Using the Internet to develop students' capacity for scientific inquiry

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USING THE INTERNET TO DEVELOP STUDENTS’ CAPACITY FOR SCIENTIFIC INQUIRY*

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ABSTRACT
In this study, an interactive process in a Web-based learning environment was planned for the cultivation of students’ cooperative learning skills and capacity for scientific inquiry. Based on detailed analyses of students’ computer protocols, interview protocols, and test scores, this project sought to analyze the changes in students’ scientific concepts and the development of their science process skills (SPS) after they had completed a series of Web-based lessons. Forty senior high school students were chosen and grouped into eight heterogeneous groups for online cooperative learning. As the data showed, the Web-based course used in this study can help students gain a better understanding of subject-related concepts and improve their science process skills. We also found that students with different SPS abilities had significantly different SPS improvement. Low-SPS students have made the most rapid progress in building their science process skills while the high-SPS students made the least progress after interacting with four Web-based lessons. It was also found that heterogeneous grouping in a cooperative learning environment increases the weak learners’ motivation and participation.

INTRODUCTION
The Internet provides fast and easy access to many areas of knowledge; the use of its numerous information-gathering tools can also develop students’ capacity for thinking, analyzing, and constructing knowledge (Riedling, 1999). One of the Internet’s powerful functions is the variety of channels which provide for social interaction. Through these channels, students can communicate with peers,

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teachers, specialists, scientists, and so on. The Internet supports students’ cooperative learning by providing an environment in which searching for information, analyzing data, and communicating ideas becomes easier than before (Blumenfeld, Marx, Soloway, & Krajcik, 1997). Through the cooperative process, students learn how to communicate and accept opinions different from their own (Johnson & Johnson, 1984, 1987). This, in turn, facilitates their deeper understanding of scientific concepts (Brooks & Brooks, 1993) because such social interaction helps them to understand and encourages them to criticize what others think when they try to construct their own cognitive structures. The process of communicating, reconstructing, and reconciling information leads to internalized long-term understanding (Kiesler & McGuire, 1987). Social learning theory emphasizes the value of dialogue and cooperation in helping students develop and articulate their understanding. In order to achieve effective cooperation, students need to share ideas and experiences; through discussion they can arrive at reasonable interpretations of the subjects they are studying (Blumenfeld et al., 1997). Therefore, the new computer technology can empower students to construct and reconstruct knowledge as a result of their interaction, which encourages them to be self-reflective in well-designed learning environments (Parker, 1999). Thus, online discussions can be designed to promote knowledge construction and the development of cognitive abilities.

The use of networking technology for cooperative learning has several advantages: a) it can promote the comprehension of learning materials through integrating students’ viewpoints; b) it can encourage the sharing of personal learning experiences and thoughts; c) it can help students to articulate both what they know and their developing intellectual interests, so that they learn to integrate pre-knowledge into new knowledge; and d) it can increase students’ participation in a group or team, and thus their sense of themselves as team members (Steeples, 1993; Watabe, 1995). Research to date shows how discussions help students to integrate the various possible perspectives or viewpoints on a particular topic (Clark & Slotta, 2000; Hoadley & Linn, 2000; Linn, 1995), how online cooperative learning environments promote students’ conceptual development (Fishman & D’Amico, 1994) and metacognition (Park, 1999), how students are encouraged to use new problem-solving strategies through cooperative learning (Gallupe, Bastianutti, & Cooper, 1991), and how their social skills are promoted in an online cooperative learning environment (Edelson, 2001; Hoadley & Linn, 2000; Krajcic, 2000). Hoadley and Linn (2000) analyzed students’ social interactions in “SpeakEasy,” a tool for online discussions in KIE (Knowledge Integration Environment), and found that asynchronous communication in “SpeakEasy” promoted students’ comprehension and integration of the relevant scientific concepts through sharing their ideas and reflecting on their own thoughts. However, some students were weak in answering others’ questions and in integration knowledge because of their attitude, motivation, learning style, social skills, computing ability, or gender (Reyth-Marom, Chajut, Roccas, &
Sagiv, 2003). It appears to be difficult for Internet novice users to learn cooperatively and efficiently. In order to take full advantage of the cooperative learning environment made possible by the Internet, we provided some training programs in social and computing skills before investigating students’ online interactions and their effect on cognitive development.

