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Using Computers to Individually-generate vs. Collaboratively-generate Concept Maps

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ABSTRACT
Five eighth grade science classes of students in at a middle school were assigned to three treatment groups: those who individually concept mapped, those who collaboratively concept mapped, and those who independently used their study time. The findings revealed that individually generating concept maps on computers during study time positively influenced science concept learning above and beyond independent use of study time, but that collaboratively generating concept maps did not. Students in both individual and collaborative concept mapping groups had positive attitudes toward concept mapping using Inspiration software. However, students in the collaborative concept mapping group did not like working in a group. This study contributes to the limited body of knowledge concerning the comparative effectiveness of individually and collaboratively-generating concept maps on computers for learning.

Keywords
Collaborative learning, Computer-based learning, Concept mapping, Meaningful learning, Science learning

Introduction

Within a constructivist framework, learning takes place as learners progressively differentiate concepts into more complex understandings and also reconcile abstract understanding with concepts acquired from experience. New knowledge is constructed when learners establish connections among knowledge learned, previous experiences, and the context in which they find themselves (Bransford, 2000; Daley, 2002; Jonassen, 1994). Chang, Sung, and Chen (2001) propose that concept mapping, a form of visualization, is a powerful learning strategy consistent with constructivist learning theory in that it is a study strategy that helps learners visualize interrelationships among concepts (Duffy, Lowyer, & Jonassen, 1991).

Scientists agree with educators that visualization facilitates thought. J. H. Clark states that, “Visualization has been the cornerstone of scientific progress throughout history. Much of modern physics is the result of the superior abstract visualization abilities of a few brilliant men. …Virtually all comprehension in science, technology and even art calls on our ability to visualize. In fact, the ability to visualize is almost synonymous with understanding. We have all used the expression ‘I see’ to mean ‘I understand.’” (as cited in Earnshaw & Wiseman, 1992, p. v). The authors propose that because visualization is a factor in scientific understanding, visualization of concepts should be a focus of science curriculum.

That concept mapping facilitates learning has been demonstrated in bodies of research on visual aids and visualization processes. Research on visual displays or visual representations as adjunct aids to text has demonstrated that they facilitate both recall and comprehension (Gobert & Clement, 1999; Mayer, 1989; Mayer & Gallini, 1990). Conceptual understanding can also be facilitated by requiring students to build meaningful and appropriate mental representations and concrete, visual representations of concepts being taught (Gobert & Clement, 1999, p. 40). While visually representing concepts, learners construct knowledge rather than absorb others’ representations of knowledge. Making visual representations is a natural cognitive activity which facilitates active synthesis of concepts and phenomena (Ajose, 1999).

Concept Mapping

Concept mapping by students is a common visualization method assigned by instructors in elementary and secondary schools as well as adult learning environments to provide students with access to their own visual representations of knowledge structures (Gaines & Shaw, 1995). According to Novak (1998), concept mapping is a process of organizing and representing concepts and their relationships in visual form. Concept mapping is one tool that can overtly engage students in meaningful learning processes. Further, concept mapping promotes meaningful learning and retention of knowledge for long periods of time and helps students negotiate meaning (Hyerle, 2000; Novak, 1990). Concept mapping is a schematic device for representing interrelationships among a set of concept meanings embedded in a framework of propositions and two-dimensional, hierarchical, node-link diagrams that represent verbal, conceptual, or declarative knowledge in visual or graphic forms (Quinn, Mintzes, & Laws, 2003).

The effectiveness of concept mapping for learning has been tested in several contexts across many content areas. For instance, using a Biology Achievement Test and the *Zucherman Affect Adjective Checklist* as measures, Jegede, Alaiyemola, and Okebukola (1990) found that concept mapping raised mean scores on achievement in biology (p =.00) and decreased male students' anxiety levels (p= .01) in fifty-one tenth grade students. In 1990 Novak, the originator of the term "concept maps," reviewed investigations of the effect and impact of concept mapping. Such a summary revealed that the process promotes novel problem solving abilities and increases students' positive attitudes toward the content being studied.

In a meta-analysis of 18 concept mapping studies, Horton, MacConney, Gallo, Woods, Senn, and Hamelin, (1993) concluded that concept mapping on paper has positive effects on both knowledge attainment and attitudes for students at the elementary level, middle school level, high school level, and the college level. Concept mapping raised individual student achievement in the average study by .46 standard deviations (from the 50th to the 68th percentile). Concept mapping also improved student attitudes toward content being studied.

