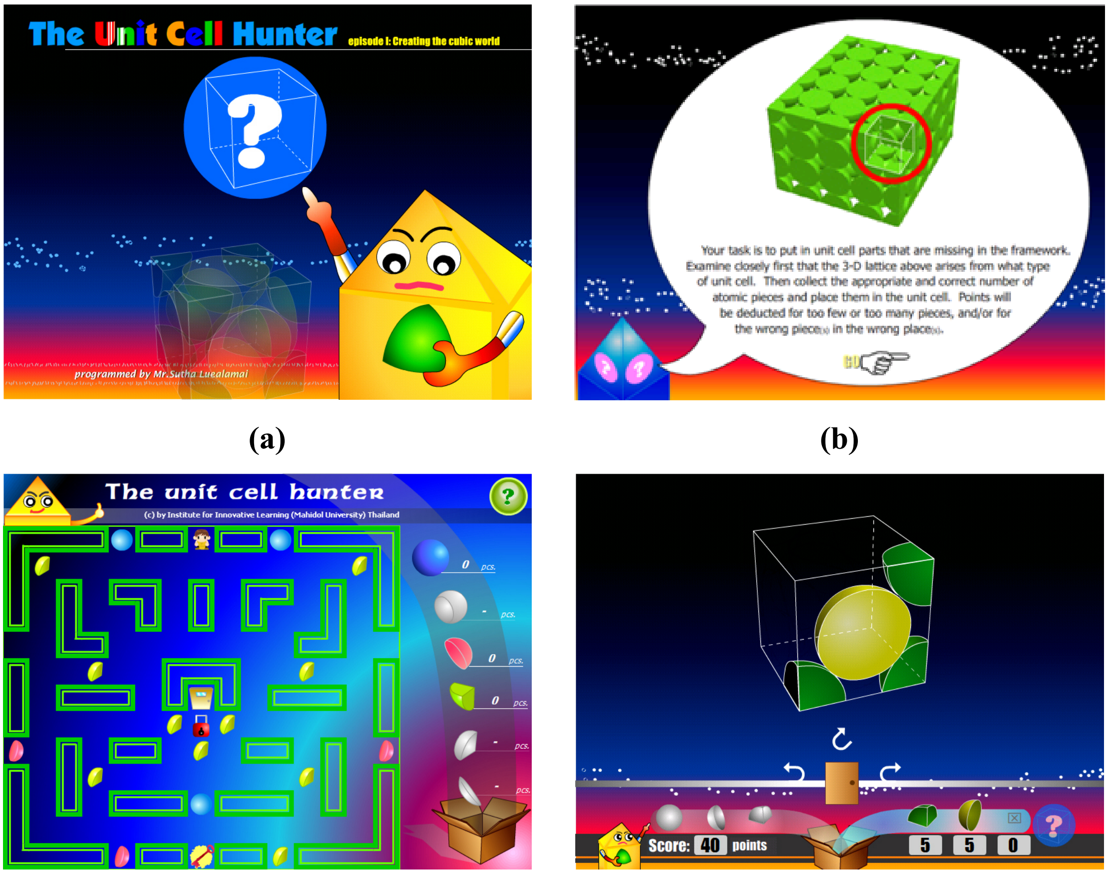


Figure 4-4 The step-by-step 3D simulation of unit cell translation to reproduce the larger structure in the VUC.

4.1.2 The UCH

The UCH or The Unit Cell Hunter is a computer simulation game developed for practicing on the unit cell structures. Figure 4-5 (a)-(d) shows some main screens of the UCH (see Appendix B).



(a) (b)

(c) (d)

Figure 4-5 Some main screens of the UCH game: (a) first screen, (b) deduction scene, (c) collection scene, and (d) construction scene.

The students acquire skills and visual knowledge in going through the manipulative and cognitive challenges from levels 1 to 4. Also the researcher have made the unit cell framework for each type rotatable to facilitate the assembly of the pieces as shown in Figure 4-6.

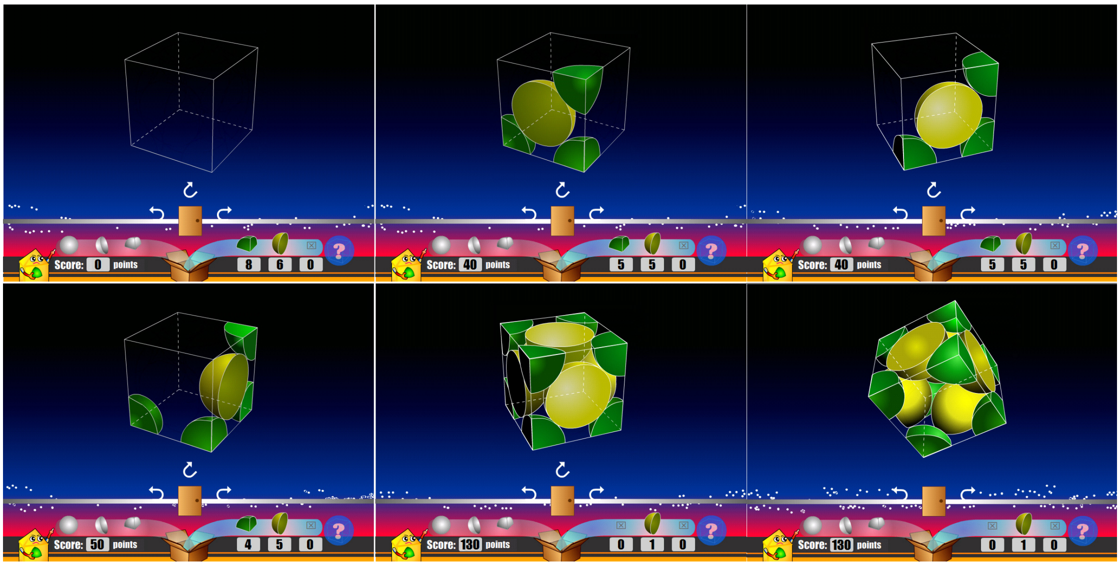


Figure 4-6 Rotatable cubic framework allowing different viewpoints.

Because the atomic pieces may visually block each other in the static framework thus causing perceptual inconvenience to the students, the researcher have created a rotatable cubic frame to make the blocked unfilled spaces visible and ensure that correct pieces are put in as shown in Figure 4-7.

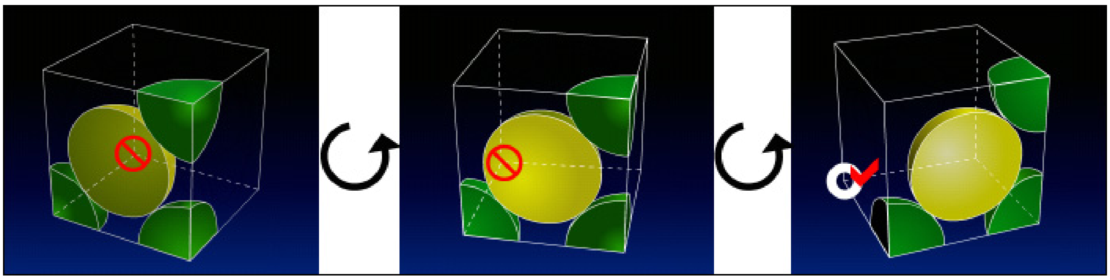


Figure 4-7 A rotatable cubic frame for better visualization and playing of the game.

4.1.3 The IMP

The IMP or the Interactive Multimedia PowerPoint is the PowerPoint slide containing multimedia files in various format, i. e., Microsoft Video for Windows (*.avi) and Shockwave Flash (*.swf).

The IMP is the most versatile component of CLM. It can be easily controlled by user in the same manner as other PowerPoint slides. In addition, the IMP that recorded on the CD-ROM prompts to be utilized without any necessarily to install other plug-in program while the VUC has to.

The IMP consists of 3D-animations and interactive animations. Although the 3D models in IMP can not be explored thoroughly in all viewpoints like the model in the VUC, they have more interactive features. For example, the lecturer can control the steps of animation in order to give learners concurrent narration. Figures 4-8 to 4-11 show other simulations in the IMP (see more examples in Appendix C).

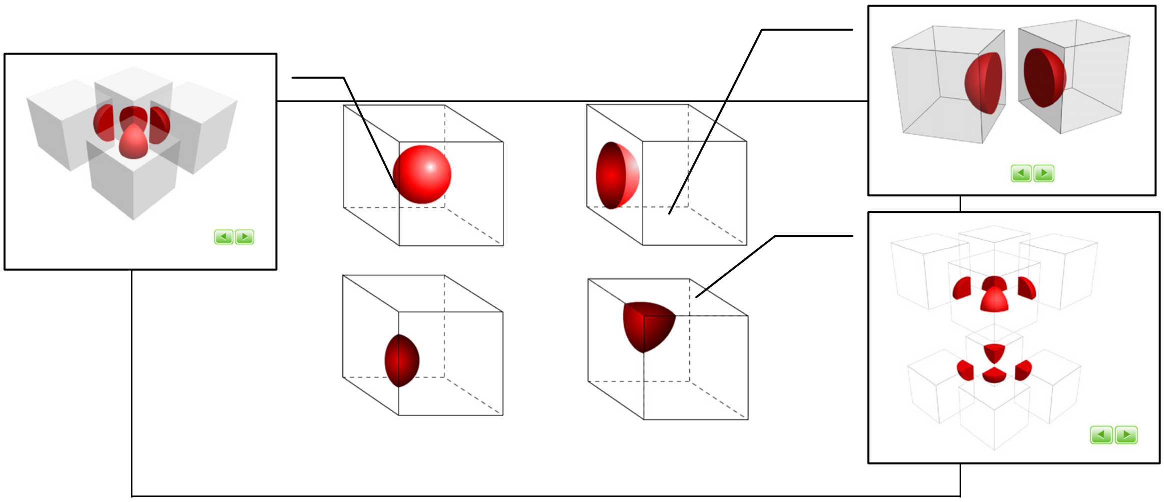


Figure 4-8 An interactive shows division of an atom into its atomic parts and their shape at different position in a cubic frame.

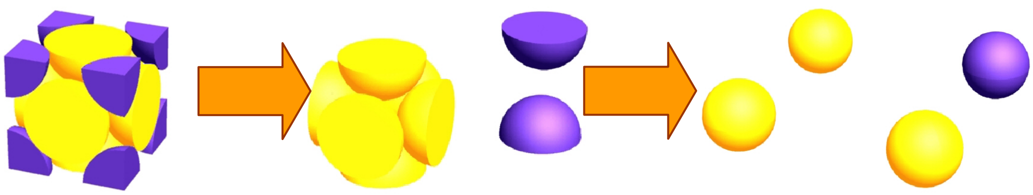
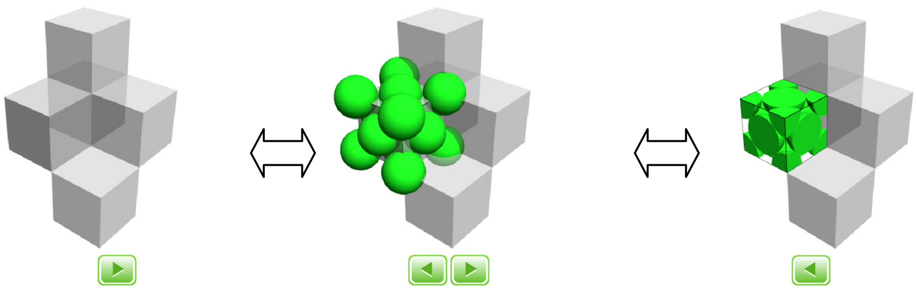
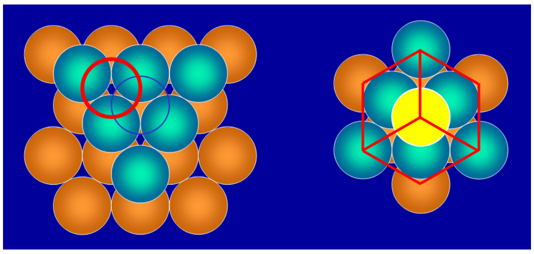


Figure 4-9 A simulation show constructing of atomic parts in face-center cubic unit cell into atoms.



(a)



(b)

Figure 4-10 Some interactive models in the IMP (a) an interactive shows a definition of unit cell (b) complex structure of various atomic layers stacked on each others and the relevant atoms in CCP unit cell that derived from the left image.

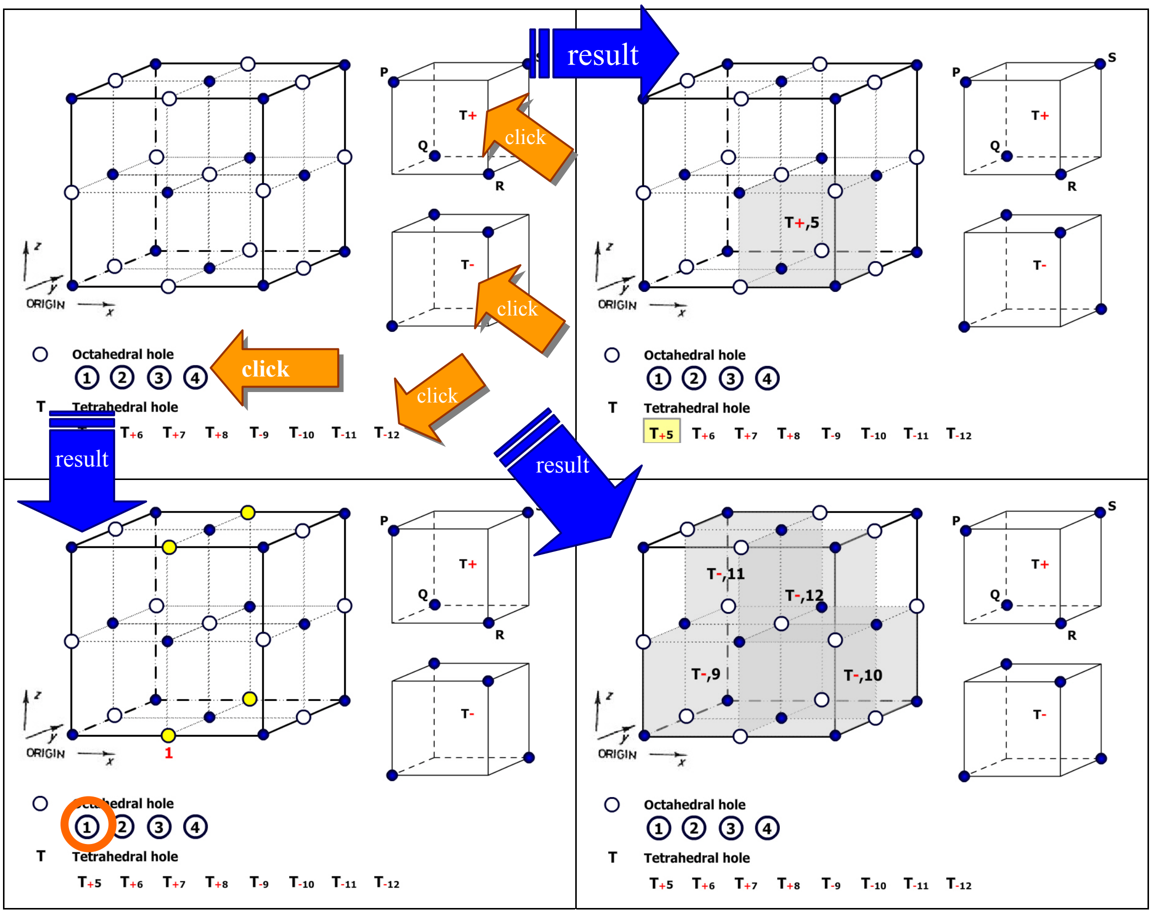


Figure 4-11 An interactive simulation shows positions of octahedral holes and tetrahedral holes in a single unit cell.

4.2 The Pilot Study I Results

The results from the pilot study I consist of paired t-test within group and independent t-test between groups.

4.2.1 The Paired Samples t-test Results Within Group

The mean pretest and posttest scores of the traditional group with the results of paired t-test are shown in Table 4-1. The traditional group studied with physical models while the supplemented group studied with the CLM. The students in the CLM-supplemented group were also allowed to investigate the physical models for comparison purpose. The students of both groups were tested for their understanding on six topics (topic a – topic f) of crystal structures and unit cells (see Appendix G) including:

a) link between the unit cell and images of the atoms involved
b) identify unit cell type
c) identify atomic pieces in different types of unit cell
d) identify number of atoms in the unit cell
e) describe the type of unit cell with least space
f) deduce the unit cell in a crystal structure.

Although the pretest data of traditional group (Table 4-1) seems different from the CLM-supplemented group (Table 4-2), there is no significant difference found in all topics when analyzed with the independent t-test statistic as shown in Table 4-3.

