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本文提出一個 Web-based 合作探究學習系統，以全球資訊網(World Wide Web, WWW) 為知識探究來源，利用探究性問題去引導學生思考以進行探究，再利用概念構圖法讓學生去建構屬於自己的知識，並且在學習過程中，讓學習者溝通彼此所收集到的證據、學習者的個人想法以及所建立的個人概念圖，達到互助合作、資訊分享的目的。為了有效整合探究學習策略、合作學習策略與概念圖知識表徵法於 WWW 上，本文也提出適用於網路上的合作探究學習模式及學習活動。針對所提出的合作探究學習模式及學習活動，本文設計實驗以探討學生在網路上的合作探究學習之學習歷程。

Abstract

This study proposes a Web-based collaborative inquiry learning system. It uses the World Wide Web (WWW) as a source of knowledge exploration, and uses exploratory problems to guide students to think and explore. Then, it uses concept mapping to help students construct their knowledge. In the process of learning, learners are allowed to exchange the evidence they have collected, their personal opinions, and the concept maps that they have built. In order to effectively integrate the inquiry learning strategies, collaborative learning strategies, and concept mapping knowledge representation in the system, this study proposes a collaborative inquiry learning model and learning activities. Experiments were designed based on the collaborative inquiry learning model and activities to investigate students' learning processes in the collaborative inquiry learning on the Web.

Keywords: Web-based learning, collaborative learning, inquiry learning, concept map.

1. Introduction

Traditional instruction is based on the premise that knowledge is transferred to students by a teacher. As a result, much of the teaching process is focused on the repetitive practice of factual knowledge and problem-solving rules, while the acquisition of scientific attitudes and problem-solving skills tend to be ignored (Tobin, Briscoe & Holman, 1990). In contrast, modern science education focuses on enabling students to take an active role in learning through their own exploratory processes. Specifically, it tries to help students learn how to organize and construct their own views, reflect on problems, form hypothesis, and seek evidence. Such processes can help students build up their thinking skills and cultivate their problem-solving abilities, thus facilitating the learning of scientific concepts (Tabak, Smith, Sandoval & Reiser, 1996).

Inquiry learning is a strategy about student exploration of knowledge. Though researchers have proposed different definitions of inquiry (Suthers, 1996; Sandoval & Reiser, 1998; Looi, 1998; White and Frederiksen, 1998), they generally agree that there are at least four critical steps when conducting inquiry learning: generating hypothesis, collecting data, interpreting evidence, and drawing conclusions. During the inquiry process, the teacher raises problems, provides information related to the problem, engages students in forming hypothesis, aids exploration, explains data, verifies hypothesis, and discusses or reports their results. Such processes aim to train students to use the inference method, encourage students to learn on their own, and help them gain insight into the rules and principles required in problem solving. Previous research found that inquiry learning enhances students' learning achievement, especially in the aspects of problem solving skills, ability to explain data, critical thinking, and understanding of concepts in learning science (Chiappetta &

Russel, 1982; Haury, 1993; Saunders & Shepardson, 1987).

With the advent of Internet technology, many researchers used computers and the Internet to design a variety of inquiry learning tools. Pryor and Soloway (1997) developed an inquiry learning software package titled ScienceWare. With the assistance of ScienceWare, students can use simulation tools to verify their hypotheses in the process of exploring and establishing their knowledge models. Northwestern University in the United States developed a learning environment named BGuiILE (Biology Guided Inquiry Learning Environment) in which students learn about biology. This computer-assisted inquiry-learning environment aims not only to make students learn about biology, but also to give them experience in scientific exploration (Tabak, Smith, Sandoval & Riser, 1996). Linn and her colleagues (2000) designed a goal-comprehensive and Internet-based inquiry-learning environment for science learning named Knowledge Integration Environment (KIE). The learning environment supports a learner's problem-solving activities with various assistance software tools, combining them with the abundant resources on the Internet as the source of information necessary for problem solving (Linn, Bell, & Hish, 2000; Slotta & Linn, 2000).

Despite its merits, inquiry learning has encountered challenges in implementation. When there is a shortage of equipment in schools, teachers have trouble using the inquiry teaching method in the classroom. In addition, inquiry learning may turn out to be more of a hurdle for students, except for the brighter few. Moreover, for inquiry learning method to be more effective, it is necessary to strengthen the explorative learning motives of students, to inform them with exactitude what scientific exploration skills are required, and to give them some understanding of the background knowledge (Edelson, Gordin & Pea, 1999).