Through online interactions, the networking technology makes students’ thinking “visible.” Also, the networking technology makes databases more accessible through querying functions, makes learning contexts more realistic through the use of multimedia and animations, and makes information more varied through the use of information banks. Research on students’ engagement in scientific argumentation, data analysis, and theory/hypothesis testing has been emphasized (Kuhn, 1993; Linn, 1995), as has the role of computers and the Internet in teaching about these learning abilities (Cavalli-Sforza, Weiner, & Lesgold, 1994; Linn, 1995; Ranney & Schank, 1995). When students are engaged in learning activities that require them to find identical explanations by consulting a variety of sources of scientific information on the Web, they need to learn how to do meaningful classification, inference, hypothesis testing, and so on. A Web-based learning environment can promote students’ science process skills by providing graphing and data-query tools for meaningful classification and inference, simulations and animations for constructing/testing hypotheses, and online forums for communication/social interactions. For the purposes of this study, a learning environment was designed which provided an online forum for the cultivation of cooperative learning; data queries and animations were also designed for the promotion of science process skills. The online forum in this study provided peer-to-peer discussions that enabled students to: a) learn together in a group (Johnson & Johnson, 1984); b) ask/answer questions and get answers; and c) support teammates in overcoming obstacles to their learning or impediments to the successful completion of research assignments. Therefore, in this project a series of Web-based lessons was developed to cultivate students’ conceptual development, science process skills, and cooperative learning skills. The research question in this study is: how are students’ concepts and science process skills promoted after completing a series of Web-based lessons?

METHODS

Both quantitative and qualitative methods in social and educational studies have some measure of validity (Gall, Borg, & Gall, 1996). Both approaches have helped educational researchers to make important discoveries. In this study, the author used multiple methods, including quantitative and qualitative ones, for the collection of data. The purpose of this integrated research approach was to compensate for the shortcomings of one methodology with the strengths of another (Kafai, 1995; Mischler, 1990). Thus, for gathering data, a range of observation and assessment instruments was used: paper-and-pencil tests,
computer protocols, informal classroom observation, and semi-interviews. An experimental method combined with semi-structured interviews was used to investigate the effects of students’ online cooperative learning at the senior high school level.

Subjects

The subjects in this study were 40 first-year senior high school students from an intact class in the northeast region of Taiwan. There were 23 females and 17 males, grouped into eight heterogeneous groups for cooperative learning. To minimize effects due to gender, there was a nearly equal number of males and females in each group. The scores on the Senior High School Entrance Examination in both mathematics and science and a pretest on students’ knowledge of concepts regarding the tides were used as standards for the grouping of students. After grouping, the Entrance Examination and pretest scores for each group were tested with ANOVA ($F = 0.318, p > 0.05$). This showed that there was no significant difference among the eight groups with respect to prior knowledge.

Research Instruments

The Web-Based Learning Environment

Three broadly cooperative methods, adaptable to most subjects and grade levels, are used in many research fields: Student Teams-Achievement Divisions (STAD), Teams-Games-Tournaments (TGT), and Jigsaw II (Slavin, 1996). STAD was used in this study to promote effective learning. With STAD, students need to help their teammates so that their team will succeed. The only way a team can be successful is if all its members master what they are learning. In this study, the Web-based learning environment was set up for asynchronously interactive learning using Student Teams-Achievement Divisions (STAD; Slavin, 1996).