Table 4-1 The results of Paired Samples t -test and the mean pretest and posttest scores of the traditional group (maximum score in each topic is 4 points).

Topic	Pretest		Posttest		p-value
	Mean	SD	Mean	SD	
a	3.83	0.58	4.00	0.00	0.1694
b	2.83	1.27	4.00	0.00	0.0043*
c	0.50	0.90	2.83	1.11	0.0000*
d	0.00	0.00	0.00	0.00	-
e	0.25	0.45	0.25	0.45	-
f	2.00	0.85	2.00	0.43	0.5000
Total	9.42	4.05	13.08	1.99	-

* Significant difference of $p < .01$

The result in Table 4-1 of the traditional group showed that: only the posttests in topics b and c are significantly higher than those in the pretest; there is no improvement in the mean scores between pretest and posttest in questions a, d, e and f; and the students are not able to answer questions in topic d in both pretest and posttest.

The mean pretest and posttest scores of the CLM-supplemented group and the results of pair t-test are shown in Table 4-2.

Table 4-2 The results of Paired Samples t -test and the mean pretest and posttest scores of the CLM supplemented group (maximum score in each topic is 4 points).

Topic	Pretest		Posttest		p-value
	Mean	SD	Mean	SD	
a	2.75	1.22	4.00	0.00	0.0022*
b	2.33	1.30	4.00	0.00	0.0005*
c	0.00	0.00	2.50	1.00	0.0000*
d	0.00	0.00	2.50	0.52	0.0000*
e	0.25	0.45	2.17	1.03	0.0001*
f	1.42	1.08	2.42	0.79	0.0020*
Total	6.75	4.05	17.58	3.35	-

* Significant difference of $p < .01$

The posttest mean scores in all topics are significantly higher than those of the pretest.

4.2.2 The Independent t-test Results Between Groups

The pretest, posttest, and percentage gain score of each group and the t-test results (as p-value) between groups of each learning topic are shown in Table 4-3. The independent t-test was used for examining significant difference between the score of the traditional group and the CLM-supplemented group.

In traditional group, there is no percentage gain in topics d and e, the highest percentage gain was observed in topic c followed by b, whereas there is only a small percentage gain in topics a and f. In the CLM-supplemented group, the highest percentage gain was observed in topic b followed by c, d (equally), a, e and f, respectively.

Significantly higher percentage gain were observed in topics a, d, and e for the CLM-supplemented group.

Table 4-3 Comparison of the pretest score, posttest score, and percentage gain in each topic between the traditional and CLM supplemented groups.

Topic	Traditional group			CLM-Supplemented group			p-value		
	pretest	posttest	%gain	pretest	posttest	%gain	pretest	posttest	%gain
a	3.83	4.00	8	2.75	4.00	58	0.0133	-	0.0091*
b	2.83	4.00	50	2.33	4.00	75	0.3509	-	0.2234
c	0.50	2.83	69	0.00	2.50	63	0.0819	0.4489	0.5735
d	0.00	0.00	0	0.00	2.50	63	-	0.0000*	0.0000*
e	0.25	0.25	0	0.25	2.17	49	1.0000	0.0000*	0.0002*
f	2.00	2.00	15	1.42	2.42	36	0.1577	0.1274	0.1371

* Significant difference of $p < .01$

- unavailable because dividing by zero (students' score are all equal in these topics)

4.2.3 Students' Attitudes toward the CLM

The results in Figure 4-12 show student attitudes toward the CLM by answering the 1-to-5-rating scale questionnaire on 5 statements including:

1. Does the VUC unit help you to understand the crystal structures and the unit cells contents better?
2. Relative to 2D still images, does the VUC help you to understand the contents better?
3. Relative to 3D still images, does the VUC help you to understand the contents better?
4. Relative to physical models made from ping-pong balls, does the VUC help you to understand the contents better?
5. Does the UCH game help increase 3D visualization skills?

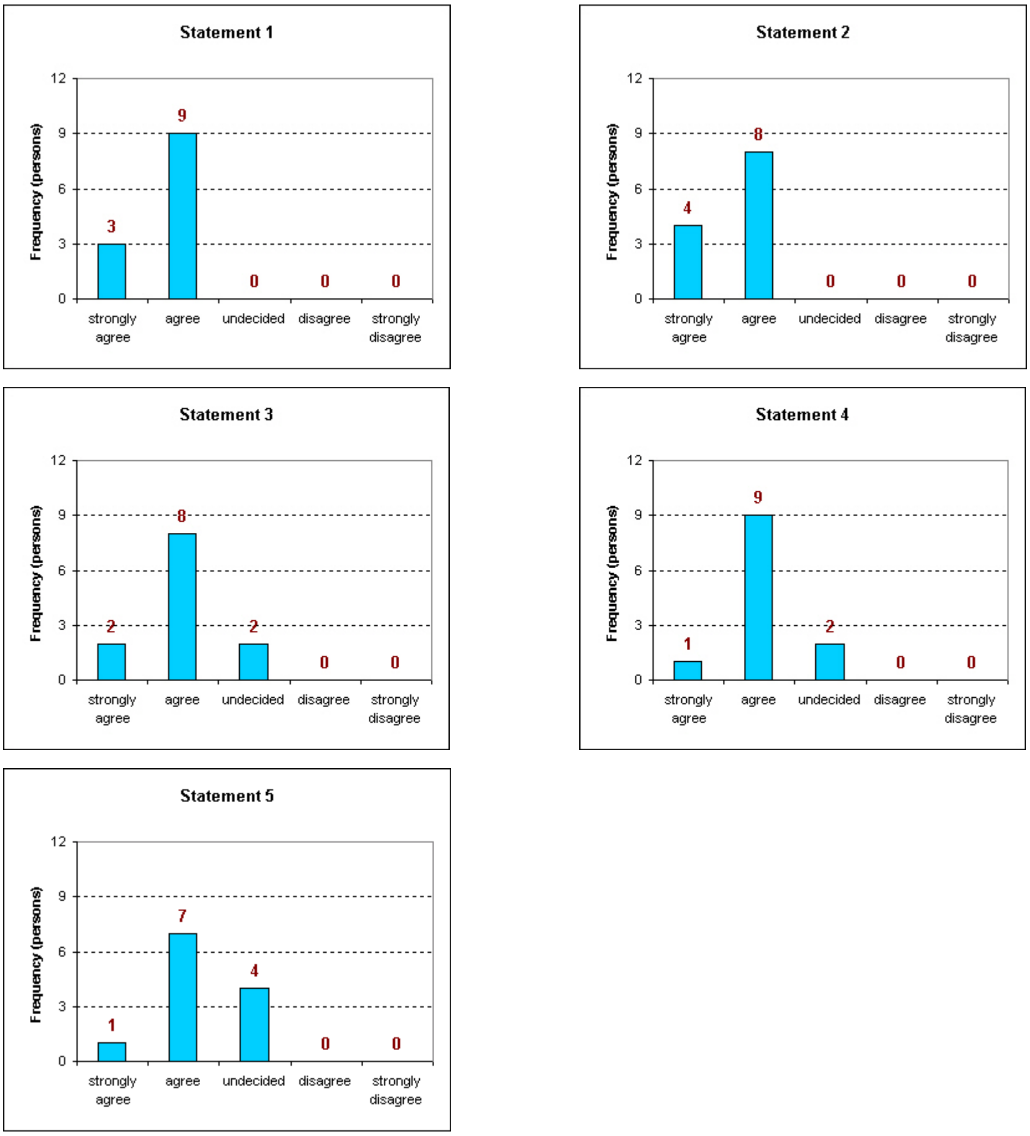


Figure 4-12 Frequencies of students' responses at each statement of questionnaire in the pilot study I.

Most of the students agreed that the CLM helped them understand the content of crystal structures and unit cells better when compared to physical models and the 2D still images in traditional lecture.

4.2.4 Students' Opinions Toward the CLM

The students from both traditional and CLM-supplemented groups were randomly selected to interview for their opinion on using either the physical models or the CLM in supporting their understanding of the crystal structures and unit cells. The traditional group students who used only the physical models commented that although these models help them to understand better than learning only from the text, they are not flexible in representation. One model always depicts just one issue. Excerpts from the interviews are as follows:

"Paper model and ping pong model can represent only a limited number of unit cells. One cannot cut the ping pong balls to give fractions thereof easily. The paper box 'atoms' are painted and do not represent spheres."

Moreover, they also concurred that counting the number of atoms using physical models are quite difficult. One from the interviews expresses that:

"Box models from folding of opaque paper can generate successive unit cells; however, they do not permit viewing of the content of the inner part"

Excerpts from the interviews about the opinion of the students in the CLM-supplemented group when comparing the CLM to the physical models are as following:

"A program with complete parts makes viewing easier than the physical ones."

"Computer-based models show the number of atoms and the nature of the holes better than the physical ones."

Some students preferred the paper box models because they are more realistic and tangible. However, they commented that the computer generated models, being transparent, would be preferable in making the central atom easily visible to the box model of the body-centered cubic with the central atom blocked from view.

4.3 The Pilot Study II Results

The results in the pilot II study consisted of debriefing, pair t-test, posttest score in percentage, and students' attitudes toward the CLM.

Result of debriefing conducted to learner after playing game is reported first. Then, the result of pair t-test conducted on pairs of pretest and posttest score is shown, followed by students' posttest score in percentage. Last, the result of students' attitudes toward the CLM that obtained from questionnaire is reported.

4.3.1 Debriefing Results

At the end of activities, students participated in the debriefing, a group discussion guided by the researcher, to ensure that they achieved the learning objectives as much as possible. After playing the UCH game, all participants adjourned to a room with a round table and began the three phases of debriefing as follows:

4.3.1.1 Description phase

The researcher asked the participants to recount their experiences in the game. Occasionally, the participants were asked questions to prompt them to recall events that they had not paid sufficient attention to or had forgotten to mention. Some of the questions were:

- What happened during game playing?
- Which task was the most difficult?
- How did you feel?
- How many participants managed to assemble all the pieces? How did you do it?
- Which aspects of the game were most challenging? How did you overcome the problems?

Some interesting comments from this phase:

- Those who succeeded in assembling the pieces without any mistakes agreed that the 3-D models of the unit cells in each VUC helped in their playing of the game.
- The most difficult task in the game was to figure out the unit cell from the crystal structures. They agreed that different colored atoms helped them visualize the unit cell, which was being deduced, more easily.
- It was very challenging, especially, in the case of the hexagonal close packing because of the large number of types and pieces of atoms involved.

4.3.1.2 Analysis phase

The emphasis was for the participants to relate problems encountered in the game to those of learning about the unit cell. Some questions to help achieving the objectives were:

- Which activity(ies) could you have used for better learning about the unit cell?

- Were there any simulated situations that you normally do not find in your classroom?

- Were there aspects of normal classroom learning about the unit cell not addressed in the game simulation?

Toward the end of this phase, the researcher made a summary of what the participants had contributed to ensure common understanding so they could apply what they had learned together.

Results from phase 2 showed that all participants could very well relate tasks performance in the game to learning the contents of the unit cell. They also concurred that all tasks had relevance to all the unit cells. On the contrary, they found that some unit cells had not been simulated in the game.

4.3.1.3 Application phase

This phase emphasized what the game had to offer so that the participants understood what they had learned to solve problems in the classroom and in their daily life. The researcher asked the participants about what they had learned and how they were going to exploit it based on such questions as follows:

- Has your experience in playing game helped you in any special way? Please elaborate.

- Can you imagine any future situation that you can bring your experience to bear upon? How?

We found that the participants were confident that they could apply the knowledge gained from game in authentic learning situations:

1. The participants indicated that they understood the arrangement of atoms in the unit cell and crystal structures.

2. One third of the participants also believed they could visualize other unit cells (not yet simulated) better so much so that they thought they could apply their newly acquired skills in solving future visual-spatial problems.

4.3.2 The paired samples t-test Results

The paired samples t-test result of the pretest and posttest scores obtained from the pilot-test is shown in Table 4-4.

Table 4-4 The result of Paired Samples t – test between the pretest and the posttest scores of the pilot study II.

Paired Samples Statistics				
		Mean	**N**	**Std. Deviation**
Pair	posttest score	16.8261	23	2.07040
1	pretest score	3.3913	23	1.58800

Paired Sample Test					
	Paired Differences		t	df	Sig. (1-tailed)
	Mean	Std. Deviation			
Pair1 posttest score - pretest score	13.43478	2.55532	25.214	22	.000*

* Significant difference of $p < .01$

The results show significant differences between the pretest and posttest mean scores ($p < .01$).

4.3.3 Posttest Score in Percentage

The percentage posttest scores of most participants are satisfactorily high compare to criteria score of 80% as shown in Table 4-5. Seventy percent of students gained the score higher than 80%.

Table 4-5 The students' posttest scores from the pilot-test of the pilot study II (max = 20).

Student No	Posttest score	
	Point	Percent
1	20.00	100
2	18.00	90
3	16.00	80
4	19.00	95
5	19.00	95
6	14.00	70
7	18.00	90
8	16.50	83
9	15.50	78
10	18.00	90
11	15.00	75
12	19.00	95
13	17.50	88
14	19.00	95
15	19.00	95
16	17.00	85
17	14.00	70
18	18.00	90
19	12.00	60
20	15.00	75
21	17.00	85
22	14.50	73
23	16.00	80

4.3.4 Students' Attitude Toward the pilot-CLM

The results in Figure 4-13 show student attitudes toward the CLM by responding the rating scale questionnaire on eight statements including:

1. Does the VUC unit help you to understand the crystal structures and the unit cells contents better?
2. Relative to 2D still images, does the VUC help you to understand the contents better?
3. Relative to 3D still images, does the VUC help you to understand the contents better?
4. Relative to 3D physical models such as ping-pong model, does the VUC help you to understand the contents better?
5. Is the UCH fun even though it is on a very sophisticated topic?
6. Does the UCH require knowledge gained from the VUC?
7. Does the UCH game help increase 3D visualization skill?
8. Does the UCH have close linkage with the VUC?

The results obtained are presented separately for each statement as graph. For most statements, the highest frequency of the students' opinions fall in the range of 'strongly agree' to 'agree' especially for statement 2 which falls in the category of 'strongly agree'.

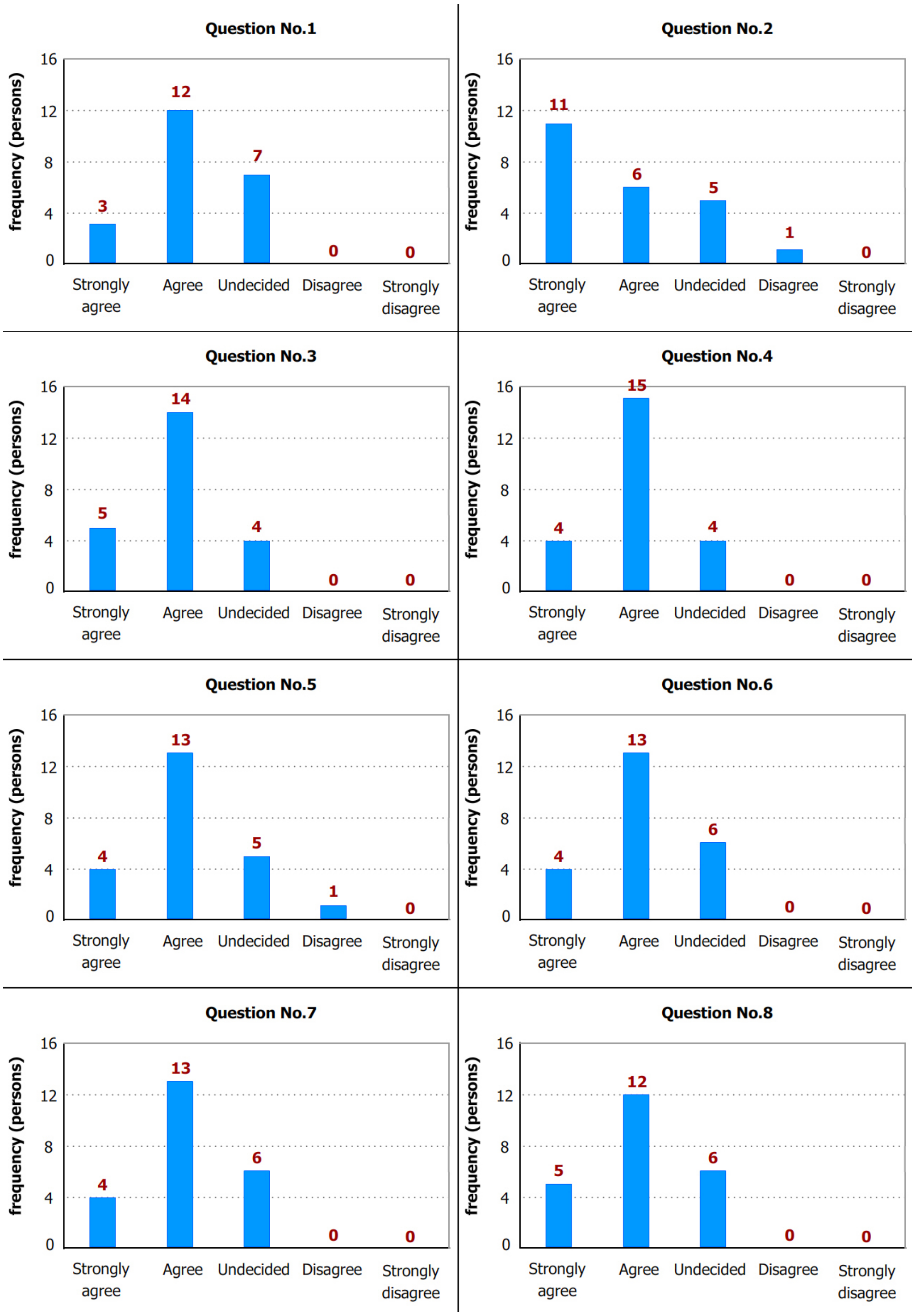


Figure 4-13 Frequencies of students' responses at each statement of the pilot-questionnaire in the pilot study II.