The problems described above may be overcome with the following solutions:

1. Making up for the inadequacy of school facilities with on-line exploration over the Internet. The Internet is characterized by an abundance of information, speedy update, and ease of access. Therefore, inquiry learning conducted over the Internet is an ideal solution for the inadequacy of equipment in schools.
2. Helping students better understand the theme of a learning unit by employing concept mapping. The concept mapping method is widely adopted learning strategy in science education (Novak, 1990b). This study uses concept mapping for planning exploration procedures, representing the formed hypotheses, and organizing the explored knowledge. We hope the constructed map may serve as the ‘anchor’ of the entire learning process and will aid the learner to proceed to meaningful learning.
3. Taking advantage of collaborative discussion and information sharing to overcome the difficulties encountered in inquiry learning, lower the hurdles in the way of inquiry learning, and enhance the motives and results of learning. With collaborative learning, the members of a group are encouraged to help each other achieve the shared goals of learning, thereby improving individual learning as well (Slavin, 1985; 1996). Researchers were not only interested in the application of collaborative learning in a classroom context, but many were also highly interested in exploring the behavior and effects of collaborative learning in cyberspace by building environments for collaborative or cooperative learning using computers (Mevarech & Light, 1992; Jehng, 1997; Chang, Wang, Dai, & Sung, 1999). This was found to enhance students’ ability to think critically, solve problems, and improve interpersonal communication skills (Marjanovic, 1999).

This study proposes a Web-based collaborative inquiry learning system, which uses the World Wide Web (WWW) as a source for knowledge exploration, and uses exploratory problems to guide students to think and explore. Then, it uses concept mapping to help students construct their knowledge. In the process of learning, learners are allowed to exchange the evidences they have collected, their personal opinions, and the concept maps they have built individually. In order to effectively integrate inquiry learning strategies, collaborative learning strategies, and concept mapping knowledge representation into the system, this study proposes a collaborative inquiry learning model and learning activities. Experiments were also designed to investigate students' collaborative inquiry learning.

2. Collaborative Inquiry Learning Model

Based on previous studies of inquiry models (Igelsrud & Leonard, 1988; Sandoval and Reiser, 1998; Suthers, 1996; Suthers & Jones, 1997; Tinnesand & Chan, 1987), we conclude that the inquiry process should include the following: 1. **familiarizing**; 2. **hypothesizing**; 3. **exploring**; 4. **explaining**; 5. **revising**; and 6. **reporting**. In fact, one of the objectives of science education is to learn such inquiry skills.

Additionally, to take advantage of collaboration, a collaborative inquiry process, which combines the inquiry skills with collaborative skills, is well worth proposing (Spitulnik & Krajcik, 1998; Suthers, Toth & Weiner, 1997).

However, collaborative learning as implemented in current systems is limited to textual communication, with little information being shared among peers. Nor does not exist an effective knowledge representation to organize the results of collaborative exploration. Moreover, either the works created by the individual or the products by

the group are ignored. With those problems still to be addressed, collaborative inquiry learning via computer leaves considerable rooms for further research.

The four phases of our proposed collaborative inquiry-learning model are summarized in Table 1. In order for learners to catch the focus in each phase, the learning in each phase is further divided into various learning activities, each corresponding to a learning objective, such as inquiry skills and collaboration skills. Table 1 shows the learning activities in each phase and their corresponding learning objectives for practicing inquiry skills or collaboration skills, as well as the results in each phase.

(Insert Table 1 here)

Phase 1: anchoring and planning

In the first phase, the learner begins by reading a piece of material that is exploratory in nature and highly worthy of discussion. Then the learner reflects upon the problems raised in the reading material, forming his/her own hypothesis. Next, the learner presents the evidence that supports his/her hypothesis in the form of concept maps. Because learning and organizing knowledge with concept maps is known to be effective (Novak, 1998, Chang, Sung & Chen, 2001; Sung, Chen & Chang, 2000), it should be feasible to use concept maps to familiarize the learner with the main topics of the reading material. Some researchers think concept mapping is an appropriate planning tool for problem solving (Suthers, Toth and Werner, 1997), so concept mapping is used in the system as a tool for representing knowledge and forming hypotheses.

A concept map is a collection of many propositions, with each proposition consisting of two concept nodes and a relation link between concepts (Novak, 1990,

1991, 1998). For example, a concept map that describes the statement “the Great Pyramid, one of the seven wonders of the ancient world, was built with the linear slope or spiral slope technique” may look like Figure 1.