Four lessons related to the Earth Science curriculum—a lesson on earthquakes, one on cold fronts, one on astronomy, and one on tides—were developed in order to cultivate students’ science process and cooperative learning skills. For instance, the lesson on tides used daily life questions, real data, and animations to prompt students’ scientific inquiry (see Figure 1) and promote their conceptual development regarding the formation of tides, the tide cycle, and the impact of tides on daily life. In this lesson, students needed to apply their science process skills: communicating, interpreting data, formulating hypotheses, and predicting outcomes in order to solve problems. The lesson on tides had three sections. In the “Data Query” section, students could search for data on the sea level in order to find the tide pattern (see Figure 2). In the “Constructing/Testing of Hypotheses” section, students could choose an appropriate model to explain the data observed
Figure 1. Science process skills designed in lesson Tides.
in the previous section. Four possible models were shown to students in verbal and animated forms. The tide data according to each model were dynamically generated with time, so that students could compare the generated and observed data; this could help them test their hypotheses about the formation of tides (see Figure 3). In the “Problem-Solving” section, a real situation related to tides was provided. Students playing the role of a chief of the water resource institution needed to decide when to enable flood discharge under both typhoon attack and rip-tide conditions. Real data related to the path of a typhoon, rainfall, the water level in a reservoir, the sea level at the outlet of a river, and the drainage area was provided to students so that they could solve this problem (see Figure 4). All the learning activities in these four lessons were on the Web, and students’ learning processes were tracked using network technology. Especially for the lesson on tides, the records of student learning paths and communication protocols were used to make clear how students sought and shared information in their problem-solving processes.

**Instruments of Data Collection**

Student data was collected in the following ways:

1. Cognition-Related Tests: a) The concept test. A 13-item multiple-choice test was designed to test students’ concepts on key topics including the formation of tides, the tide cycle, and the impact of tides on daily life. This test was validated by a university faculty member and two high school teachers; its Cronbach $\alpha$ was 0.61. According to Hatcher’s and Stepanski’s claim (1994), a Cronbach alpha coefficient even as low as 0.55 can be accepted for social science studies, so that the low Cronbach alpha coefficient for the concept test was acceptable. Examples of the test items are shown in Appendix A. b) The test of science process skills. According to the definition of the Science—A Process Approach (SAPA), science process skills (SPS) are a set of broadly transferable skills that are routinely used by practicing scientists in many disciplines (Padilla, 1990). Cognitive scientists
call science process skills procedural knowledge (“knowing how”) (Glynn & Duit, 1995). Gagné (1965) classified science process skills into basic and integrated skills. The basic skills are observation metric measurement, classification, communication, prediction, and inference; the integrated skills are identifying variables, constructing a table of data, constructing a graph, describing relationships between variables, acquiring and processing data, analyzing investigations, constructing hypotheses, defining variables operationally, designing investigations, and experimenting. Three of the science process skills—communication—describing relationships between variables, and constructing hypotheses, were designed into the Web-based lessons in this study. The test of science process skills, including 43 multiple-choice items, was developed by Mao (1994) and used to measure students’ science process skills in communicating data (using different

Figure 3. The animation of model IV in the “constructing/testing of hypothesis” session.
Figure 4. The situation designed in "problem-solving" session.
representations to describe the data), interpreting data (describing relationships between variables), and constructing/testing hypotheses (observing data—constructing hypotheses/models according data—testing hypotheses or reasoning using the self-generating hypotheses/models); its Cronbach \( \alpha \) was 0.73. Examples of the test items are shown in Appendix B.

2. Informal classroom observations. The research team visited the school six times to meet the teacher and the students, and to inspect the classroom and the computer labs. During observation, videotapes were made which were later used for checking the data collection procedure.

3. Two feedback questionnaires. Two feedback questionnaires were administered to the pupils at the end of the study project. One questionnaire surveyed their attitudes toward the learning materials and the project; it included 25 items and its Cronbach \( \alpha \) was 0.91 in tests of reliability. Another was used to investigate students’ perspectives on cooperative learning; it included 20 items concerned with group identification and individual perspectives on the process of online interaction; its Cronbach \( \alpha \) was 0.91.

4. In-depth interviews. These were conducted with 15 students in three focus groups which represented high, medium, and low interactions on the Web, according to the analysis of the computer protocols. These interviews took place at school, were semi-structured, and included questions about students’ perspectives on Web-based instruction, the online forum, the Web-based contents, and interface designs.