4.4 Implementation Study Results

Results of this study are learning achievement after studying with the CLM and efficiency of the final-CLM as a visualization tool; the correlation between the visual-spatial ability and the learning achievement; and beneficial of the final-CLM on students with different visual-spatial ability.

Although 170 students participated in the study, 37 participants did not do achievement pretest, thus, participants who did both achievement pretest and posttest were 133. For aptitude test, all 170 participants did the test. For questionnaire, some participants did not respond and some results were rejected due to their inadequate quality, for example, agree with both positive and negative statement of the same question. Therefore, the respond from only 100 participants were analyzed.

4.4.1 Effect of the final-CLM on Learning Achievement and Efficiency of the final-CLM as a Visualization Tool Results

In the achievement test, students were tested for their understanding in seven learning objectives including:

1) Can analyze crystal structures and unit cells in cubic system
2) Able to combine atomic pieces and indicate number of atoms within the unit cells
3) Can calculate the relationship between atomic radius and unit cell edge's length
4) Can utilize the relationship of unit cell parameters to calculate atomic radius of the material crystallized in cubic structure
5) Able to identify the closest-packed structure
6) Able to identify holes in the closest-packed structure
7) Able to identify the co-ordination number in the crystal structures.

A copy of achievement test is shown in the Appendix D. The results obtained for this issue are presented as follows:

4.4.1.1 Paired t-test Result

The result in Table 4-6 shows the achievement pretest and posttest mean scores of the participants together with paired t-test results as p-value.

Table 4-6 The achievement pretest and posttest mean scores at each learning objective and their paired t-test results as p-value (N=133).

Objective	Pretest Mean	Posttest Mean	p-value
1	1.9	3.1	0.00*
2	1.9	3.6	0.00*
3	1.0	1.4	0.00*
4	0.5	1.4	0.00*
5	0.7	2.2	0.00*
6	1.8	4.4	0. 00*
7	1.9	3.6	0.00*

* Significant difference of $p < .01$

The result shows that there is significant difference between the achievement pretest means score and the achievement posttest means score in all learning objectives.

4.4.1.2 Posttest Score in Percentage

The achievement posttest scores of 170 participants were calculated in percentage then they were graded using the criterion shown in Table 4-7. Number of participants fell in each grade were counted and then calculated in percentage. The result is also shown in Table 4-7.

Table 4-7 Number of participants in each grade.

posttest score in percentage	grade	Number of students (person)	Number of students (%)
< 50 %	0	9	5
50-59 %	1	19	11
60-69 %	2	40	24
70-79 %	3	44	26
> 80 %	4	58	34
	total	170	100

It was found that the percentage posttest scores of most participants are satisfactorily high compare to criteria score of 80%. More than half of the participants having an achievement posttest score higher than 70% (grade 3 and 4).

It should be noted that there was no pretest effect in this study. The data obtained from achievement posttest can be used for examining the pretest effect due to 37 students did not do the pretest. Hence, 170 participants who took posttest can be classified into two groups; 133 who took pretest and 37 who did not.

Table 4-8 shows descriptive statistics for both groups. Independent t-test was used to test if there is significant difference between the two groups. The t-test result is shown in the same table as p-value (Table 4-8).

Table 4-8 The posttest mean scores and the independent t-test results as p-value of participants who did and did not do the pretest showing no pretest effect on the posttest score in this study.

group	N	Posttest Mean Score	Std. Deviation	p-value
did not do pretest	37	18.67	3.19	0.783
did pretest	133	18.84	3.38	

The t-test result at 0.783 shows no significant difference between the posttest mean scores of both groups. This means that the posttest scores of both groups are not significantly different. Doing the pretest had no effect on the achievement posttest scores.

4.4.1.3 Independent t-test Result Between Groups (the Traditional Group and the CLM Group)

The mid-term test scores of two groups of students who learned with the traditional lecture and who learned with the CLM, were provided by the lecturer. The independent t-test result for significant difference between the two groups (as p-value) is shown in Table 4-9.

Table 4-9 The independent t-test result for significant difference between the mid-term test scores of the traditional group and the final-CLM group.

group	N	Mean Test Score (percent)	Std. Deviation	p-value (1-tailed)
traditional group	183	51.31	17.96	0.000*
the final-CLM group	169	62.83	18.88	

* Significant difference of $p < .01$

The t-test result at 0.000 shows significant difference between the mean test scores of both groups. This means that the score of the CLM group is significantly higher than that of the traditional group.

4.4.1.4 The Effect Size of Intervention with the CLM

Cohen (1988) described an effect size of 0.2 as ‘small’, 0.5 as ‘medium’, and 0.8 as ‘large’. However, he warned against using his labels to interpret relationship magnitudes within particular social science disciplines or topic areas. Valentine and Cooper (2003) stated that some areas, like education, are likely to have smaller effect size than others, using Cohen’s labels may be misleading. Similar suggestion was also given by Coe (2002): “It seems to be a feature of educational interventions that very few of them have effects that would be described in Cohen’s classification as anything other than ‘small’. This appears particularly so for effects on student achievement”. Durlak (2009) also stated that not only the magnitude of the effect that is important, but also its practical value that must be considered. For example, based on what has been achieved in many different types of interventions, educational researcher have indicated that effect sizes around 0.2 are of policy interest when they are based on measures of academic achievement.

The other way to interpret the effect size bases on one feature of an effect size that it can be directly converted into statements about the overlap between the two samples in terms of a comparison of percentiles (Coe, R., 2002). The conversion table of effect sizes into the percentiles is shown in Appendix J.

By using the percentile, the effect size 0.6 of this study can be interpreted that the average person in the CLM group would score higher than 73% of the traditional group. Using the Cohen’s benchmark, the effect size 0.6 of this study can be interpreted that the intervention magnitude of the CLM is quite high.

4.4.1.5 Percentage gain score result

The percentage gain score results of each learning objective are shown in Table 4-10. The results showed percentage gain over 50% in all objectives with average gain on total posttest at 64%. When sorting in descending order, percentage gain of the objective 2 is at the most highest follows by objective 7, 5, 4, 1, 3, and 6, respectively.

Table 4-10 The percentage gain scores at each learning objective of the achievement test (N = 133).

Objective	Mean score		% gain score
	pretest	posttest	
1	1.79	3.06	57
2	1.53	3.60	84
3	0.57	1.36	55
4	0.22	1.33	63
5	0.33	2.10	66
6	0.67	3.63	55
7	0.33	3.61	70
total posttest	5.44	18.70	64

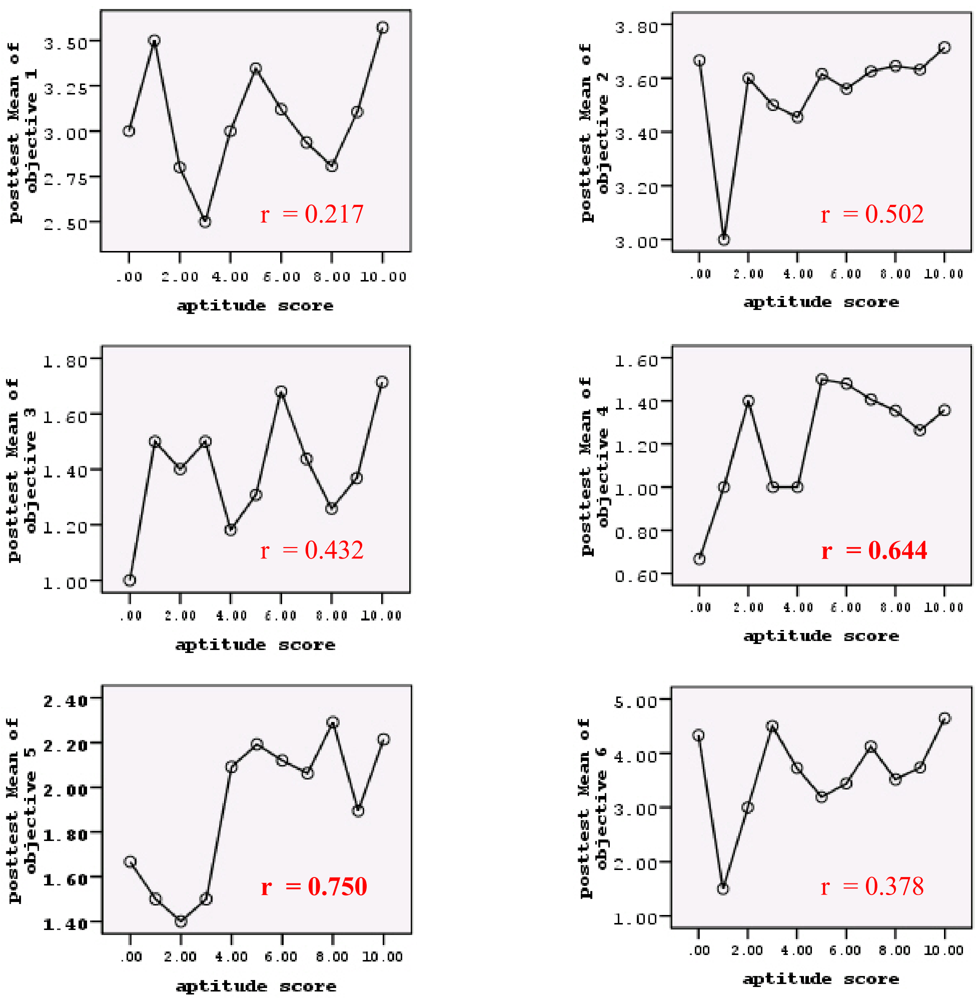
4.4.1.6 Pearson's Correlation of Each Learning Objective

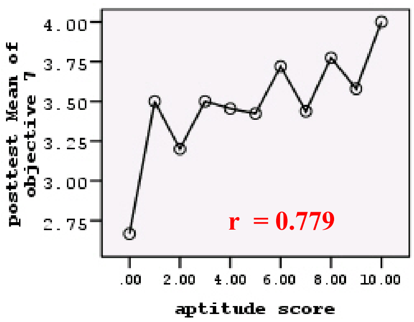
The correlation coefficient between the visual-spatial ability and the learning achievement of each learning objective (see section 3.7.2 for the data analysis method) are summarized in Table 4-11.

Table 4-11 The correlation coefficient between the visual-spatial ability and the learning achievement of each learning objective.

Learning objective	Correlation coefficient (r)
1	0.217
2	0.502
3	0.432
4	0.644
5	0.750
6	0.378
7	0.779

The results indicate that the correlations between the visual-spatial ability and the learning achievements varied among learning objectives. This means that learning achievement depends differently on the visual-spatial ability for each learning objective, in other words, each objective requires different level of ability. The objective 7 has the highest correlation, followed by objective 5, 4, 2, 3, 6, and 1, respectively. The results are also presented as graph in Figure 4-14.





Learning Objectives:

(1) Can analyze crystal structures and unit cells in cubic system,

(2) able to combine atomic pieces and indicate number of atoms within the unit cells,

(3) Can calculate the relationship between atomic radius and unit cell edge's length,

(4) Can utilize the relationship of unit cell parameters to calculate atomic radius of the material crystallized in cubic structure,

(5) Able to identify the closest-packed structure,

(6) Able to identify holes in the closest-packed structure, and

(7) Able to identify the co-ordination number in the crystal structures

Figure 4-14 Plots between the mean posttest score at each learning objective and the corresponding aptitude score showing the correlation of the learning achievement and the visual-spatial ability together with their correlation.

4.4.1.7 Students' Attitude Toward the final-CLM

The results in Figure 4-15 show students' attitudes toward the final-CLM. Eight statements were asked to determine whether the final-CLM helps the students visualize and acquire better understanding, to verify the efficiency of the final-CLM as a visualization tool. The questionnaire statements including:

(1) Visualizing three dimensional structures from complex 2D still image is difficult and takes time.

(2) The IMP can help visualize 3D structure, that is, visualization using the computer tools is easier and can reduce time.

(3) Learning by using the IMP as a 3D visualization tool is more effective than using still images.

(4) Learning with the IMP can improve the visual-spatial ability.

(5) UCH game can enhance the visual-spatial ability.

(6) Individual practice with the CLM in a spare time might lead to better understanding.

(7) Learning on crystal structure and unit cell by using still image is more challenge than the IMP.

(8) Visualizing and understanding a complex 3D structure from still image is not a problem at all.

The result show that most students agreed with all positive questions from statement 1 to 6, and disagreed with negative questions of statement 7 and 8.

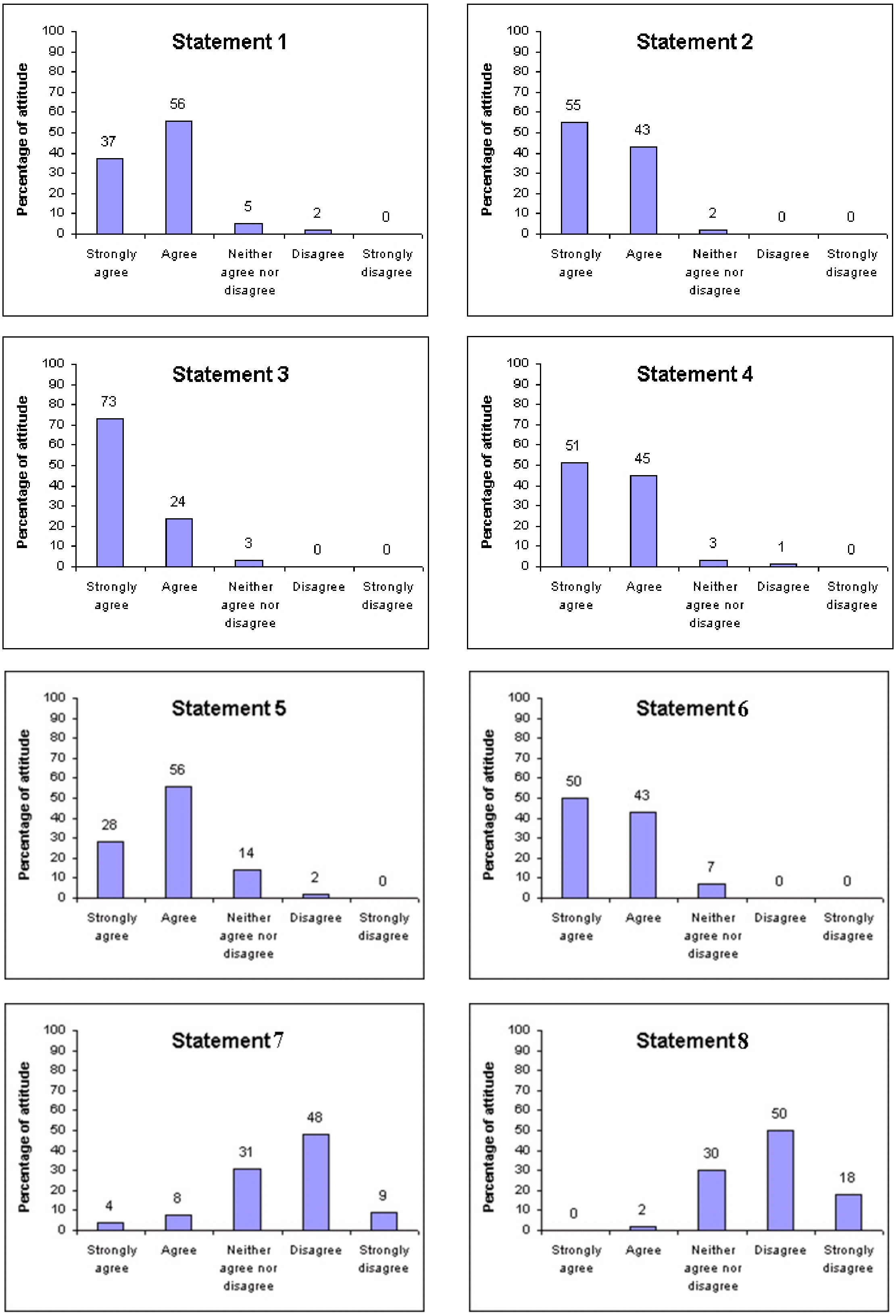


Figure 4-15 Response frequencies at each rating scale showing students' attitude in the implementation study.