(Insert Figure 1 here)

For instance, there are three learning activities in phase 1 depicted in Table 1, with objectives to put learners through the processes of “familiarizing with the topic” and “forming hypotheses.” First learners are provided reading material by the system. After reading and reflection (learning activity 1), they form their hypotheses about the reading material. This activity acquaints the learners with the process of “familiarizing with the topic.” The processes of familiarizing materials and identifying problems are viewed as the anchoring stage. After the anchoring stage, the students propose tentative hypotheses and answers to the inquiry problems raised in the reading material. This is learning activity 2, in which students experience the process of “forming hypotheses”. The last learning activity is for learners to present their understanding of the reading material and the evidence relevant in forming their hypothesis in the form of concept maps. The results of this phase will be presented with concept maps built by individuals. Therefore, the reading material plays an anchoring role in this phase, giving the learners a direction to follow in future activities.

Phase 2: individual inquiry

After the first phase, learners already have a certain degree of understanding of the knowledge of the inquiry problem, and have formed hypotheses. In the second phase, the learners may search resources and look for the evidence supporting their hypotheses on the Web by using a browser. Additionally, the learners are required to use the notepad function in the system to compile and edit the related information

they have found. The notepad they have compiled will be their products in this phase. Finally, the learners should revise their original concept maps as constructed in phase 1 according to what they have learned by reading the information they have found on the Web and the views they have found supporting or contradicting their hypotheses. The major learning activities and objectives in phase 2 are also shown in Table 1.

Phase 3: collaborative inquiry

Collaborative learning emphasizes the interactive processes among learners. This study puts emphasis on the three parts of collaborative learning: data sharing, product sharing, and idea sharing. In phase 3, therefore, we pay the most attention to the sharing of individual notepads, the sharing of individual concept maps, and the discussions between the learners and their peers. Sharing individual notepads is equivalent to sharing data; sharing individual concept maps is equivalent to sharing products; and the discussions and communication between peers are equivalent sharing ideas. When the members fail to reach a consensus, they can revise their ideas through discussion, questioning, debate, and explanation. The learning activities and their objectives of this phase are shown in Table 1.

Phase 4: concluding group's results phase

In addition to individual products, one aim of collaborative learning is for the learning group to have a collective product. Some researchers think the effort to create the group product in collaborative learning is an effective catalyst for discussion and mutual assistance among group members (Slavin, 1996), and therefore an important part of the collaborative learning process. This study asserts that the concept map built by the group can serve as the group product. McManus & Aiken (1995) believe that for creating a collective product, voting is one strategy worthwhile trying. Following this idea, the system had each group produce its core concept map through voting.

The owner of the winning concept map would then be in charge of revising that concept map to be the group concept map. The other members of the group were able to see the map change in real time on the Web, and could give personal feedback via a chat room. Through discussion, communication, and revision by the members, a group concept map was produced. The objectives of phase 4, shown in Table 1, are getting learners to engage in knowledge communication, knowledge negotiation, and knowledge consolidation (Jehng, 1997).

3. Experiment

3-1 Subjects

The subjects of the experiment are 17 freshmen students from departments unrelated to information science at National Taiwan Normal University, Taipei. None of them have seen the reading material used in the experiment beforehand. They were divided into six groups, with five groups of three students and one group of two.

3-2 Material

The reading material used in this experiment is an article, titled “The Mystery of The Great Pyramid”. In this article an exploratory question “Do you think the Great Pyramid was built by humans?” is posed. Two opposing views are presented in the article. One supports the proposition that the Great Pyramid was built by humans, while the other questions that possibility. The reading material provides evidence on both sides of the argument, allowing students to reflect on how to generate their own hypotheses after reading. A search on the Web found a wealth of content related to the supportive and dissenting views: nine related Chinese websites contain 3655 Web pages supporting either view. Therefore, there is abundant information to provide enough evidence to be quoted in the students’ inquiry process.

3-3 Procedures

This experiment lasts 100 minutes. Considering that the learners were not familiar with the system, the time for system tutorial and explanation must be incorporated into the design of the experiment. The flow of the experiment is shown in Table 2.

(Insert Table 2 here)

4. Results and Discussion

This experiment has collected a large corpus of data generated by learners in their inquiry process, including notepads, concept maps, records of their discussions, and titles of Websites visited. The inquiry process and results will be explained in the following subsections.

4-1 Anchoring and planning phase

In the first phase, the learners were asked to express their understanding of the concept in the reading material using the concept mapping method. They were also asked to propose tentative answers to the inquiry problems. Figures 2 and 3 are two typical concept maps.

(Insert Figures 2 and 3 here)

The two concept maps show students have great differences in representing their knowledge. The concept map in Figure 2 clearly illustrates the view that the Great Pyramid was not built by humans, and the related evidence in the reading material is organized in the map to support this view. But student 6a, who authored Figure 3, does not seem to have produced a concept map related to the reading material to answer the questions. Only a collection of concepts from the reading is organized in a meaningless manner. It is unclear what his view is.