Concept mapping is quickly learned and easily understood by students; the minimum use of text makes it easy to scan for a word, phrase, or general idea; and visual representation allows for development of a holistic understanding that words alone cannot convey (Plotnick, 1997). Also, concept mapping provides a useful organizational cue for retrieving information and concepts from memory by providing a representation of interrelationships among that information and those concepts. In teaching, concept maps can be assessed as representations of declarative and procedural knowledge in the science classroom (Rice, Ryan, & Samson, 1998; Ruiz-Primo & Shavelson, 1996).

In a controlled study by Cifuentes and Hsieh (2003a, 2003b), college students who (a) visualized interrelationships among science concepts, (b) mapped relationships between new concepts learned and prior learning, and (c) created connections both visually and verbally in their hand written study notes performed significantly higher on a test than those students who did not show such interrelationships, relationships, and connections in their study notes (p=.02). The researchers concluded that visualization is effective as a metacognitive strategy for college level students. Due to the theoretical propositions and evidence reported above, theorists and researchers agree that students should be encouraged to generate concept maps during study time.

Computer-supported Visual Learning

Incorporating visual thinking tools into the teaching and learning process opens up new avenues for constructivist learning (Anderson-Inman, 1996). Concept mapping can be directly and easily supported by personal computers and computer software (Anderson-Inman & Ditson, 1999; Anderson-Inman & Zeitz, 1993; Fischer, 1990; Royer & Royer, 2004). The use of computer-based visualization tools such as Inspiration™ and Visio™ enable learners to interrelate the ideas that they are studying in multidimensional networks of concepts, and to label and describe the relationships between those concepts (Jonassen, Carr, & Yueh, 1998; Jonassen, 2000). Anderson-Inman (1996) indicated that computer-based visualization makes the learning process more accessible to students, and it alleviates the frustration felt by students when constructing and revising concept maps using paper and pencil.

Cifuentes and Hsieh (2004) explored the comparative effects of computer-based and paper-based visualization as study strategies for middle-schoolers' science concept learning. In their quasi-experimental study, although visualization on paper improved test scores for middle schoolers, scores on a test did not improve as a result of computer-based visualization during study. Qualitative findings indicated that students were quite unskilled at visualization and required training in both basic computer skills and computer-based visualization to successfully apply a computer-based visualization strategy. Students in that study also required more training in development of computer graphics to be effective visualizers on computers.

Because of the finding that students require training in computer-based visualization, Hsieh and Cifuentes (2006) developed a seven-and-a-half hour visualization and computer skills workshop for preparing students to represent interrelationships among science concepts. In their controlled study, eighth grade students who used computer visualization as a study strategy outscored students who constructed visualizations on paper and those who did not construct visualizations at all during study time (p=.00). Hsieh and Cifuentes concluded that, given training in computer visualization, middle school students can generate visual representations that show interrelationships among concepts to both build and demonstrate their understanding. These findings provided evidence of the effectiveness of student-generated visualization using computers for the improvement of concept understanding.

Royer and Royer (2004) also investigated the difference between hand drawn and computer generated concept mapping using Inspiration™ software on desktop computers with 9th and 10th grade biology classes. The group using the computer created more complex maps than the group that used paper and pencil. Also, students preferred using Inspiration™ to paper and pencil for concept mapping. Royer and Royer theorize that "computers enabled students to communicate more clearly, to add and revise concept maps more easily, and to discover relationships between sub-concepts more readily." (p. 79)

Collaboratively-generating Concept Maps

According to Fischer, Bruhn, Grasel, and Mandl, (2002) collaborative processes can support learners' scientific knowledge construction more effectively than independent processes. Lumpe and Staver (1995) demonstrated that collaboratively creating propositions using paper and pencil in small groups can have positive effects on student achievement. They compared collaborative conceptualizing of photosynthesis with individual conceptualizing of photosynthesis and found that high school students who collaborated out-performed those who worked independently on a comprehension test (p=.00).

A visual representation technique such as concept mapping can be integrated into collaborative learning activities (Chiu, Wu, & Huang, 2000). During the process of collaboratively developing visualizations, the role of the student can evolve from being a passive learner to becoming an active, social learner. Students' perceptions and representations of those perceptions are challenged during collaboration, and learning builds on what learners have already constructed in other contexts (Fischer, Bruhn, Grasel, & Mandl, 2002; Brandon & Holingshead, 1999). For instance, Novak and Gowin (1984) found that concept mapping provided for meaningful knowledge construction by providing a means for learners to communicate representations of their cognitive structures with other learners. Roth (1994) suggests that when students generate concept maps on paper in small groups, they are able to demonstrate what they know about a subject while listening, observing, and learning from others, resulting in the modification of their own meaningful understandings.