4.4.2 Correlation between the Visual-Spatial Ability and the Learning Achievement

The result of Pearson's Correlation test between the visual-spatial ability and the learning achievement is shown in Table 4-12.

Table 4-12 The Pearson's correlation between the visual-spatial ability and the learning achievement.

Correlation		Aptitude	Total posttest score
aptitude	Pearson Correlation	1	**.207****
	Sig. (2-tailed)		.007
	N	170	170

** Correlation is significant at the 0.01 level (2-tailed).

The correlation at 0.207 shows positive correlation at low level between the visual-spatial ability and the learning achievement.

The correlation between the visual-spatial ability and the learning achievement was also investigated using the mean scores as described in section 3.7.2. The result as graphical representation is shown in Figure 4-16 and the data for the plot is shown in Table 4-13.

Table 4-13 The data employed for the plot.

Aptitude score	N	Total posttest mean score	Std. deviation
0	3	17.00	5.29
1	2	15.50	7.78
2	5	16.80	3.11
3	2	18.00	4.24
4	11	17.91	2.02
5	26	18.58	3.61
6	25	19.12	3.32
7	32	19.03	3.30
8	31	18.65	2.82
9	19	18.58	3.73
10	14	21.21	2.69
total	170	18.81	3.33

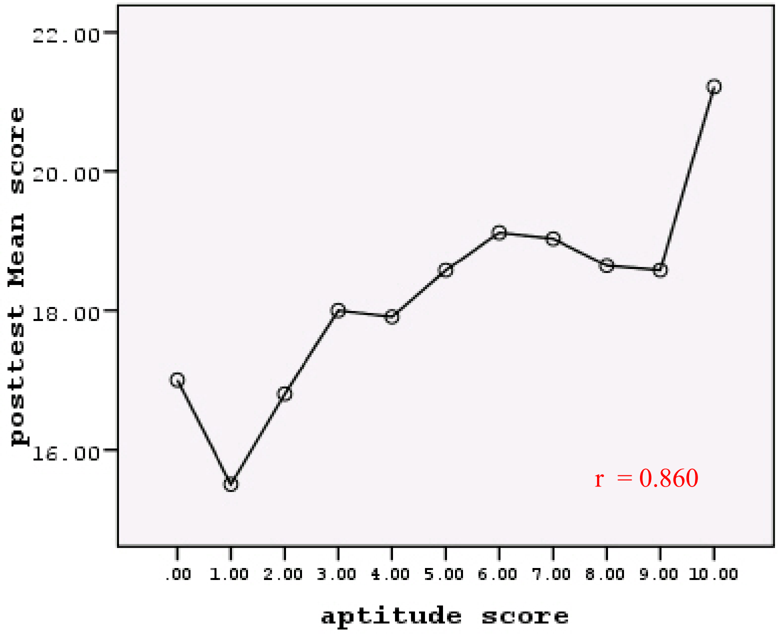


Figure 4-16 Plot between the total posttest mean score and the corresponding aptitude score shows correlation of the learning achievement and the visual-spatial ability together with their Pearson's Correlation Coefficient.

This result shows that when analyzed using the mean scores, high correlation at 0.860 between the learning achievement and the visual-spatial ability is revealed.

4.4.3 Beneficial of the CLM on Students with Different Visual-Spatial Ability

When the aptitude scores were graded and the students' achievement posttest scores in each grade were averaged and tested for their significant difference using one- way ANOVA with Scheffe's Multiple Comparison, it was found that there is no significant difference between groups as shown in Table 4-14. It indicates that there is not significant difference between groups of different visual-spatial abilities.

Table 4-14 *One-way ANOVA* with *Scheffe's Multiple Comparison* results.

(a) Descriptive result

Descriptive			
Aptitude grade	**N**	**Total posttest mean score**	**Std. Deviation**
0	23	17.35	3.21
1	26	18.58	3.61
2	25	19.12	3.32
3	32	19.03	3.30
4	64	19.19	3.23
Total	170	18.81	3.33

(b) one-way ANOVA result

ANOVA				
Posttest score				
	Sum of Squares	**df**	**Mean Square**	**Sig.**
Between Groups	63.672	4	15.918	.220
Within Groups	1812.922	165	10.987	
Total	1876.594	169		

CHAPTER V
DISCUSSION

In this chapter, the results from two pilot studies and the implementation study were discussed. In the pilot study I, an effectiveness of the pilot-CLM as a visualization tool was assessed comparing to other instructional media. For the pilot study II, both components of the pilot-CLM, the VUC and the UCH were evaluated for their efficiency, especially on the UCH, through the debriefing process. In the implementation study, students' learning achievement was measured using the achievement test. Data were analyzed to find if the final-CLM would effect the learning achievement on the crystal structures and unit cells topic. Apart from the data collected by the researcher, the mid-term examination data of two groups of students who learned with the traditional lecture and who learned with the CLM was also provided by the lecturer, for determining the effect of the CLM on the learning achievement. The efficiency of the CLM as a visualization tool was discussed using the gain scores and the correlation between the posttest scores and the visual-spatial abilities. The questionnaires were employed to measure students' attitude toward the CLM as a visualization tool in all study phases. Attitudes from students were also the evidence to confirm the efficiency of the CLM as a visualization tool for their studying. These results could give value information for answering the research question 1. Students' visual-spatial ability was measured by using the aptitude test. Then, students' visual-spatial ability and the learning achievement were analyzed for their correlation to answer the research question 2 and 3, respectively.

5.1 The Pilot Study I

The pilot study I aimed to examine the effects of the pilot-CLM on students' achievement and attitude. In particular, this study set out to determine whether the CLM would help students understand and visualize the crystal structures and unit cells better than using other media, physical models and still images.

The paired t-test results of the pretest and the posttest scores within group shows that students in the traditional group improve their knowledge only on topic *b* and *c* (Table 4-1), while the CLM-supplemented group improve their knowledge on all topics; a, b, c, d, e, and f (see Table 4-2). This implies the efficiency of the CLM over the physical models.

The independent t-test results (p-value) between groups in Table 4-3 show that the posttest score of the CLM-supplemented group in topic *d* and *e* are significantly higher than those of the traditional group. This result indicates that the pilot-CLM could better enhance knowledge acquisition in these topics than the physical models. This is also supported by a larger percentage gain in the topics (Table 4-3). In addition, percentage gain score of topic *a* is also significantly higher than that of the traditional group and it should be noted that none of the students in the traditional group were able to give the correct answer in the posttest on topic *d* and *e*.

These topics; *a*, *d*, and *e,* require high visualization ability as following details:

Topic *a*: *link between the unit cell and images of the atoms involved*; learners must be able to visualize the correct unit cells structure from the images of the atoms involved (see Appendix G).

Topic *d*: *identify number of atom in unit cell*; learners must know position and volume of atomic pieces in order to combine them to spherical atom.

Topic *e*: *describe the type of unit cell with least space*; learners must visualize and compare the space (void) within unit cell.

It is difficult to achieve these topics from 2D still images because learners cannot explore unit cells in whole directions.

Similarly, the lack of posttest improvement on the topic *d* and *e* in the traditional group also suggested the superiority of the CLM over the physical models in increasing accurate visualization of the unit cells.

The questionnaire result from the pilot study I can be concluded that:

1. The VUC unit helped them to understand the crystal structures and the unit cells content better.

2. Relative to 2D still images, the VUC helped them to understand the contents better.

3. Relative to 3D still images, the VUC helped them to understand the contents better.

4. Relative to physical models made from ping-pong balls, the VUC helped them to understand the contents better.

5. The UCH game helped increase 3D visualization skills.

It can be seen that, the students' attitude on the CLM are very positive. Most felt that this type of instructional media helped them to understand the topic better compared with exposure to the still images, or even the physical models and made the lecture more interesting and enjoyable. They also thought that the UCH game helped increasing 3D visualization skills.

The positive attitude of the students toward the CLM was also evidenced from students' interviews. Most students voiced that they enjoyed learning via the CLM which helped them in several ways as shown in the following excerpts:

"Counting atoms in the unit cell with the computer generated models was much easier and also realistic."

"Construction of the unit cell on the screen facilitated the connection between the crystal structures and the unit cells."

This information leads to the conclusion that learning the abstract topic of crystal structures and unit cells needs comprehensible and realistic models. The results from both pilot-test and pilot I-questionnaire imply that the CLM help promoting students' visual-spatial ability in learning about this abstract topic. Moreover, appropriate learning motivation using instructional games can also enhance the learners' attention in learning difficult topics. The results in this study clearly indicate the benefit of the CLM in enhancing the students' achievement in crystal structures and unit cells. It can be used to supplement the traditional teaching either with or without the physical models.

5.2 The Pilot Study II

This study emphasizes to examine effect of the VUC and the UCH game on learning the unit cells using debriefing. Afterward, the pilot-test and questionnaire were also discussed.

Data from three phases of debriefing indicate that learners can recall events that they had paid attention to, relate problems encountered in the games to those of learning about the unit cell, and apply knowledge gain to the topic. The consensus that 3D models in the VUC helped in playing the UCH from debriefing implies the relationship between the CLM components as shown in Figure 5-1.

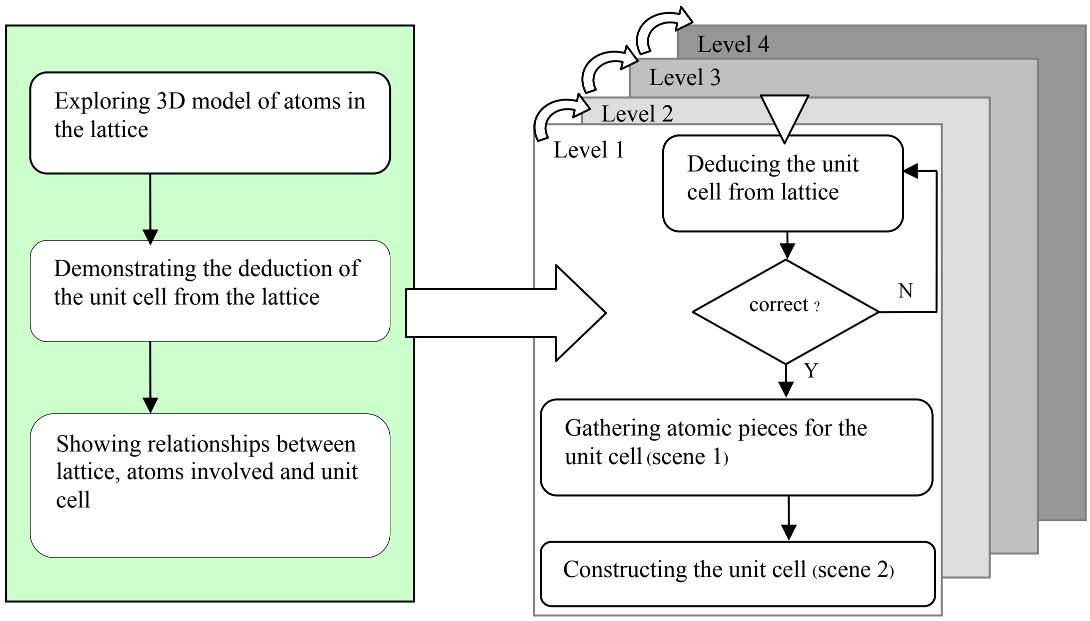


Figure 5-1 Relationship between the VUC and the UCH.

How the students utilize knowledge from the VUC to practicing in the UCH games is presented in Figure 5-2.

Figure 5-2A shows that, at beginning of each level in the UCH, students can use their knowledge gained from "*simulation of the unit cell translation*" and "*deduction of the unit cell*" to find the unit cell type. In Figure 5-2B, the students employ "*3D model of unit cell*" for collecting relevant unit cell pieces and constructing a correct and complete unit cell type.

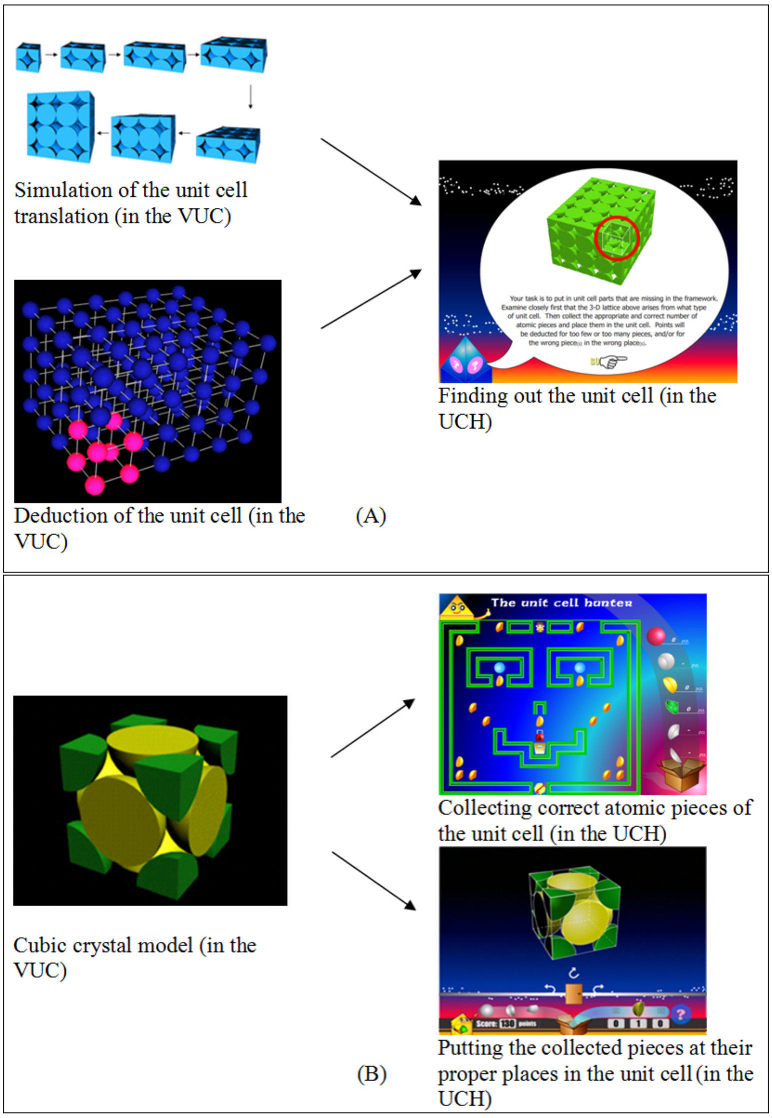


Figure 5-2 Diagram showing the way the student utilizes knowledge acquired from the VUC to play the UCH game.

The paired t-test result of this study shows significant difference between pretest and posttest mean score; the posttest mean score is significantly higher than the pretest mean score. The result that 70 percent of all participants gained the posttest score higher than 80%, indicated students' learning achievement on the topic.

Students' attitude confirmes benefit of the CLM on learning about the unit cells.

Most students' agreed that:

1. The VUC component helped them to understand the crystal structure and the unit cell contents better.
2. Relative to 2D still images, the VUC helped them to understand the contents better.
3. Relative to 3D still images, the VUC helped them to understand the contents better.
4. Relative to physical models such as ping-pong model, the VUC helped them to understand the contents better.
5. The UCH fun even though it is on a very sophisticated topic.
6. The UCH required knowledge gained from the VUC.
7. The UCH game helped increase 3D visualization skill.
8. The UCH have close linkage with the VUC.

Especially, on statement 2, their attitude fall in the category of strongly agree (see Figure 4-13).

All of these results imply that the CLM could enhance the learning achievement and very helpful for students on learning about the crystal structures and unit cells.

Results obtained from both pilot studies imply the usefulness and the need for 3D-computer models as provided in the pilot-CLM. Hence, the final-CLM was developed for the target participant on the basis of these results.

5.3 The Implementation Study

The discussion started with the effect of the CLM on the learning achievement and the efficiency of the CLM as a visualization tool, followed by the correlation between the visual-spatial ability and the learning achievement, and ended with the beneficial of the CLM on students with different visual-spatial abilities.