This study tries to use concept mapping as a tool for anchoring concepts in the reading material and for planning hypotheses, but the results indicate that it may produce tremendously different effects when applied on different learners. For some learners, it remains a difficult tool to use for knowledge representation and solution planning. We found after interviews that the reasons are largely the lack of knowledge about concept maps, unfamiliarity with the user interface, awkwardness in trying to represent their knowledge in concept maps, failure to understand the problems, or doubts about the reading materials.

4-2 Individual inquiry phase

In the second phase, the learners go on the Web to find evidence that supports their hypothesis. They compile the evidence they have found and record it using the notepad provided by the system. Finally, they revise their original concept maps according to the information in the notepad. Table 3 lists the number of Web pages visited by the students in the inquiry processes and the number of Web pages quoted in the notepad.

(Insert Table 3 here)

As shown in Table 3, the learners did use the Web to search for evidence related to their own views. The lowest number of Web pages visited by a single student was 17, and the highest, 37.

Some students' notepads are filled with information they culled from the Web. Figure 4 shows an example of a notepad, which includes the addresses of the Web pages quoted and the abstract of their content written by the student. Students who visited more Web pages than others did not necessarily put down the information they found in their notepads. As shown in Table 3, student 6b visited 37 Web pages without

entering any information in the notepad, and student 5c browsed 35 Web pages but recorded only information found in one of them. It seems that when students browse too many Web pages, they may become less concentrated in reading and reflecting on page content.

(Insert Figure 4 here)

The experiment found that browsing Websites is indeed a valid form of inquiry activity. This finding is consistent with those of Suthers et al. (1997) and Toth et al. (2000). Chavero et al. (1998) used the number of Web pages visited by students as one indicator for the amount of inquiry activity taking place. But our study found that the number of Web pages visited might not be a proper indicator of judging the level of inquiry activity, because the quantity of Web pages browsed has no direct relationship to the quality of mental activity. Our study also used the content of notepads as a basis for judging how much the students had read and thought over the assigned material. We found that those students who had compiled their notepads with more detail and substance actually did better in later phases. Therefore, it is helpful to use the notepad to assist students' exploration. The study also found that a few students have difficulty in organizing their findings, so it may be helpful for the achievement of inquiry activities to establish an exploration assistance mechanism. This mechanism may help or oblige students to compile the information they found online, and enter it in the notepad after some reflection and organization.

4-3 Collaborative inquiry phase

The activities in phase 3 are designed with a view to encouraging learners to have discussions with their partners. We hope that they engage in collaboration on the Web and revise their concept maps and the content of their notepads based on what they learn from the discussions. We observed the discussions in the groups, and found

that there was much discussion in all the groups. Sharing of ideas and debating individual views can be seen in the discussion records, and the students are found to praise or challenge one another. An example of such a record is shown in Figure 5.

When student 1b proposed that aliens built the Great Pyramid, student 1c immediately countered with his hypothesis that it is a man-made structure. Student 1b then challenges student 1c for evidence, which student 1c failed to produce. Student 1a maintained that it was built by a Sun god and invited other group members to look at his notepad for supporting evidence.

(Insert Figures 5 and 6 here)

After Web inquiry, students need to incorporate newly found evidence into their original concept maps. For example, Figure 6 was revised by student 4c from the original concept map shown in Figure 2. Some evidence found in Web inquiry was incorporated into the original concept map. Newly added concept nodes such as architectural technology ahead of its time, the 18 stone slabs in the Great Pyramid, the golden proportion of the Pharaoh Temple, and the highly difficult techniques in building the great passage way are not presented in the original reading material. Those belong to new evidence the learner obtained from his Web inquiry.

Although most learners attached new evidence to their original concept maps, a few of them revised the concept nodes or links previously established. In interviews most students said it takes too much effort to make changes to previous concept nodes and links, and so avoided doing that. This phenomenon is consistent with what Reader & Hammond(1994) and Fisher (1990) found. Those researchers indicated that most college students were either unable to complete or unwilling to revise their concept maps. It is obvious that feedback for map construction is necessary not only for middle school children (Chang, et al., 2001), but also college students.

Jehng (1997) indicated that an effective collaborative learning environment could facilitate the communication, negotiation, and consolidation of knowledge among students. Chang et al. (1999) also found that collaborative learning is a way for students to achieve mutual assistance and enhance their learning effects as a result. Our system offers a group discussion mechanism, and learners are told to exchange their inquiry data (or notepads), products (or concept maps), and other related ideas. We also found that group members had actually exchanged ideas from their data and products, thus further clarifying each other's attitudes. In addition to exchange of knowledge, members also had fairly good social interaction. The finding also supports the view of Johnson and Johnson (1989) that the members in a collaborative group will grow "positively interdependent."