Research Procedure

The experimental design was the major methodological element in this study. As can be seen from Figure 5, the research procedures were divided into three parts: pretests, treatments, and posttests. Through these procedures, quantitative and qualitative data were collected. In the pretests and posttests, students’ scientific concepts, science process skills, and attitudes toward computers were investigated. Additionally, interviews were conducted after the posttests to ascertain students’ perspectives on cooperative learning. The treatments included four Web-based lessons. The first two lessons (Earthquakes and Cold Fronts) in the first experiment were designed to promote face-to-face communication in groups: each group had one computer with which to browse online learning materials and submit the group members’ thoughts through the Internet. There were eight computers in the classroom for student use during the experimental period. These two lessons were used for training in cooperative learning skills in order to take full advantage of the cooperative learning environment made possible by the Internet.

After the training of cooperative learning, students were expected to use the other two lessons (Astronomy and Tides) for the second treatment (online
Figure 5. Overview of research procedures.
cooperative learning) in the computer lab. The administrative recording and control system assured that the students would be placed in different groups. When a student logged onto the Web-based lesson, the server recognized that he/she belonged to a specific group and the students in the same group discussed their questions as an online discussion group. Most of the data were collected through the Internet. The types of collected data are shown in Table 1.

Data Analysis

The data were analyzed in several ways. In order to find out if there was a significant difference between the before- and after-treatment stages, the paired t-test for normally-distributed data or Wilcoxon signed ranks test for abnormally-distributed data was used to compare the pretest and posttest scores on concepts and science process skills. For further analysis, students were grouped into three groups: low-SPS (the lowest 33% of students in terms of SPS pretest scores), high-SPS (the highest 33% of students in terms of SPS pretest scores), and medium-SPS (the others). The repeated ANOVA was used to analyze these three groups of students’ SPS progress before and after the experiment.

Qualitative data were coded and summarized. Interview data were used to show the students’ perspectives on using Web-based lessons; their answers to online questions clearly reveal their process of hypothesis-formation and their computer protocols make clear the nature and extent of their online interactions. Descriptive statistics were used to analyze dialogue records in an online forum—in order to make clear, for instance, the frequency with which ideas or questions were posted in/to the forum, and the rate at which relevant ideas were learned.

RESULTS

The Development of Concepts and Science Process Skills

It was hypothesized that there would be a significant difference between student pre- and post-treatment concept tests. For the online cooperative learning, using a lesson on tides, the mean for the pretest was 9.30 with a standard deviation of 1.90; the mean for the posttest was 10.38 with a standard deviation of 1.81. The Wilcoxon signed rank test showed that there was a significant difference between student pre- and posttests on tide concepts ($Z = -3.24, p < .05$). This meant that the online cooperative learning environment facilitated Earth Science-related knowledge construction.

Students were expected to demonstrate improved science process skills after using these Web-based lessons. The data showed that students had significantly higher scores on the posttest ($M = 37.95$) for SPS than on the pretest ($M = 27.46, Z = -4.92, p < .05$). For further analysis, students were grouped into three groups: low-SPS (the lowest 33% on the SPS pretest), high-SPS (the highest 33% on
<table>
<thead>
<tr>
<th>Research instruments</th>
<th>Time and place</th>
<th>Learning processes</th>
<th>Data collection</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Online Pretests</strong></td>
<td>Before the experiment in the computer lab</td>
<td>Students completed online tests.</td>
<td>Scores on online tests</td>
</tr>
<tr>
<td>(Pretest on tide concepts, SPS test, and computer attitude questionnaire)</td>
<td></td>
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</table>
| **Lesson on Earthquakes**   | Two hour class in the classroom with 8 computers | 1. 1st hour: The teacher led the students to view the introduction of the lesson using a computer and Trinitron.  
2. 2nd hour: Students were divided into 8 groups. Each group interacted with the earthquake lesson based on inquiry learning, and submitted the answers through the Internet.  
3. Homework: After a week, each group was required to upload an electronic report through the Internet. | Answers to online questions |
| **Lesson on Cold Fronts** | Two hour class in the classroom with 8 computers | 1. 1st hour: The teacher led students to view the introduction of the lesson using a computer and Trinitron.  
2. 2nd hour: Students were grouped into 8 groups. Each group interacted with the cold-front lesson based on problem-based learning and submitted the answers through the Internet. | Pretest and posttest scores, computer protocols, and answers to online questions |
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<tbody>
<tr>
<td><strong>Lesson on Astronomy</strong> (Web-based lesson)</td>
<td>Two hour class in the computer lab</td>
<td>Students used computers individually and communicated with their groupmates through the Internet (online cooperative learning).</td>
<td>Computer protocols and answers to online questions</td>
</tr>
<tr>
<td><strong>Lesson on Tides</strong> (Web-based lesson)</td>
<td>Two hour class in the computer lab</td>
<td>Students used computers individually and communicated with their groupmates through the Internet (online cooperative learning).</td>
<td>Computer protocols and answers to online questions</td>
</tr>
<tr>
<td><strong>Online Posttests</strong> (Posttest on tide concepts, SPS posttest, computer attitude questionnaire, and feedback questionnaires) and Interviews</td>
<td>After the experiment in the computer lab</td>
<td>After the posttests, 15 students in 3 groups were selected for interviews (10 minutes per student).</td>
<td>Scores on posttests and Interview data</td>
</tr>
</tbody>
</table>
the SPS pretest), and medium-SPS (the others). From analysis via repeated ANOVA it was seen that the scores of all three groups on the SPS posttest were significantly higher than on the SPS pretest ($F = 133.57, p < .05$). From post hoc, we also found that students with different SPS abilities had significant differences in their SPS progress ($F = 25.85, p < .05$) (see Tables 2 and 3). As the post plot shows (see Figure 6), low-SPS students made much greater progress than medium-SPS and high-SPS students. After interacting with the four Web-based lessons, low-SPS students made the most progress on their science process skills and high-SPS students made the least progress on their science process skills.