The results to be discussed on ***the effect of the CLM on the learning achievement*** were obtained from both the implementation study performed by the researcher and the mid-term test scores of two groups of students who learned with traditional lecture and learned with the CLM provided by the lecturer.

The results from the implementation study are the paired t-test of the pretest-posttest scores and the achievement posttest scores in percentage. The results that can be analyzed from the data provided by the lecturer, are the independent t-test between the two groups and the effect size.

The paired t-test result (Table 4-6) shows significant difference between the achievement pretest and posttest mean score for each learning objective. It indicates that students perform better in all learning objectives after studying with the CLM.

When the total achievement posttest scores in percentage were compared with the criterion score at 80%, to assess the overall learning achievement, it was found that the largest group of participants (34%) has an achievement score higher than 80% (grade 4), followed by 26% of participants having an achievement score between 70-79% as shown in the Figure 5-3 below. It can be easily seen from the figure that more than half of the participants having an achievement posttest score higher than 70% (grade 3 and 4). These results indicate a satisfactorily high effect of the-CLM on the learning achievement in the difficult topic of Crystal structures and Unit cells.

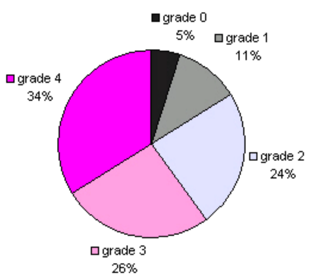


Figure 5-3 Proportion of students in each grade.

In addition, it should be noted that there is no pretest effect in the achievement posttest scores, as shown in Table 4-8.

The independent t-test result between the mid-term test scores of the traditional group and the CLM group shows significant difference between the two groups (Table 4-9). The result indicates that the CLM group has significantly higher score than the traditional group. This leads to the conclusion that the CLM could enhance the students' learning achievement. Moreover, the magnitude of the effect of the CLM on the learning achievement measured by the effect size at 0.6 indicate its quite large effect.

All of these results, both from the implementation study and the data from the lecturer, assure the efficiency of the CLM on the learning achievement at satisfactorily high level.

The results to be discussed on ***the efficiency of the CLM as a visualization tool*** are 'the relationship between the percentage gain scores and the correlation levels between the visual-spatial ability and achievement at each learning objective' and 'the students' attitude from the questionnaire'.

The percentage gain scores result shows that students gain higher than 50% in all learning objectives (Table 4-10). When the percentage gain scores at each learning objectives were sorted in descending order, the objective 2 is at the most highest followed by the objective 7, 5, 4, 1, 3, and 6, respectively. This means that the highest gain was found in objective 2, 7, 5, 4, 1, 3, and 6, respectively.

When the correlation were analyzed for each learning objective using the mean posttest score at each objective and its corresponding aptitude score, it was found that there is different correlations among objectives (see "r" value shown in Table 5-1b). When these correlations were sorted in descending order, the correlation of the objective 7 is at the most highest followed by objective 5, 4, 2, 3, 6, and 1, respectively. This means that the students' achievement depend greater on the visual-spatial ability in objective 7, 5, 4, 2, 3, 6, and 1, respectively. This correlation order is quite similar to that of the percentage gain score as shown in Table 5-1a.

Table 5-1 The descending orders together with their corresponding learning objective of: a) percentage gain score and b) the correlation between the visual-spatial ability and the learning achievement.

a)

The percentage gain score (%)	84	70	66	63	57	55	55
learning objectives	**2**	**7**	**5**	**4**	**1**	**3**	**6**

b)

the correlation (*r*) between the visual-spatial ability and the learning achievement	0.779	0.750	0.644	0.502	0.432	0.378	0.217
learning objectives	**7**	**5**	**4**	**2**	**3**	**6**	**1**

The order of the gain scores and the correlations shows repeated order in objective 7, 5, 4, 3, and 6, except only the objective 2 and 1. The repeated order implies that students gained better knowledge in the objective that requires higher visual-spatial ability. This result is evidence that the CLM could enhance the learning achievement as a visualization tool. It might be said that the CLM can help students on visualizing effectively, in other words, the CLM might improve students' visual-spatial ability.

The mismatch order was found only on objective 1 and 2 which had irregularly high gain scores. The cause of this result might arise from students' well performing in posttest using the memory recall after studying. For the other objectives, students could not use their memory to do the test; rather the well understanding was required. Appendix D shows a copy of the test item in each objective.

The efficiency of the CLM as a visualization tool was also supported by students' attitude obtained from the questionnaire.

Most students' agreed that:

1. The IMP can help visualize 3D structure, that is, visualization using the IMP is easier and can reduce time.

2. Learning by using the IMP as a visualization tool is more effective than using still images.

3. Learning with the IMP can improve the visual-spatial ability.

4. UCH game can enhance the visual-spatial ability.

These attitudes indicate that learning with computer animations and simulations in the IMP and practicing with the UCH game can enhance students' visual-spatial ability. The CLM can help visualize 3D structure easier and can reduce time. Thus, using the CLM can reduce students' cognitive load on learning the topic. These results lead to the conclusion that the CLM is an effective visualization tool to enhance the learning achievement on this topic.

At this point, the research question 1: *Can the CLM enhance students' learning achievement on the crystal structures and unit cells in the mass lecture as a visualization tool? And to what extend?*, can be answered that "the CLM as a visualization tool can enhance students' learning achievement on the crystal structures and unit cells in the mass lecture at satisfactorily high level".

The results to be discussed on ***the correlation between the visual-spatial ability and the learning achievement*** were obtained from the correlation test.

The correlation of the total posttest score and the aptitude score at .207 shows positive correlation at low level between the learning achievement and the visual-spatial ability. However, when analyzed using the mean posttest scores and the corresponding aptitude scores (Table 4-13), the result shows higher positive correlation of the learning achievement and the visual-spatial ability with the correlation at 0.860 (Figure 4-16). Students with high visual-spatial ability tend to obtain higher posttest mean score. This result indicated the positive correlation between the visual-spatial ability and the learning achievement.

At this point, the research question 2: *Is there a significant relationship between the learning achievement and the visual-spatial ability?*, can also be answered that "there is a significant relationship between the learning achievement and the visual-spatial ability".

The results to be discussed on ***the beneficial of the CLM on students with different visual-spatial abilities*** were obtained from the one-way ANOVA test.

The result of One-way ANOVA with Scheffe's multiple comparison indicates that there is no significant difference between groups of different visual-spatial abilities as shown in Table 4-14. This means that the total posttest score of students with different visual-spatial abilities are not significantly different, that is, students with different visual-spatial abilities can benefit from the CLM.

At this point, the research question 3: *Who benefit from the CLM visualization tool: in case of different visual-spatial ability?*, can be answered that "all students with different visual-spatial ability benefit from the CLM visualization tool".

CHAPTER VI
CONCLUSION AND FUTURE WORK

6.1 Conclusion

This study aims to develop and implement the CLM as a visualization tool for enhancing undergraduate students' learning achievement on crystal structures and unit cells. Two study phases, the pilot studies, and the implementation study were conducted. Requirements of the CLM features were investigated in the pilot studies. The results led to the modification of the pilot-CLM to the final-CLM for the target group in the implementation study. Evidences from statistical analysis support the final-CLM usefulness for mass lecturing on crystal structures and unit cells. The results of implementation study lead to the following conclusions:

1.) Statistical analysis results support the effect of the CLM on the learning achievement and the efficiency of the final-CLM as a visualization tool for enhancing students' learning achievement on the topic of crystal structures and unit cells, in the mass lecture.

2.) There is a positive correlation between the visual-spatial ability and the learning achievement in this topic.

3.) All students with different visual-spatial abilities benefit from the CLM visualization tool.

Those conclusions arise from two advantages of the CLM:

1.) 3D animation and simulation presented in the IMP help reducing cognitive load in processing working memory while visualizing the complex structure.

2.) The UCH games can motivate students' attention, thus, the games can increase learners' cognitive capacity.

6.2 Future works

The conclusions mentioned above lead to the following future works:

1. The computer visualization tool like the CLM should be developed for other topic concerning chemical structures, e.g. chemical bonding, and stereo-chemistry, to help students promote their learning achievement.

2. For some specific topics, comparison between a physical model and a computer model should be made to find which model is more appropriate or otherwise their combination is necessary.

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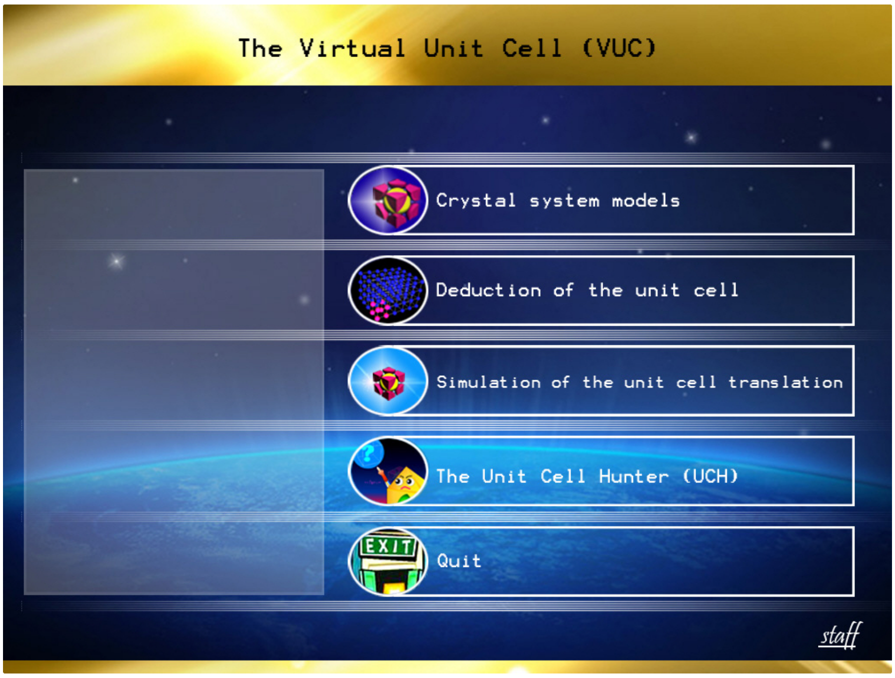
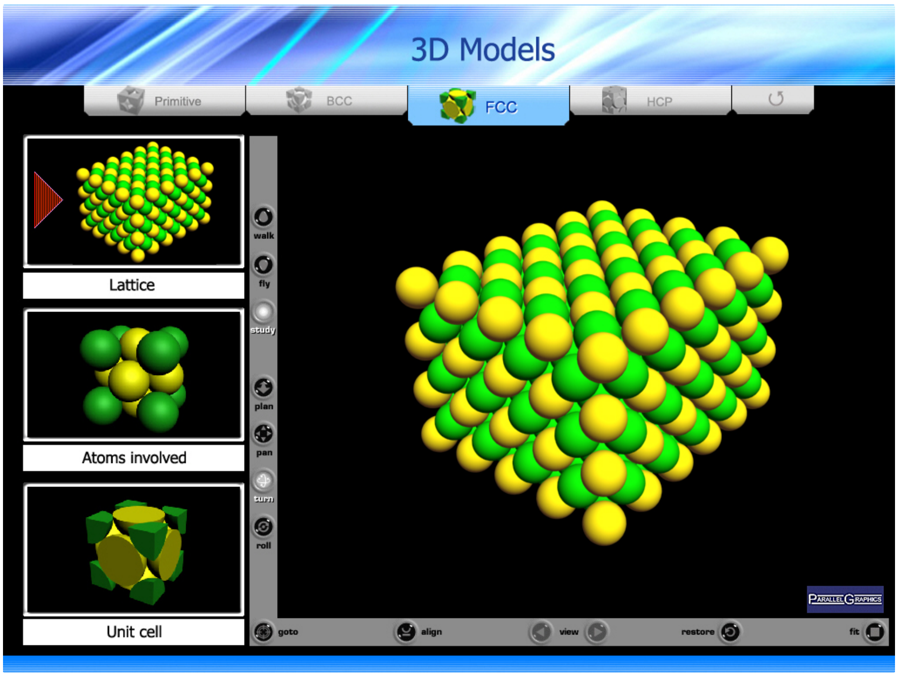
APPENDICES