4-4 Concluding group's results phase

The activities in the fourth phase utilize voting strategy. Each group selects one individual concept map through voting, and the owner of that concept map is responsible for revising it according to the opinions of the group members. Eventually, the group concept map is thus generated. Table 4 illustrates the voting status of all the subjects. Students with an asterisk affixed after the ID won the most votes in the group, and are responsible for revising their own concept map after communication and discussion with other group members. The final result is the group concept map. In Table 4, "Agree" means that the student's hypothesis or conclusion meets the idea "the Great Pyramid was built by humans", and "Disagree" means students believe the proposition "the Great Pyramid was not built by humans".

(Insert Table 4 here)

We can see some interesting results in Table 4. More members of group 2 are opposed to the idea that the Great Pyramid was built by humans, but their final vote

selected a group concept map that supports the idea of men building the Great Pyramid. A similar situation occurred in group 4. After analyzing the dialogue of the groups, we found the reason may be that the members want to have a more complete concept map from which a group concept map is easily revised. They were willing to choose a better concept map, even if it represents ideas contradicting their own views.

Moreover, the hypotheses of members may change after communication and discussion. For example, Table 4 shows that student 1a displays dramatic changes in his views, from supporting the idea that the Great Pyramid was built by humans to opposing that idea. We can find the reason for his cognitive change by analyzing his notepad.

We realize from the notepad of student 1a that he changed his original view in the individual inquiry phase, as the content was full of information about the Sun God and numerical coincidence about the Great Pyramid. We interviewed the student to ask what changed his mind, and found the cause was in the process of searching for evidence. He found more evidence showing there are many mysterious and inexplicable numerical and architectural riddles about the Great Pyramid, and so changed his view.

4-5 Analysis of questionnaire results

Seventeen items were issued in this questionnaire. The objective is to know whether students can easily accept the collaborative inquiry-learning model proposed in the paper, if they have any difficulty using the system, their cognitive changes, and other questions they may encounter.

From the questionnaire, we found that the students (94%) think learning by “drawing concept maps” is acceptable, and all of them (100%) agree that “drawing

concept maps” is a very interesting activity. Most students consider the more difficult aspect in concept mapping is lack of time, and the second largest problem is unfamiliarity with the user interface.

Searching the Web for related information is indeed helpful for students to clarify important points in the reading material (88%), and learners agree the inquiry process is enjoyable (76%). Most students think there is a sufficient amount of related information available on the Web for exploration (71%).

When the collaborative mechanism is incorporated into the learning process, learners share information collected on the Web and their own ideas with partners. Through sharing, their ideas become clearer and firmer (75%). Ninety-four percent of the students agree that sharing information collected on the Web and their personal ideas help them clarify what they really think.

Information sharing mentioned in this study includes sharing of products (concept maps), data (notepads), and ideas (dialogue and discussion). The students’ favorite form of sharing is dialogue and discussion, followed by the content of notepads, and, finally, their concept maps.

As for creating the group concept map, 81% of the students agree this activity is helpful for reconciling the differences between group members. But most think it very difficult to generate a group product (59%), and more than half are not satisfied with their group concept maps (53%). We also found in the questionnaire that most of the students are willing to change their ideas for the sake of the group product (65%).

In summary, students show positive attitudes towards using a collaborative inquiry learning strategy. All of them agree that it would be worthwhile to try to use this system in the classroom (100%).

5. Conclusions

Some researchers have suggested that the design of learning environments adopt a ‘design science’ approach (Brown, 1992; Collins, 1991). Through the comprehensive evaluation of flexibly arranged learning facilities, we may find some more beneficial learning environments for students. In this study we propose a Web-based collaborative inquiry learning model and learning activities, with the aim to effectively integrate three popular classroom strategies: collaboration, inquiry, and concept mapping. The experimental results indicate that students do benefit from the arrangement of four-phase collaborative inquiry: anchoring and planning, individual inquiry, collaborative inquiry, and concluding group’s results. They also show positive attitudes toward such a learning model.

Though the initial results are encouraging, there remain some limitations worthy of consideration. First, previous studies indicated that concept mapping is not an easy task for students (Reader & Hammond, 1994; Chang, et al., 2001). In this study we also found that concept mapping may serve as a device for anchoring ideas and planning hypotheses, yet its difficulty of operation makes students reluctant to change their ideas represented in concept maps. So appropriate mechanisms for guiding and feedback may make this strategy more efficient.

Second, in the individual inquiry phase, learners enthusiastically explored the Web for evidence, and the Web pages they visited were related to the topic. However, they did not expend much effort organizing the results of their readings and expressing them in their notepads. Some mechanisms of reminding and pushing users to examine the consistency between their hypotheses and collected data may be useful for selecting and organizing appropriate material.