The comparative results revealed that students made significant progress in all three science process skills—communicating, interpreting data, and constructing/testing hypotheses (see Table 4). The computer protocols (two students’ data were missing) showed that the selection proportions in four explanation models for the causes of tides (see Figure 7) were: 35 students (92%) chose model IV (Earth’s Rotation + Moon’s Gravitation + Earth’s Gravitation) and three (7.8%) chose model III (Moon’s Gravitation + Earth’s Rotation). The data showed that most students chose the model with the total effects of the earth’s rotation, moon gravitation, and earth’s gravitation to explain the tides. However, the computer records also revealed that only 10 students (26%) could use one or two facts found in the observed data to test their selected models and give reasons why the model could explain the formation of tides. The other students did not provide sufficient evidence to prove their ability in testing a hypothesis.

### Table 2. Descriptive Statistics on Pretest and Posttest for Science Process Skills

<table>
<thead>
<tr>
<th></th>
<th>Pretest</th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>No.</td>
<td>Mean</td>
<td>SD</td>
<td>Mean</td>
</tr>
<tr>
<td>Low SPS</td>
<td>13</td>
<td>21.77</td>
<td>1.74</td>
<td>29.23</td>
</tr>
<tr>
<td>Medium SPS</td>
<td>14</td>
<td>27.69</td>
<td>1.44</td>
<td>32.85</td>
</tr>
<tr>
<td>High SPS</td>
<td>13</td>
<td>32.92</td>
<td>1.89</td>
<td>33.69</td>
</tr>
</tbody>
</table>

### Table 3. Repeated ANOVA for Performance on Science Process Skills

<table>
<thead>
<tr>
<th></th>
<th>df</th>
<th>MS</th>
<th>$F$</th>
<th>$p$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Main effects</td>
<td>1</td>
<td>388.15</td>
<td>133.57*</td>
<td>.000</td>
</tr>
<tr>
<td>Interaction</td>
<td>2</td>
<td>75.12</td>
<td>25.85*</td>
<td>.000</td>
</tr>
</tbody>
</table>
Online Communication

The topics in the online forum were classified into six categories: science process skills, instructional materials, Web functionality, equipment problems, affection, and irrelevant topics (see Table 5). The degree of interpersonal reliability was shown to be 0.85 (Pearson $r = 0.85$, $p < 0.01$) after statistical analysis of the results of two classifiers. From the frequency analysis, it was shown that students posted mostly on topics related to science process skills (see Table 5); topics related to equipment problems were posted least. If the sum of the number of topics related to science process skills and instructional materials represented learning-related interactions, the proportion of learning-related interaction was 54.9%. Thus, about half of all posted topics were related to learning interactions. In addition, the correlation coefficient between number of individual posts concerned with science process skills and individual scores on a feedback questionnaire about perspectives on cooperative learning was 0.46 (Pearson $r = 0.46$, $p < 0.05$). That is, the more positive a student’s perspective on cooperative learning, the more that student tended to participate in the online forum.
Table 4. Wilcoxon Signed Ranks Test in Communicating, Interpreting Data, and Constructing/Testing Hypotheses