APPENDIX A

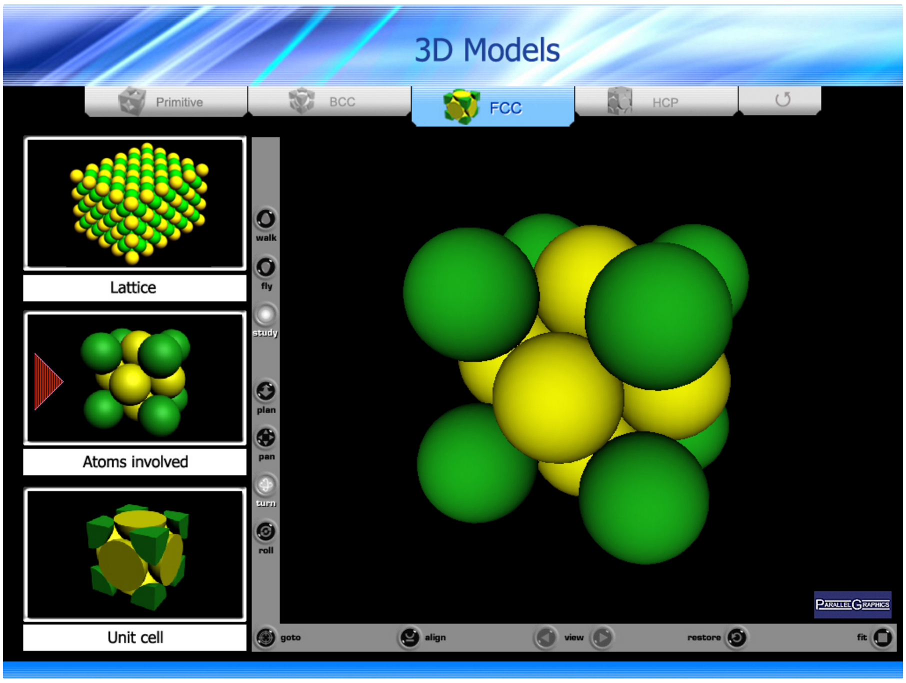
Screen Shots of the VUC



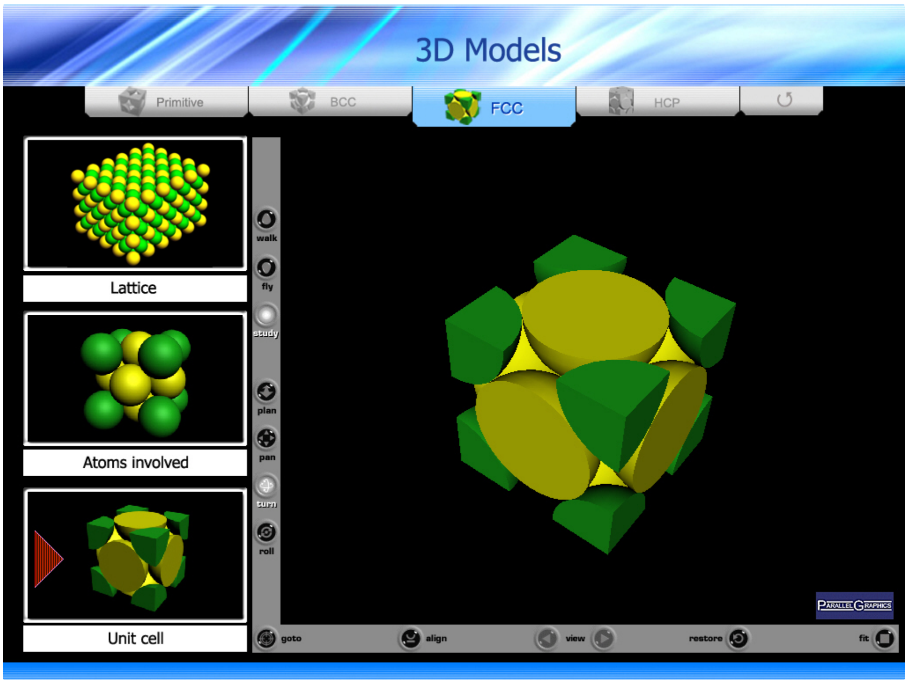
Main screen



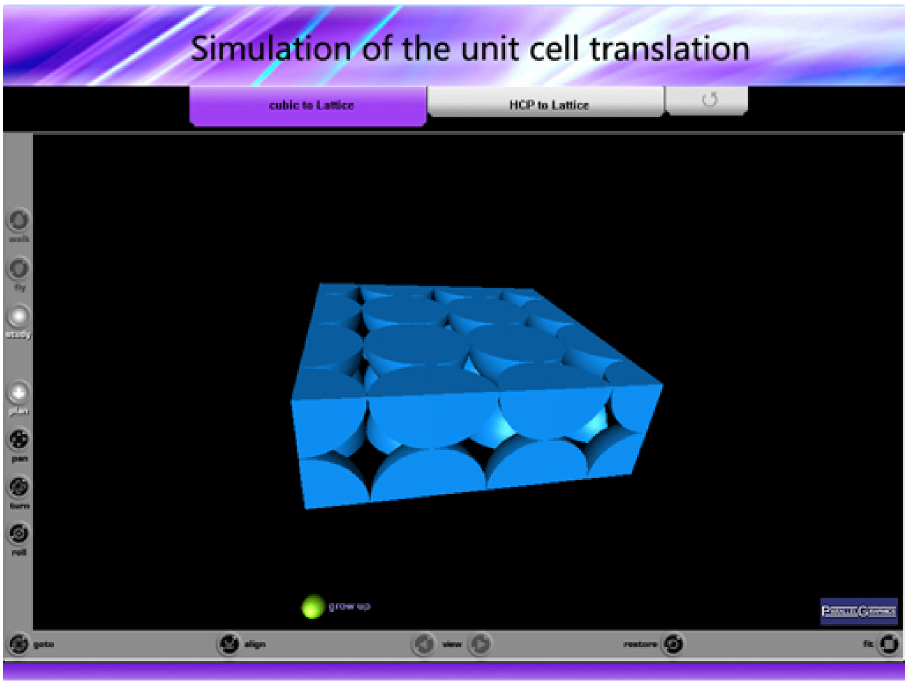
Crystal model



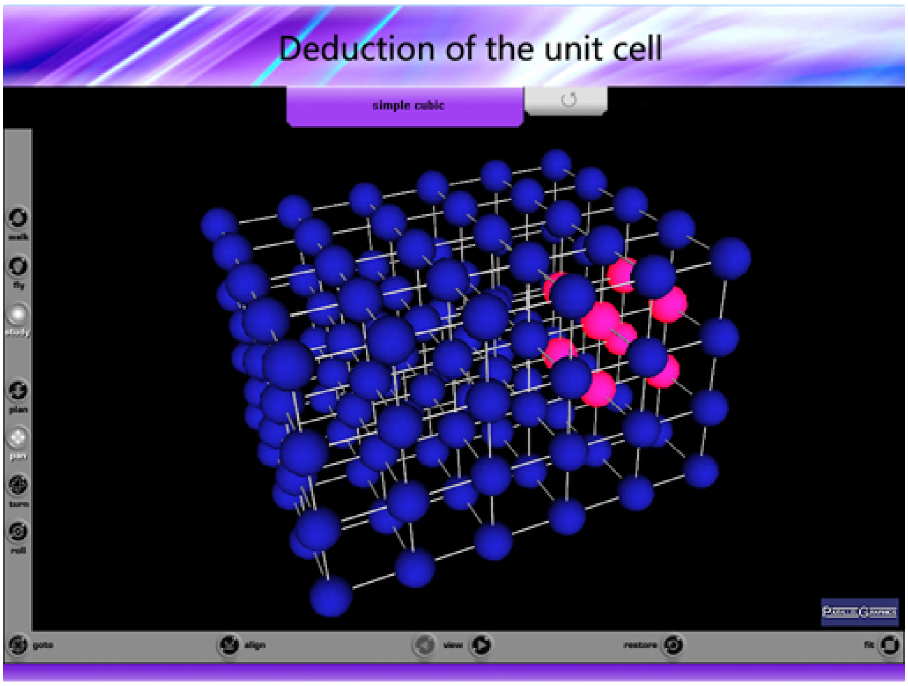
Atoms involved model



Unit cell model



Simulation of the Unit Cell translation

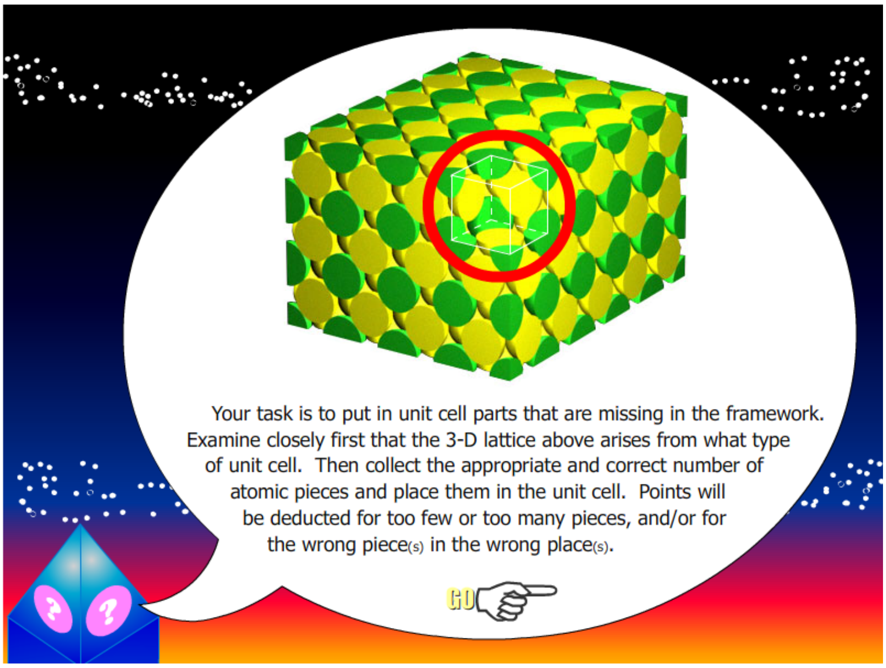


Deduction of the Unit cell

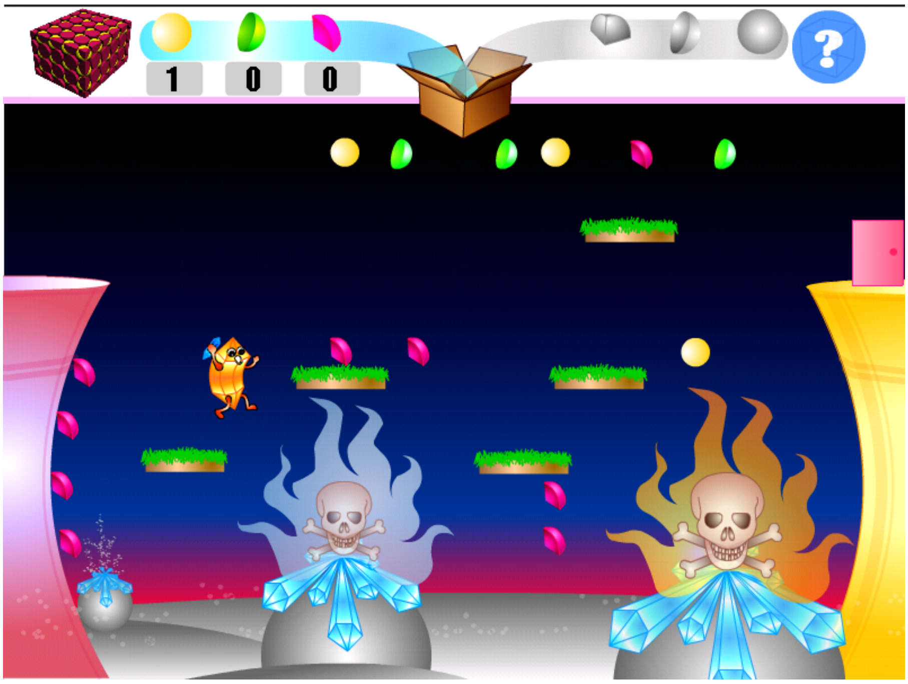
APPENDIX B

Screen Shots of the UCH

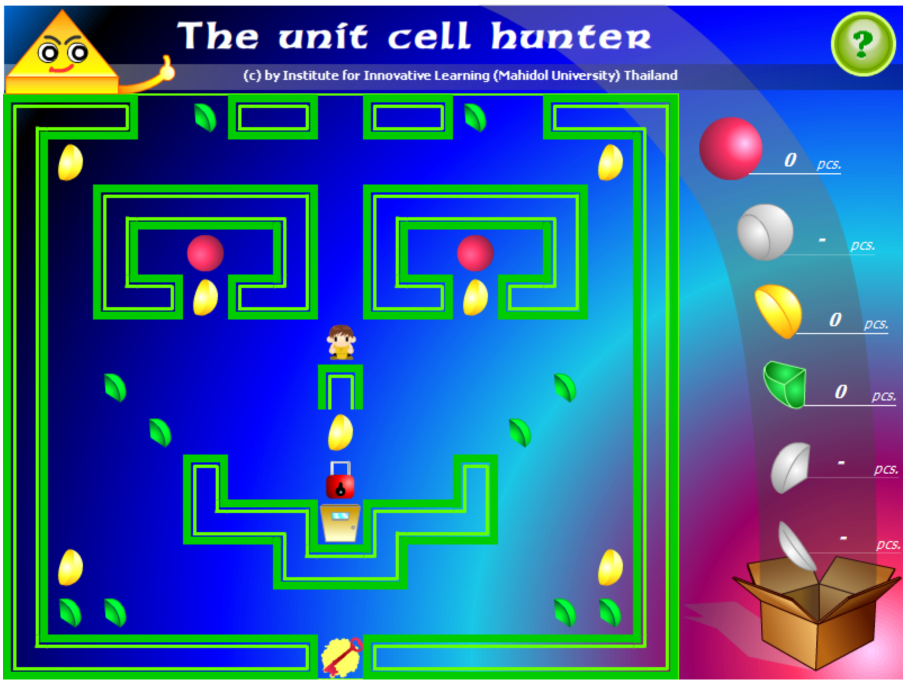
Title screen



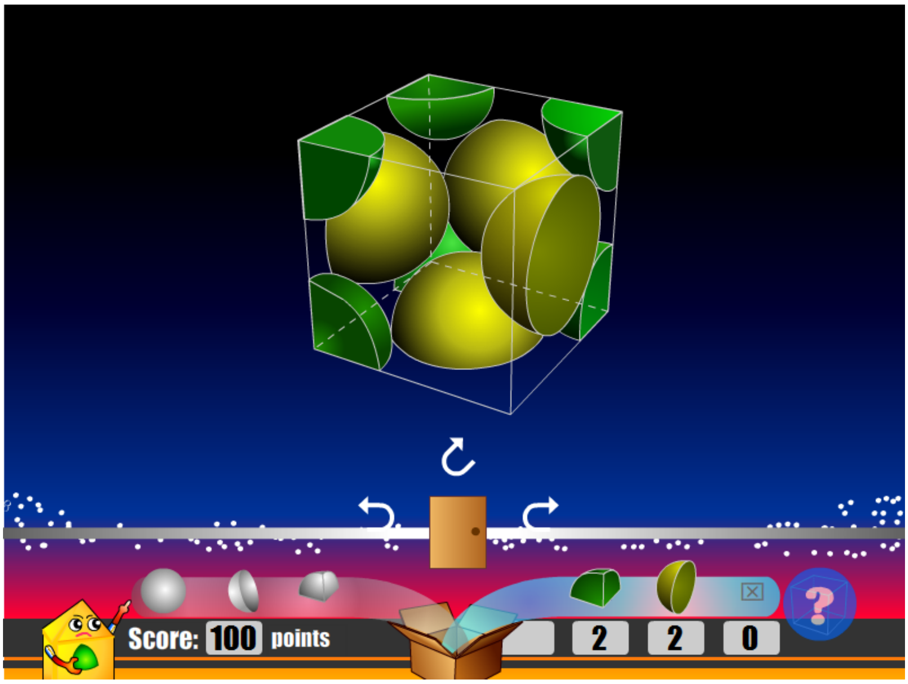
Deduction screen



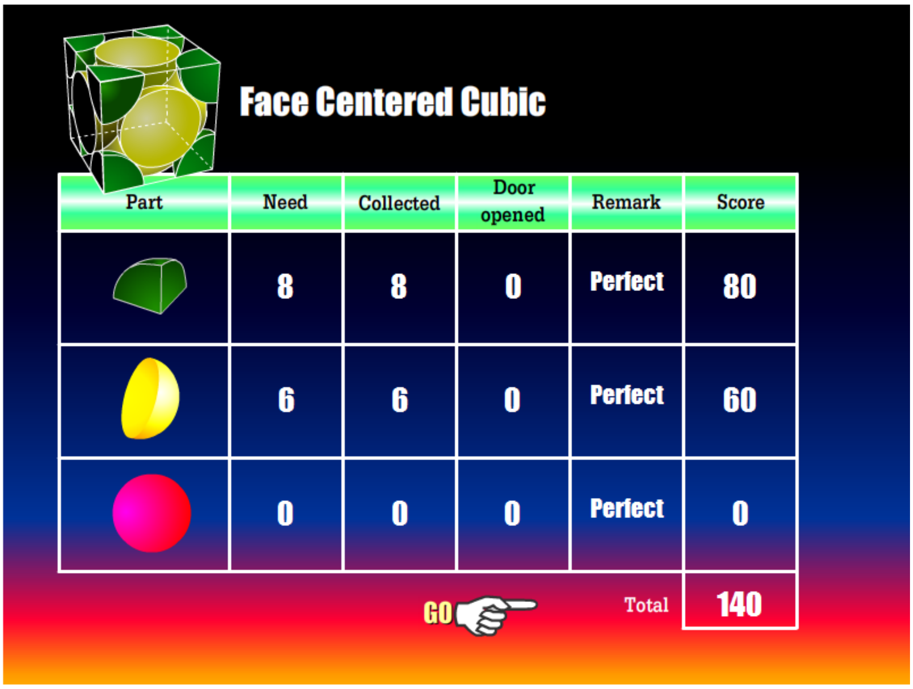
Collection screen (version 1)



Collection screen (version 2)