Third, in the concluding group's results phase, the voting mechanism can help members generate the group product. However, in the process of negotiation, communication, and consolidation, they often need to sacrifice their individual ideas to accommodate the students who have produced more complete products. Consensus is a comparatively rare situation. Since the group product is an important indicator of a group's achievement, which can serve as a valid motivator to foster group members' coherence (Slavin, 1996), so it is worthwhile to search for a better method of creating a group's product and preserving the uniqueness of each member's products. A more adaptive and optimized, for both students and teachers, collaborative inquiry learning model may be anticipated if future researchers focus on the above issues.

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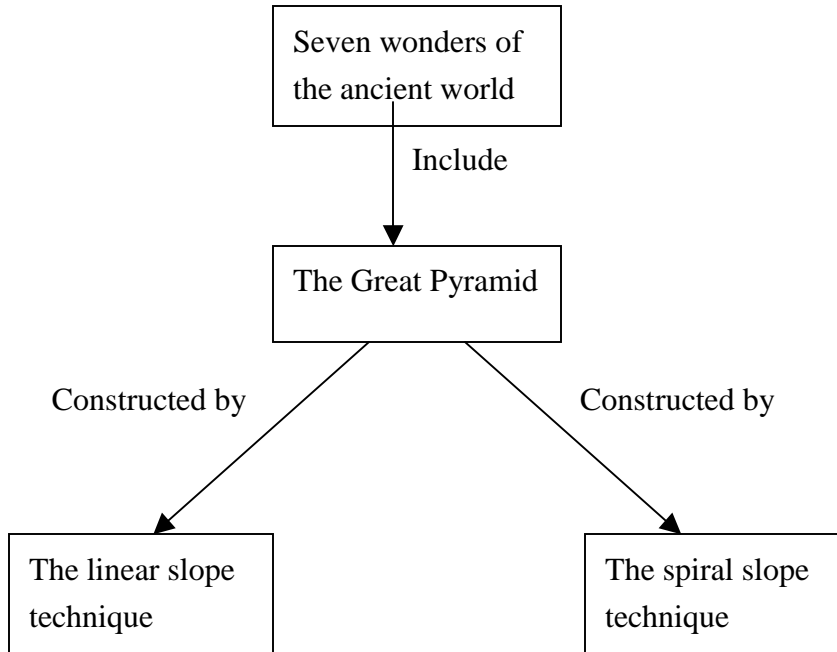