<table>
<thead>
<tr>
<th></th>
<th>Pretest</th>
<th>Posttest</th>
<th>Wilcoxon Signed Ranks Test</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Mean</td>
<td>SD</td>
<td>Mean</td>
</tr>
<tr>
<td>Communicating</td>
<td>66.67</td>
<td>27.10</td>
<td>82.05</td>
</tr>
<tr>
<td>Interpreting data</td>
<td>59.74</td>
<td>11.85</td>
<td>68.97</td>
</tr>
<tr>
<td>Constructing/testing</td>
<td>76.35</td>
<td>7.69</td>
<td>88.31</td>
</tr>
</tbody>
</table>

* *p < 0.015

Figure 7. Models for the causes of tides.
The description statistics regarding the feedback questionnaire showed that 43.5% of all students were satisfied with the texts, 45.6% were satisfied with the design of the images, 46.1% were satisfied with the contents, 53.1% were satisfied with the online learning environment, and 66.8% of the students were satisfied with the online forum. The data gained from interviewing the three student groups (15 students) showed that most students thought the Web-based courses were more interesting than the textbooks because of the animations and interactions. The online discussions made students feel more involved in the learning activities. Few students (only two) did not feel comfortable when participating in the online discussions because of their low Chinese typing speeds.

Table 5. Frequency Analysis of Online Interaction Contents

<table>
<thead>
<tr>
<th>Catalog</th>
<th>Examples of protocols</th>
<th>Frequency</th>
<th>Mean (per person)</th>
</tr>
</thead>
<tbody>
<tr>
<td>I. Related to Science Process Skills</td>
<td>3s: What is the average sea level difference? 3m: Find the sea level difference for each time period, take the sum, and calculate the average.</td>
<td>114</td>
<td>2.85</td>
</tr>
<tr>
<td>II. Related to Learning Materials</td>
<td>4a: Which question are you working on?</td>
<td>78</td>
<td>1.95</td>
</tr>
<tr>
<td>III. Related to Equipment Problems</td>
<td>3l: My computer does not work.</td>
<td>9</td>
<td>0.23</td>
</tr>
<tr>
<td>IV. Related to Web Functioning</td>
<td>6t: If you open a new IE browser for the online forum, you do not need to use the “back” button to find the learning materials.</td>
<td>24</td>
<td>0.6</td>
</tr>
<tr>
<td>V. Related to Affective Issues</td>
<td>8s: Hurry to join the online discussion!</td>
<td>45</td>
<td>1.13</td>
</tr>
<tr>
<td>VI. Unrelated Topics</td>
<td>2m: Today is very cold!</td>
<td>83</td>
<td>2.07</td>
</tr>
</tbody>
</table>

**Perspectives on Web-Based Lessons**

*Students’ Opinions*

The description statistics regarding the feedback questionnaire showed that 43.5% of all students were satisfied with the texts, 45.6% were satisfied with the design of the images, 46.1% were satisfied with the contents, 53.1% were satisfied with the online learning environment, and 66.8% of the students were satisfied with the online forum. The data gained from interviewing the three student groups (15 students) showed that most students thought the Web-based courses were more interesting than the textbooks because of the animations and interactions. The online discussions made students feel more involved in the learning activities. Few students (only two) did not feel comfortable when participating in the online discussions because of their low Chinese typing speeds.
The teacher interviewed students informally and collected their opinions about Web-based learning. Some students reported that the Web-based course promoted their motivation to learn earth sciences by providing multiple-representation learning activities. However, the computer cannot replace the teacher’s role in helping students to overcome their learning weaknesses. It was suggested by the students that Web-based lessons must provide an opportunity for teacher-student communication so that the teacher can help them solve problems.