In the only research study found investigating the comparative effects of individually vs. collaboratively generated concept maps, Brown (2003) compared test scores among students who collaboratively generated concept maps or individually generated concept maps on paper. A comparison of student comprehension of concepts showed that those students who collaboratively-generated concept maps on paper (M = 2. 34, SE = 0.56) outperformed students who individually generated concept maps on paper (M= 0.46, SE = 0.52) in high school biology.

In summary, studies have investigated the effects of concept mapping on paper, concept mapping on computers, and concept mapping individually and collaboratively on paper. Such studies have shown that concept mapping positively affects students' concept learning. When students have computer skills, computer-generated concept mapping also positively affects students' learning of concepts beyond concept mapping on paper. In addition, the literature indicates that collaboratively generating concept maps on paper positively affects learning beyond individually generating concept maps. Therefore, the next logical step in the body of research on visualization is a comparison between computer-based individually-generated concept maps and computer-based collaboratively-generated concept maps to determine which strategy is most appropriate.

Research Questions

In order to determine the comparative effects of individually vs. collaboratively-generating computer-based concept maps on eighth grade middle school science learning, the researchers administered treatments and compared scores on a subsequent comprehension test. Research questions were- (1) Did middle school students who collaboratively or individually generated computer-based concept maps perform better on a comprehension test than those who studied independently and did not generate computer-based concept maps? (2) Did middle school students who collaboratively generated computer-based concept maps perform better on a comprehension test than those who individually generated computer-based concept maps? (3) How did students' attitudes toward generating concept maps during study time differ between those who individually-generated concept maps and those who collaboratively-generated concept map? And (4) What specific learning strategies were used in each group to prepare for the comprehension test and did they differ according to group?

The researchers hypothesized that students who individually and collaboratively generated concept maps on computers would outscore those who did not, that students who collaboratively generated concept maps would outscore students who individually generated concept maps, that attitudes toward concept mapping would be positive across groups, and that students would apply different strategies across groups.

Methodology

Mixed methods were applied to answer the research questions. Using a quasi-experimental posttest-only-control-group design the relative effects of a computer-based individual concept mapping strategy, a computer-based collaborative concept mapping strategy, and a self-selected learning strategy on science concept learning were investigated. Posttest scores were compared across three treatment groups. Qualitative data were analyzed to describe attitudes toward concept mapping and study strategies employed across groups as well as to explain quantitative findings.

Participants

The potential participants were the entire eighth grade student body of a rural middle school in Texas (N=89). However, eleven of the students did not turn in consent forms, one was absent for part of the treatment, and three others were absent for testing. Therefore, 74 students (32 boys and 42 girls) in five eighth grade science classes participated in this study. All of those students took science from one teacher and all eighth grade students and science classes were assigned to that same teacher. The study was conducted in the natural school setting as part of the science curriculum with treatments randomly assigned to five classrooms taught by one teacher. This approach meant that student participants were not randomly selected and that treatment group sizes differed, two weaknesses of the study.

The control group consisted of 12 classmates; the individual group consisted of 31 students from 2 different classes; and the collaborative group consisted of 31 students from 2 different classes. The ethnic distribution of the classes combined was 62% African American, 34% Hispanic, and 7% white. Over 84% of students were economically disadvantaged. Ethnicities and socio-economic status of students were equally distributed across the classes.

Using mathematics and reading performance scores on the Texas Assessment of Knowledge and Skills to assure equivalence of student achievement across groups, the researchers randomly assigned the teacher's classes to one of the three experimental groups. Those groups were- control, computer-based individual concept mapping strategy, and computer-based collaborative concept mapping strategy. Chi-square results indicated that no significant difference existed among the control, individual, and collaborative groups on their prior math and reading performance scores on the standardized Texas Assessment of Knowledge and Skills ($X^2 = 1.13$, $p = .57$ and $X^2 = .30$, $p = .86$ respectively).

To determine whether the groups differed in their knowledge of the four science topics to be used in the experiment: "Tools of Modern Astronomy," "Characteristics of Stars," "Lives of Stars," and "Star Systems and Galaxies," students were asked to report the extent to which they had been previously exposed to the information presented in the science essays that they studied during the four day experiment. Four Pearson Chi-Square tests were conducted for the comparison among three groups. The Chi-square results indicated that there was no significant difference in group knowledge of the topics among the students across the four topics (X^2 = 4.82, p = .57; X^2 = 5.92, p = .43; X^2 = 3.93, p = .69; and X^2 = 4.09, p = .67).