Figure 1: An example of a concept map

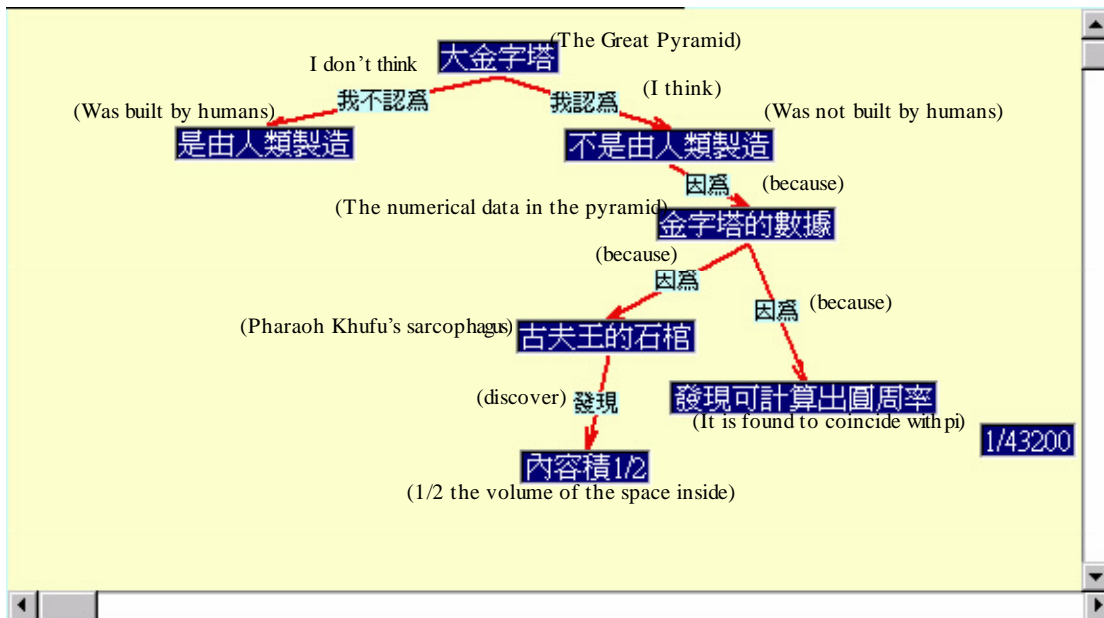


Figure 2: Concept map produced by student 4c in phase 1

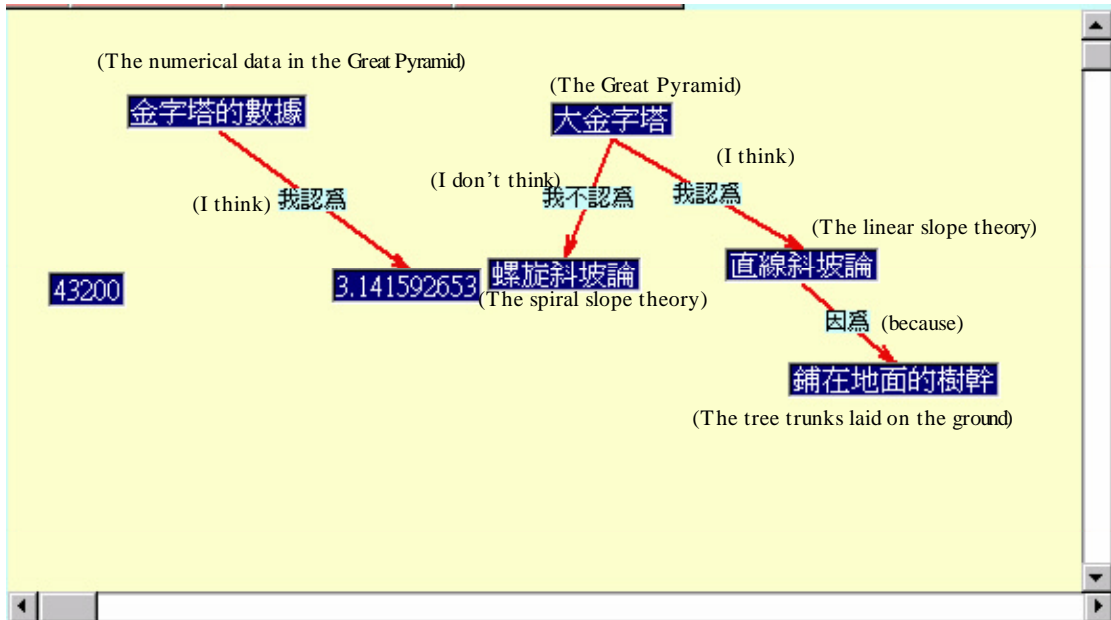


Figure 3: Concept map produced by student 6a in phase 1

<http://www.ntut.edu.tw/~s8370021/great.htm>
 consists of 203 levels of stone blocks
 total weight: 6 million tons
 2,300,000 stone blocks used in total
<http://www.tvbs.com.tw/code/tvbs-g/light-y-file/world-p/y20210w-4.asp>
 The height of the Pyramid of Pharaoh Khufu times 10 million (98 million miles) happens to be the distance between the Sun and the Earth. Furthermore, the meridian passing through the Pyramid divides the land and oceans into equal halves.

Figure 4: An example of notepad

[1b]: I think it was built by alien beings.

[1c]: I think it was built by humans.

[1b]: Why do you say that?

[1c]: I have no proof.

[1b]: Get out of here.

[1a]: There you go! It was built by the Sun God!

[1c]: There is no evidence of alien presence in the Great Pyramid.

[1b]: No evidence means impossible.

[1b]: You've been reading too much mythology.

[1a]: It was mentioned in my notepad!