**Teacher’s Opinion**

The teacher was interviewed informally. She said that the computer displays could help students to understand abstract concepts through animations and simulations, but that it was time-consuming to design such computer-based lessons and to maintain the computers in good condition. The teacher also said the cooperative learning environment provided by this study could excite creativity through brainstorming among teammates. However, students’ computer skills would influence their progress. If some students needed more time, the teacher could not achieve the planned rate of progress.

**DISCUSSIONS AND CONCLUSIONS**

The results showed that the online cooperative learning environments facilitated Earth Science-related knowledge construction and the cultivation of science process skills in communicating, interpreting data (describing relationships between variables), and testing hypotheses. However, the recorded protocols showed that most students (about 74%) could not say why they chose a specific model to test and could not make any comparison between the observed data and the data generated from the chosen model. The in-depth interviews indicated that about 66.7% of all interviewed students did not know how to test whether or not their selected model matched the observed data. The process of hypothesis-testing designed for the lesson on tides, a one-shot activity, needs to be modified into a step-by-step instructional process because testing hypotheses is a higher-level skill and not easy to learn (Gagné, 1965). Hypothesis formation and testing is one of the high-level skills, and teaching it requires time and effective teaching strategies (Padilla, Okey, & Garrard, 1984). Therefore, further study will be needed in order to find the best instructional strategies and design a series of lessons which can cultivate students’ high-level skills in scientific inquiry.

Students responded positively to the online cooperative learning and Web-based lessons. In order to examine the effects of cooperative learning, this study designed a cooperative learning environment using network techniques to enrich


students’ science process and communication skills. The value of heterogeneous grouping for cooperative learning is that students can help each other reconstruct their knowledge and promote their abilities. The “networking” technique was more specifically used in this study to provide a cooperative learning environment that could help “low cognitive” students overcome the barriers to their task comprehension and completion, general understanding of science and science process skills, and communication skills. In such an environment, high-cognitive students can help low-cognitive students work on learning tasks. As shown by the data, the Web-based course used in this study can help students gain a better understanding of concepts related to the subject matter, and of the scientific inquiry process. From the data, we found that students with different SPS abilities had significant differences in their SPS progress. Low-SPS students made the most progress on their science process skills, and high-SPS students made the least progress on their science process skills after interacting with four Web-based lessons. High-SPS students did not make much progress, probably due to the ceiling effect—there was not much room for them to progress further. On the other hand, low-SPS students can benefit greatly from cooperative learning because they can learn from others. Many research studies have also found that heterogeneous grouping benefits low-cognitive students more than high-cognitive students (Hooper & Hannafin, 1991; Johnson & Waxman, 1985; Van Oudenhoven, Van Berkum, & Swen-Koopmans, 1987). Through cooperative interaction, then, “high cognitive” students elaborated the concepts when they explained their ideas to low-cognitive students, and low-cognitive students “reconstructed” their knowledge after receiving new information and ideas from high-cognitive students (Hooper, 1992). In summary, heterogeneous grouping increases weak learners’ motivation and their participation in a cooperative learning environment.

The remarkable contributions of this study are: 1) developing a series of Web-based lessons to facilitate students’ cooperative learning, conceptual knowledge, science process skills, and motivation to learning Earth Science; and, 2) through the techniques of networking and heterogeneous grouping, helping low-ability students overcome their barriers in conceptual comprehension and cognitive skills. Future research can address ways to promote students’ higher-level SPS skills such as constructing/testing hypothesis and modeling through the collection of students’ thinking-aloud data and in-depth interviews.

ACKNOWLEDGMENTS

The author is grateful for the assistance of Huey-Jean Wu and the students at National Luodong Senior High School, Taiwan, Republic of China.
APPENDIX A
Examples of the Concept Test Items

Item 5: Which following description about tide is wrong? (A) Topography would affect tides in some way. (B) The Moon’s gravity is the major force to evoke tides. (C) There are four times of high water per day. (D) The time of high water changes every day in a month.

Item 6: If the time of Typhoon attack is close to the time of high water, it will cause a serious flood in an outlet of a river. Which date is the most possible in such situation? (A) Lunar fourth (B) Lunar seventh (C) Lunar fifteenth (D) Lunar twentieth.