Assembled screen

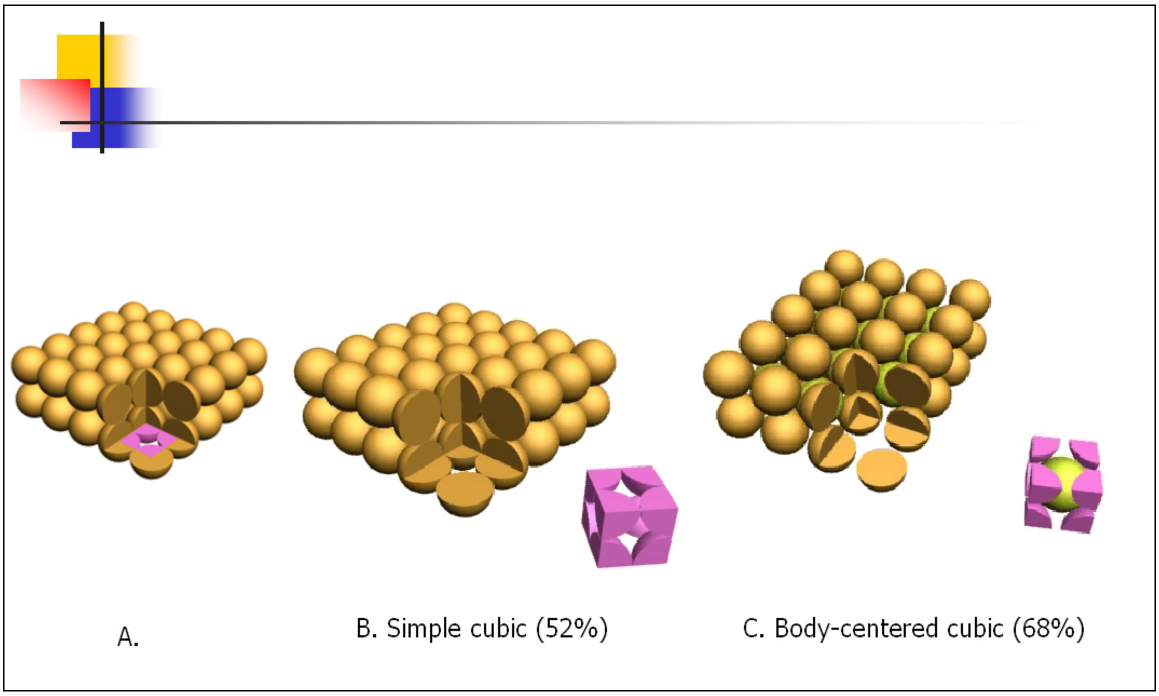


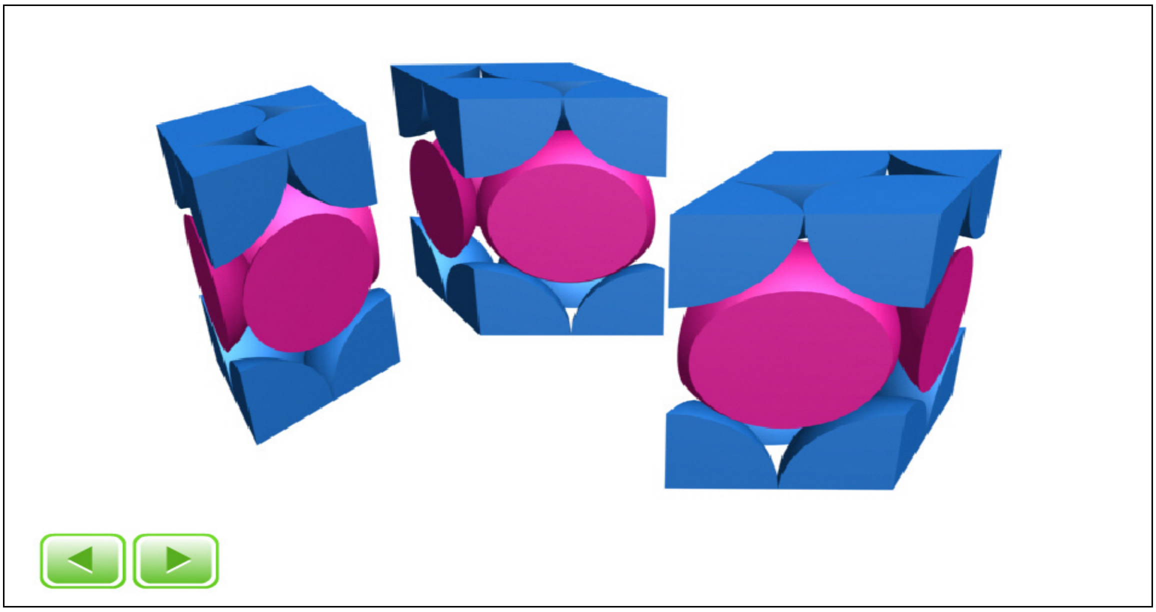
Score / result screen

End screen

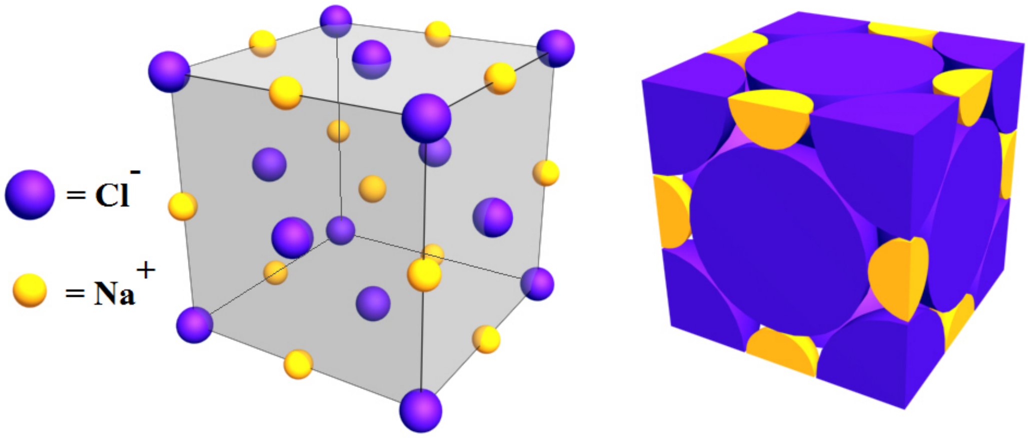
APPENDIX C

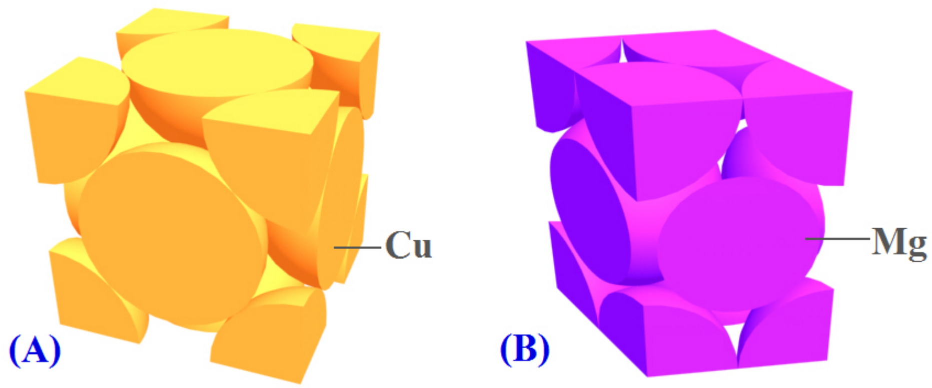
Some Screen Shots of the IMP





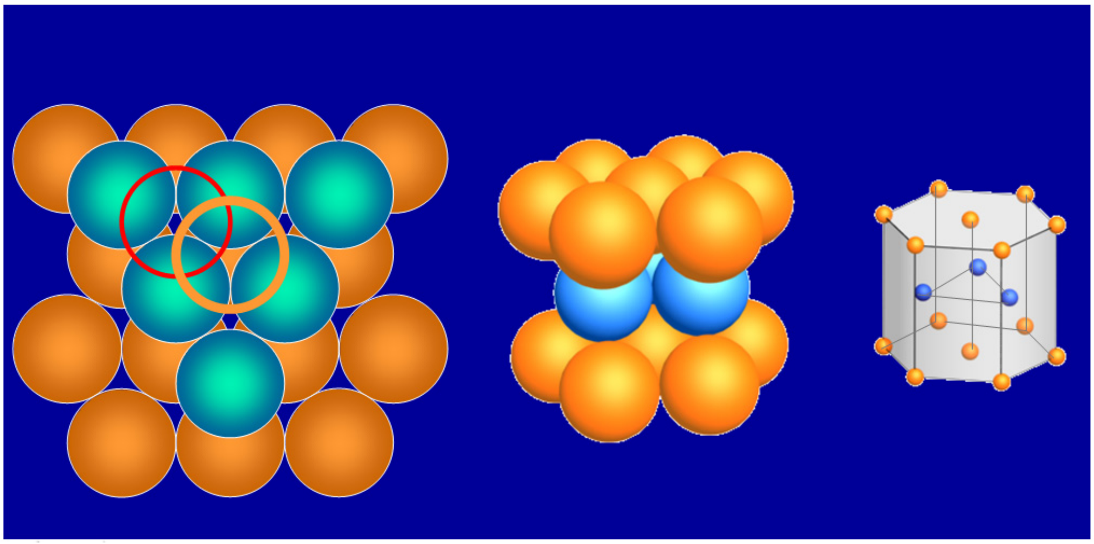
NaCl



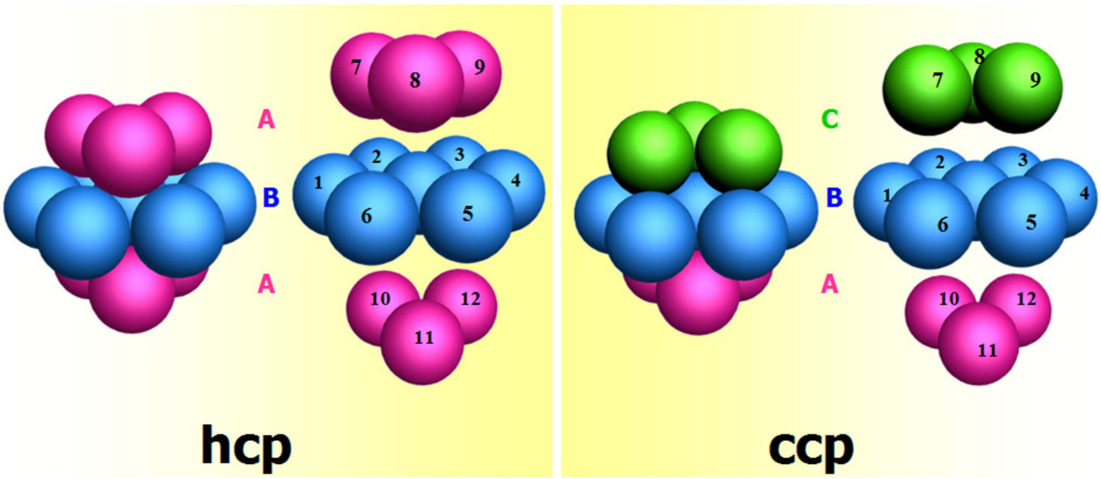


Most metals crystallize in one of the two closest packed arrangements. A, Copper adopts cubic closest packing. B, Magnesium adopts hexagonal closest packing.

Hexagonal closest packing (hcp), ABAB…



Coordination number



APPENDIX D

Achievement Test

Name____ Code ________________

Achievement test

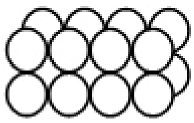
Choose the Correct Answer from the Multiple-Choice List. (40 min)

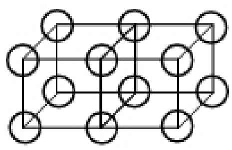
++

[Objective 1]

1. The dimension of Cubic crystal system is
   a) $a = b = c$; $\alpha \neq \beta \neq \gamma \neq 90^o$
   b) $a = b \neq c$; $\alpha = \beta = \gamma \neq 90^o$
   c) $a = b = c$; $\alpha = \beta = \gamma = 90^o$
   d) $a \neq b \neq c$; $\alpha = \beta = \gamma = 90^o$

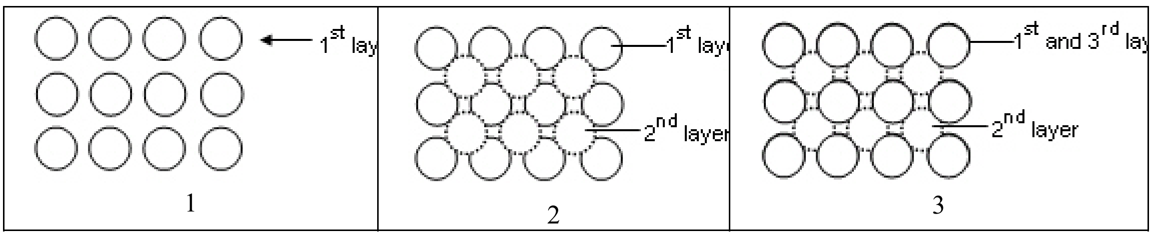
2. The type of unit cell obtained when two arrays of square planner are arranged exactly over each other is





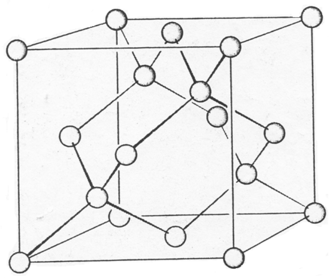
   a) body-centered cubic
   b) simple cubic
   c) face-centered cubic
   d) hexagonal closest pack

3. When the first atomic layer in picture 1 are overlaid with the second layer as in picture 2 and the third layer is overlaid on the same position to the first layer as in picture 3. The unit cell obtained is



   a) body-centered cubic
   b) simple cubic
   c) face-centered cubic
   d) hexagonal closest pack

4. The unit cell present the crystal lattice of diamond is

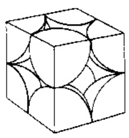


Crystal structure of diamond

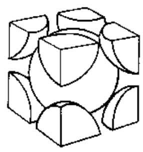
a) body-centered cubic
b) face-centered cubic
c) simple cubic
d) hexagonal closest pack

[Objective 2]

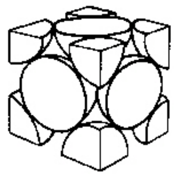
Use the following pictures for answering the item 5-7.



simple cubic unit cell



body-centered cubic unit cell



face-centered cubic unit cell

5. The number of atoms per a single simple cubic unit cell is

a. 1 b. 2 c. 4 d. 6

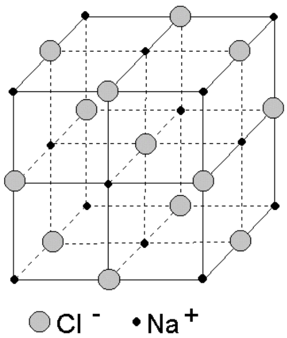
6. The number of atoms per a single body-centered cubic unit cell is

a. 1 b. 2 c. 4 d. 6

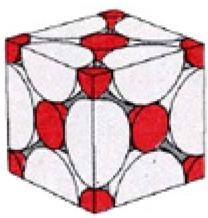
7. The number of atoms per a single face-centered cubic unit cell is

a. 1 b. 2 c. 4 d. 6

8. The number of Na atoms in a single unit cell of Sodium Chloride is



NaCl crystal structure

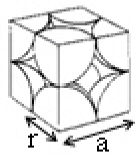


NaCl unit cell

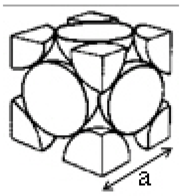
a) 2
b) 4
c) 6
d) 8

[Objective 3]

Use the following pictures for answering the item 9-10.



simple cubic



face-centered cubic

9. The relation between radius of atom (r) and edge length (a) of the solid crystallized in simple cubic structure is

   a. $r = \frac{\sqrt{3}}{4}a$ b. $r = a/2$ c. $r = 2a$ d. $r = \frac{\sqrt{2}}{4}a$

10. The relation between radius of atom (r) and edge length (a) of the solid crystallized in face-centered cubic structure is

    a. $r = \frac{\sqrt{3}}{4}a$ b. $r = a/2$ c. $r = 2a$ d. $r = \frac{\sqrt{2}}{4}a$

☺☺

[Objective 4]

11. Cu crystallizes in face-centered cubic structure. If the edge length of its unit cell is 4 Å, its atomic radius is

    a. $\frac{\sqrt{3}}{2}$ Å b. $\sqrt{2}$ Å c. $\frac{\sqrt{2}}{3}$ Å d. $\sqrt{3}$ Å

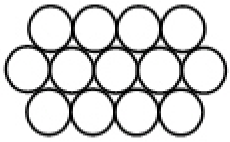
12. If a metal crystallized in body-centered cubic structure has a unit cell volume of 8 nm^3, its atomic radius is

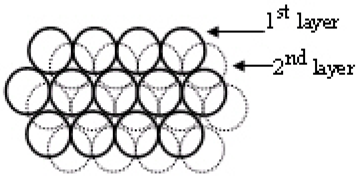
    a. $\frac{\sqrt{3}}{2}$ nm b. $\sqrt{2}$ nm c. $\frac{\sqrt{2}}{3}$ nm d. $\sqrt{3}$ nm

☺☺

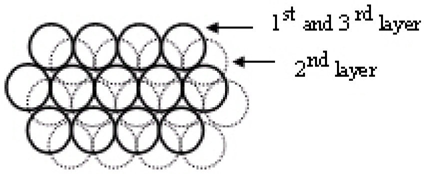
[Objective 5]

13. The three close packed layers are arranged such that the second layer is arranged over the voids of the first layer and the third layer overlay on the second layer at the same position as the first layer as in picture 3. The unit cell obtained is


1



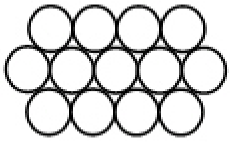
2

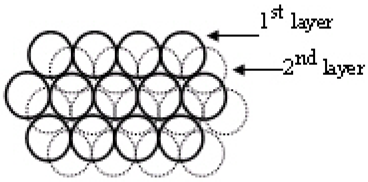


3

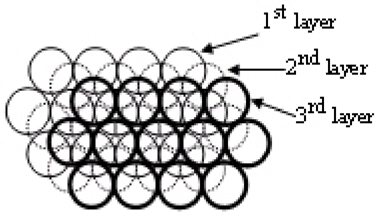
a) body-centered cubic
b) simple cubic
c) cubic closest pack
d) hexagonal closest pack

14. The three close packed layers are arranged such that the second layer is arranged over the voids of the first layer and the third layer overlay on the voids of the second layer as in picture 3. The unit cell obtained is


1



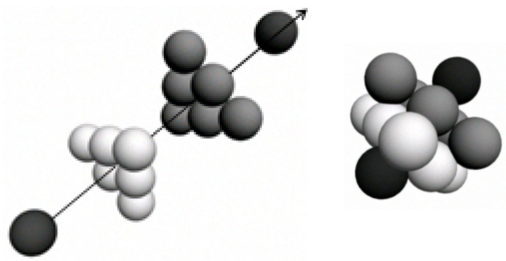
2



3

a) body-centered cubic
b) simple cubic
c) cubic closest pack
d) hexagonal closest pack

15. Close packed layers of ABCABC… pattern makes



a) Body-centered cubic (BCC)
b) Simple cubic
c) Cubic closest pack (CCP)
d) Hexagonal closest pack (HCP)