Figure 5: An example of chat room discussion

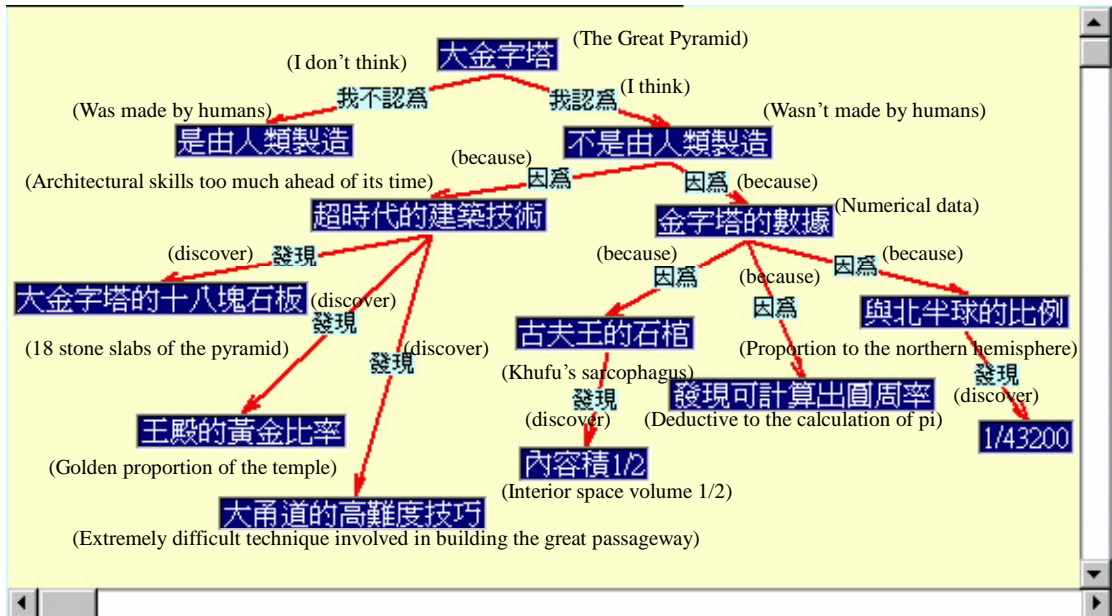


Figure 6: Concept map produced by student 4c in phase 3

Table 1. Learning activities, objectives, and results in collaborative inquiry learning.

| Stages | Learning activities | Learning objectives | Results |
|---------|---|--|---|
| Phase 1 | 1. Individual reading of the material 2. Forming hypothesis 3. Constructing individual concept maps | 1. Familiarizing with the topic 2. Forming hypothesis | 1. Individual concept maps |
| Phase 2 | 1. Looking for supportive evidence on the Web 2. Revising concept maps and editing notepads according to new evidence | 1. Exploring 2. Revising | 1. Revised individual concept maps 2. Individual notepads |
| Phase 3 | 1. Sharing notepads 2. Sharing concept maps 3. Discussion using chat room 4. Revising individual notepad and concept map | 1. Data sharing 2. Product sharing 3. Idea sharing 4. Explaining and revising conclusions | 1. Individual concept map 2. Individual notepad 3. Chat room dialogue |
| Phase 4 | 1. Data sharing in the group 2. Questioning, cooperation, negotiation, compromise 3. Voting to decide the group's core concept map 4. Revising the group concept map | 1. Knowledge communication 2. Knowledge negotiation 3. Knowledge consolidation | 1. Group concept map 2. Chat room dialogue |

Table 2. Experiment procedures

| Experiment procedure | Time (minutes) |
|-------------------------------------|----------------|
| System tutorial | 10' |
| Phase 1: anchoring and planning | 20' |
| Phase 2: individual inquiry | 20' |
| Phase 3: collaborative inquiry | 30' |
| Phase 4: concluding group's results | 10' |
| Survey with questionnaire | 10' |

Table 3. Number of Web pages visited by the students

| ID | Number of Web pages visited | Number of Web pages quoted in the notepad |
|----|-----------------------------|---|
| 1a | 36 | 3 |
| 1b | 27 | 2 |
| 1c | 30 | 3 |
| 2a | 19 | 2 |
| 2b | 17 | 3 |
| 2c | 30 | 2 |
| 3a | 24 | 5 |
| 3b | 29 | 3 |
| 3c | 17 | 1 |
| 4a | 17 | 4 |
| 4b | 21 | 0 |
| 4c | 18 | 1 |
| 5a | 21 | 0 |
| 5b | 30 | 3 |
| 5c | 35 | 1 |
| 6a | 17 | 1 |
| 6b | 37 | 0 |

Table 4. Initial hypotheses, final conclusion, and voting status

| Group | ID | Initial hypothesis | Final conclusion | Vote for |
|-------|-----|--------------------|------------------|----------|
| 1 | 1a | Agree | Disagree | 1b |
| | 1b* | Disagree | Disagree | 1b |
| | 1c | Agree | Agree | 1c |
| 2 | 2a | Disagree | Disagree | 2b |
| | 2b* | Agree | Agree | 2b |
| | 2c | Disagree | Disagree | 2b |
| 3 | 3a | Agree | Agree | 3b |
| | 3b* | Agree | Agree | 3c |
| | 3c | Agree | Agree | 3b |
| 4 | 4a | Agree | Agree | 4c |
| | 4b | Agree | Agree | 4c |
| | 4c* | Disagree | Disagree | 4c |
| 5 | 5a | Agree | Agree | 5b |
| | 5b* | Disagree | Disagree | 5b |
| | 5c | Disagree | Disagree | 5b |
| 6 | 6a | Agree | Agree | 6b |
| | 6b* | Agree | Agree | 6b |