Item 7: Following item 6, what is the most possible position of Moon, Earth, and Sun under such situation?
APPENDIX B
Examples of Items in the SPS Test

<table>
<thead>
<tr>
<th>SPS Skills</th>
<th>The number of items</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Communicating data</td>
<td>4 (e.g.: item 16)</td>
</tr>
<tr>
<td>2. Interpreting data</td>
<td>27 (e.g.: item 19)</td>
</tr>
<tr>
<td>3. Conducting/testing hypotheses</td>
<td></td>
</tr>
<tr>
<td>3.1 Observing data</td>
<td>3 (e.g.: item 1)</td>
</tr>
<tr>
<td>3.2 Constructing hypotheses or models</td>
<td>5 (e.g.: item 2, 3)</td>
</tr>
<tr>
<td>3.3 Testing hypotheses or reasoning</td>
<td>4 (e.g.: item 4)</td>
</tr>
<tr>
<td>using the self-generating hypotheses or</td>
<td></td>
</tr>
<tr>
<td>models</td>
<td></td>
</tr>
</tbody>
</table>

(A) Communicating data

Item 16: Which figure can present the data in the table below?

Table: The water temperature vs. the frequency of a frog’s heartbeat rate

<table>
<thead>
<tr>
<th>Water temperature (°C)</th>
<th>5</th>
<th>15</th>
<th>25</th>
<th>35</th>
</tr>
</thead>
<tbody>
<tr>
<td>Heartbeat rate (times/minute)</td>
<td>22</td>
<td>86</td>
<td>192</td>
<td>314</td>
</tr>
</tbody>
</table>

(A)  
(B)  
(C)  
(D)
(B) Interpreting data

Item 19: Which description is correct according to the figure below?
(A) Boys are as tall as girls at age 13
(B) Boys are the highest at age 14
(C) Boys are shorter than girls at age 13 but boys are taller than girls at age 14
(D) Girls grow faster than boys in their early childhood.

(C) Conducting/testing hypotheses

Item 1-4 using the same data below

<table>
<thead>
<tr>
<th></th>
<th>Sunrise</th>
<th>Noon</th>
<th>Sunset</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Time</td>
<td>Position</td>
<td>Position</td>
</tr>
<tr>
<td>Spring Equinox</td>
<td>5:57</td>
<td>East</td>
<td>Elevation is South from Zenith</td>
</tr>
<tr>
<td>(3/21)</td>
<td></td>
<td></td>
<td>66.5°</td>
</tr>
<tr>
<td>Summer Solstice</td>
<td>5:05</td>
<td>East by north</td>
<td>Elevation is 90° from Zenith</td>
</tr>
<tr>
<td>(6/22)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Autumnal Equinox</td>
<td>5:42</td>
<td>East</td>
<td>Elevation is South from Zenith</td>
</tr>
<tr>
<td>(9/21)</td>
<td></td>
<td></td>
<td>66.5°</td>
</tr>
<tr>
<td>Winter Solstice</td>
<td>6:35</td>
<td>East by south</td>
<td>Elevation is south 43° from Zenith</td>
</tr>
<tr>
<td>(12/22)</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Item 1: From the data, which date has the longest length of time from sunrise to sunset? (A) Spring Equinox (B) Summer Solstice (C) Autumnal Equinox (D) Winter Solstice

Item 2: Jia-Yi locates at Tropic of Cancer. Which evidence can proof that sunlight strikes directly Jia-Yi at summer solstice?
(A) Sun rises at east by north in the early morning
(B) Sun’s angle of elevation is 90° at noon
(C) Sun sets at west by north in the evening
(D) The length of time from sunrise to sunset is the longest during a year
Item 3: Following Item 2, which method can be used to prove sunlight strikes directly Jia-Yi?
(A) Observed the shadow of a pole and see if there is no shadow in Jia-Yi at noon on summer solstice.
(B) Measure the temperature and see if it is the highest on summer solstice during a year.
(C) Measure the length of time from sunrise to sunset and see if it is the longest during a year.
(D) Observe the position of sunrise and see if it is east by north.

Item 4: According to the data shown in the above table, which model is suitable to explain the Earth’s revolution?

REFERENCE


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