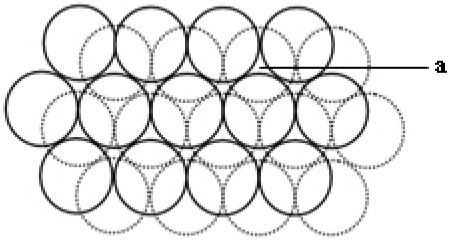
☺☺

[Objective 6]

16. Which hole occurs among six nearest neighbor atoms

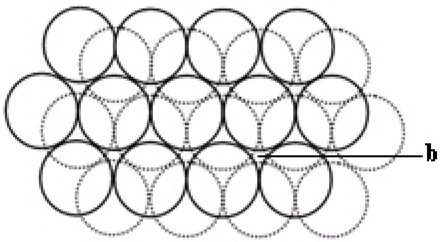
a) octahedral hole
b) tetragonal hole
c) tetrahedral hole
d) simple cubic hole

17. The hole at position "**a**" in the picture is



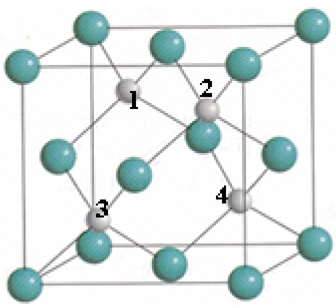
a) octahedral hole
b) tetragonal hole
c) tetrahedral hole
d) simple cubic hole

18. The hole at position "**b**" in the picture is



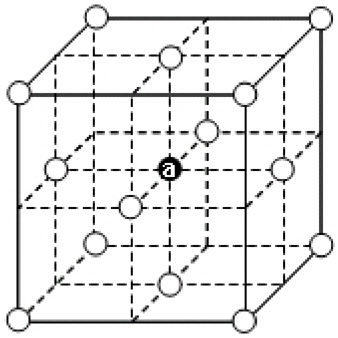
a) octahedral hole
b) tetragonal hole
c) tetrahedral hole
d) simple cubic hole

19. Atoms numbered **1**, **2**, **3**, and **4** in the following figure are in



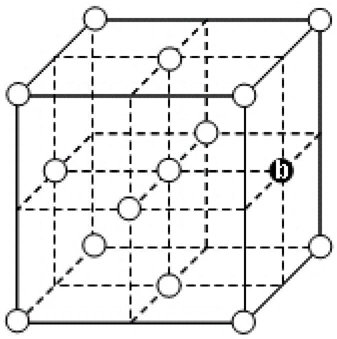
a) octahedral hole
b) tetragonal hole
c) tetrahedral hole
d) simple cubic hole

20. Atom “**a**” in the following picture is in



a) octahedral hole
b) tetragonal hole
c) tetrahedral hole
d) simple cubic hole

21. Atom “**b**” in the following picture is in



a) octahedral hole
b) tetragonal hole
c) tetrahedral hole
d) simple cubic hole

☺☺

[Objective 7]

22. The co-ordination number of an atom in simple cubic structure is

a) 4
b) 6
c) 8
d) 12

23. The co-ordination number of an atom in body-centered cubic structure is

a) 4
b) 6
c) 8
d) 12

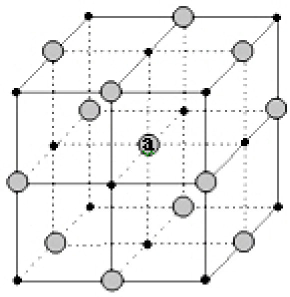
24. The co-ordination number of hexagonal closest pack structure is

a) 4
b) 6
c) 8
d) 12

25. The co-ordination number of cubic closest pack structure is

a) 4
b) 6
c) 8
d) 12

26. The co-ordination number of atom "**a**" in the picture is



a) 4
b) 6
c) 8
d) 12

☺☺☺

APPENDIX E

Aptitude Test

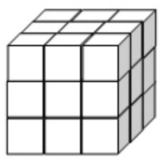
Name ____ Code __________

Aptitude test

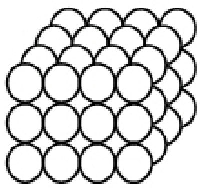
(Visual-Spatial ability Test)

Write the correct answers on this test (20 min.)

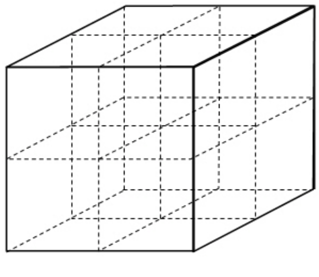
1. How many cubes are there in the following picture if they are piled up without any void in between? _________________________



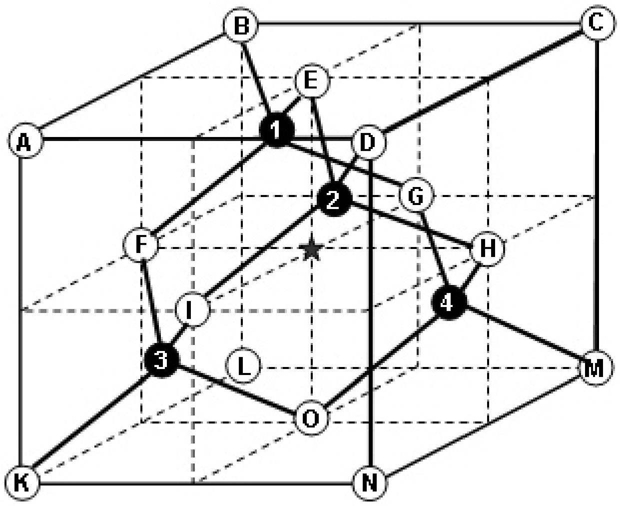
2. How many spheres are there in the following picture if there is any void in between? ______________________

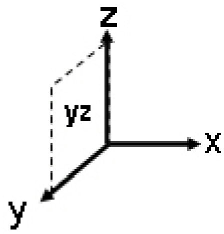


3. How many small boxes are there inside the big box? _____________________

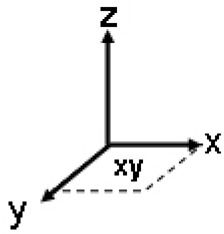


Use the following picture for answering items 4 – 8.





the yz plane



the xy plane

4. Atom "**F**" is aligned on the same vertical (yz) plane as atom ________________________

5. Atom "**E**" is aligned on the same horizontal plane as atom _________________________

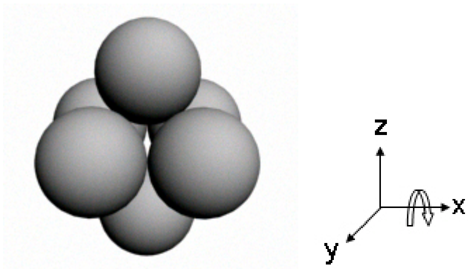
6. Atom "**1**" is aligned at above, below or on the same horizontal plane as atom "**D**"________________________

7. Atom "**2**" is aligned at above, below, or on the same horizontal plane as atom "**G**"________________________

8. Which atom is the nearest neighbor of atom "**3**"?

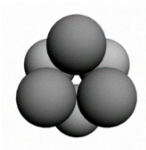
____

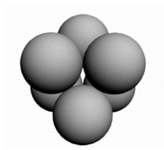
Use the following picture for answering items 9–10.

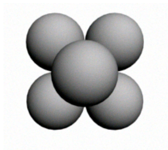


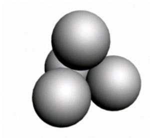
9. Which picture should not be the result if the structure is rotated around the x axis?

____

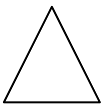

a


b

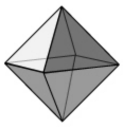

c

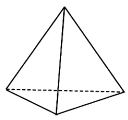

d

10. Which picture should be the result if each sphere is minimized as a point and the lines are drawn to connect them? ___________________________


a


b


c


d

APPENDIX F
Implementation Questionnaire

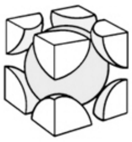
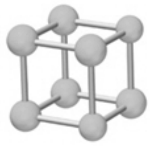
Statement	rating scale				
	strongly agree	agree	neither agree nor disagree	disagree	strongly disagree
1. Visualizing three dimensional structures from complex 2D still image is difficult and takes time.					
2. The IMP can help visualize 3D structure, that is, visualization using the computer tools is easier and can reduce time.					
3. Learning by using the IMP as a 3D visualization tool is more effective than using still images.					
4. Learning with the IMP can improve visual-spatial ability.					
5. UCH game can enhance visual-spatial ability.					
6. Individual practice with the CLM in a spare time might lead to better understanding.					
7. Learning on crystal structure and unit cell by using still image is more challenge than the IMP.					
8. Visualizing and understanding a complex 3D structure from still image is not a problem at all.					

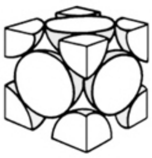
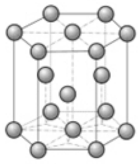
APPENDIX G

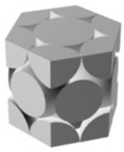
Pilot-Test

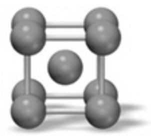
The Unit Cell Test

(Topic a) Look at the 8 pictures below and draw lines linking the pairs that are most closely related.

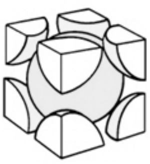
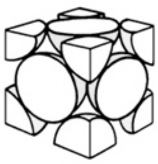
 

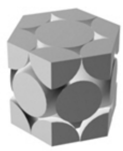
(Topic b) Place a bold letter (A or B or C or D) under an appropriate unit cell.

A. Primitive cubic B. body-centered cubic

C. face-centered cubic D. hexagonal

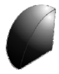
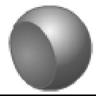
______ ______

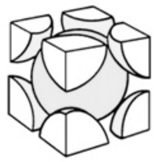
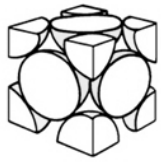
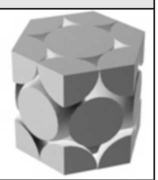
______ ______

(Topic c) **Fill in the blank in the table below the number and type of atomic pieces for each type of unit cell**

Type of Unit cell	Number of each type of atomic piece(s)		
			
Primitive (simple cubic)			
Body-centered cubic			
Face-centered cubic			

Type of Unit cell	Number of each type of atomic piece(s)			
				
Primitive (simple cubic)				

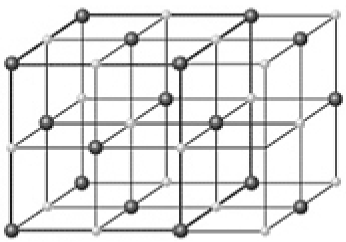
(Topic d) **State the number of atomic pieces in each unit cell below.**

	1	2	3	4
				
Number of atomic pieces in a unit cell =				

(Topic e) **From the picture above, which unit cell has the largest empty or unoccupied (by atomic pieces) space?**

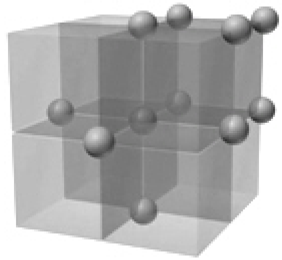
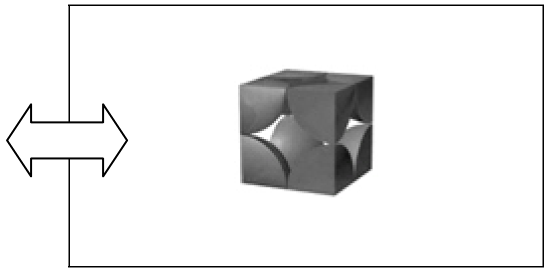
____

(Topic f-1) **Below is part of the crystal lattice of sodium chloride (table salt) solid (left). Can you apply your visualization ability acquired from the VUC unit to tell which type of unit cell (right) it belongs to?**



A. Primitive cubic
B. Body-centered cubic
C. Face-centered cubic
D. Hexagonal

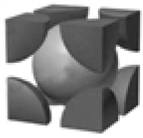
(Topic f-2) **If the unit cell (A) is deducible from the lattice (a)**

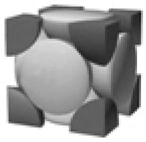



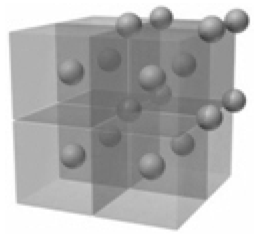
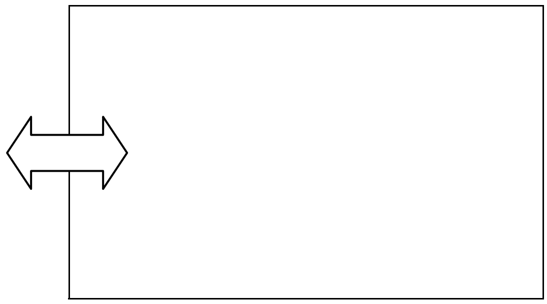
lattice (a) Unit cell (A)

Can you deduce the unit cell (A), (B) or (C) from lattice (b) or (c) and put the appropriate unit cell in the appropriate box on the right?

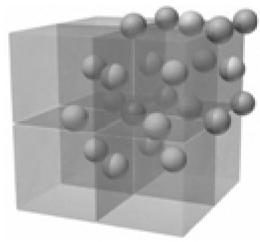
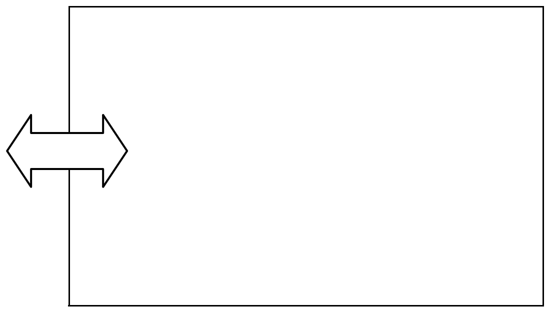

Unit cell (A)


Unit cell (B)


Unit cell (C)

Lattice (b)

Lattice (c)

APPENDIX H

Pilot-I Questionnaire

Rating Scale Questionnaire on the VUC and the UCH

Please indicate by filling (✓) in the appropriate box your attitude towards the VUC and the UCH.

Your opinions towards the VUC and UCH game	Assessment (Points in brackets)				
	Strongly agree (5)	Agree (4)	Undecided (3)	Disagree (2)	Strongly disagree (1)
1. Does the VUC unit help you to understand the crystal structures and the unit cells contents better?					
2. Relative to 2D still images, does the VUC help you to understand the contents better?					
3. Relative to 3D still images, does the VUC help you to understand the contents better?					
4. Relative to physical models made from ping-pong balls; does the VUC help you to understand the contents better?					
5. Does the UCH game help increase 3D visualization skills?					

APPENDIX I

Pilot-II Questionnaire

Rating Scale Questionnaire on the VUC and the UCH

Please indicate by filling (✓) in the appropriate box your attitude towards the VUC simulation and the UCH.

Your opinions towards the on screen VUC simulation	Assessment (Points in brackets)				
	Strongly agree (5)	Agree (4)	Undecided (3)	Disagree (2)	Strongly disagree (1)
1. Does the VUC unit help you to understand the crystal structures and the unit cells contents better?					
2. Relative to 2D still images, does the VUC help you to understand the contents better?					
3. Relative to 3D still images, does the VUC help you to understand the contents better?					
4. Relative to physical models made from ping-pong balls; does the VUC help you to understand the contents better?					
5. Is the UCH fun even though it is on a very sophisticated topic?					
6. Does the UCH require knowledge gained from the VUC?					
7. Does the UCH game help increase 3D visualization skills?					
8. Does the UCH have close linkage with the VUC?					

APPENDIX J

Conversion of Effect Sizes into Percentile

Effect Sizes	percentage of control (traditional) group who would be below average person in experimental (the CLM) group
0.0	50%
0.1	54%
0.2	58%
0.3	62%
0.4	66%
0.5	69%
0.6*	**73%**
0.7	76%
0.8	79%
0.9	82%
1.0	84%
1.2	88%
1.4	92%
1.6	95%
1.8	96%
2.0	98%
2.5	99%
3.0	99.9%

* Effect size in this study.

BIOGRAPHY

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Luealamai, S., Sukhseelueang, S., & Panijpan, B. (2009, 25-27 March). Fundamental Genetics. In Proceeding from the 16th National Conference on Genetics for National Energy Crisis Thammasat University, Thailand.

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Luealamai, S. (2010, 25-27 March). A Building Block Set: A new hands-on game for enhancing students' perception of geometry. Oral Presentation from National Conference on ThaiSim2010: Learning from experience through game and simulations. Trang, Thailand.

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