In addition, Chi-Square tests were used to investigate whether the three groups were different from each other in their frequency of accessing computers at school and at home, in the number of computer courses taken in the past, in the amount of the time spent each time using a computer in school and at home, and in the frequency of using computer tools to support various learning tasks, such as word processing, E-mail, Internet, games, spreadsheets, presentations, graphics, and webpage development. According to their self-report, students in all three groups were not different regarding previous experiences using computers (see Table 1).

Table 1. Pearson Chi-Square Group Differences in Computer Use Survey

Topic	Pearson Chi-Square	Df	Significance (2-sided)
Use computers at school	2.22	4	.70
Time spent at school computers	3.85	6	.70
Numbers of computer courses	3.09	4	.54
Frequency –use of computer at home	5.47	4	.24
Time spent at home computers	2.78	4	.60
Frequency – Create computer graphics	4.61	8	.80
Frequency – Word	2.19	4	.70
Frequency – Internet	2.72	4	.61
Frequency – E-mail	6.13	8	.63
Frequency – Chatting	5.89	6	.44
Frequency – Games	3.47	6	.75
Frequency – Spreadsheets	2.14	6	.91
Frequency – Presentations	5.20	8	.74
Frequency – Programming	.65	2	.72
Frequency – Webpage development	2.34	2	.31

*p < .05.

Design

The independent variable, group, had three levels: a control group consisting of one class of twelve students who were not trained in concept mapping, an experimental group consisting of two classes totaling thirty-one students trained to individually generate concept maps on computers, and an experimental group consisting of two classes totaling thirty-one students trained to collaboratively generate concept maps on computers. The dependent variable was science concept learning as demonstrated by comprehension test scores.

Computer-based Concept-Mapping Workshop

Prior to studying science concepts, both groups that created concept maps on computers attended a three day workshop on computer-based concept mapping. The computer-based concept mapping workshop lasted fifty minutes each of three days. The workshop had the same content, materials, and processes for each experimental group except that students in the collaborative group were informed in the last five minutes of the last day of the workshop that they would be concept mapping collaboratively the following day. Science topics explored during the computer-based concept mapping workshops were “The eye – An organ system,” “Light waves and lenses,” and “Wave behavior.” The science content of the workshops were carefully selected to assure that content did not include concepts to be covered in the experimental studying materials. The first day of the workshop the teacher trained students focusing on how to identify and visualize expository text with sequential structures using Inspiration. On the second day of workshop, the teacher trained students to identify and visualize expository text with categorical structures. For the third day of the workshop, the same teacher trained students to identify and visualize expository text with compare-contrast structures. The control group spent the same amount of time as the experimental groups with their teacher but rather than learning how to create concept maps, they watched a video about the upcoming science fair.

Procedures

Prior to conducting the study, one of the researchers spent approximately one hour training the teacher in how to use Inspiration™ to create concept maps and then another hour training the teacher on how to deliver the Computer-based Concept-mapping Workshop to the students. Led by their teacher, students in the individual and collaborative experimental groups first spent three days learning how to develop concept maps on computers using Inspiration™ in the Computer-based Concept-mapping Workshop. Every student participant had a computer account and logon ID for the school computer laboratory so that the teacher was able to trace student work and outcomes on an administrator's server.

After three days of the workshop, the control, individual, and collaborative groups were given the same science essays to study in the classroom for four days. The only difference among groups was that the control group followed their own learning strategy to study the concepts. Computers were not available to them. In the individual group, students worked independently to use their learned computer-based concept mapping skills to show interrelationships among concepts during their study time. Each student worked alone at a computer.

However, in the collaborative group, students were required to study together within groups of three per computer using their learned computer-based concept mapping skills to collaboratively create concept maps that showed interrelationships among concepts during their study time in the classroom. Each of the three group members was assigned to be either the group's leader, reporter, or monitor. The role of the leader was to encourage group input and use the mouse to create the concept maps according to group input. The role of the monitor was to provide input regarding creation of bubbles and links. The role of the reporter was to print out group concept maps and summarize group work during study time. Roles were rotated daily so that each group member could fulfill each role. Students had not had prior training in how to work in such groups nor did they receive training as part of the experiment. The same teacher for all groups implemented instructional procedures during the four day experimental period. When students from any group asked for help and information, the teacher gave feedback equally to the students.

The experimental procedure for all three groups followed three steps each of the four experimental days: First, as was typical in the classroom when students studied concepts in their text, the teachers gave ten minutes of instruction for each group. Second, after the teacher's instruction, the students in the control group studied individually to prepare for the comprehension test. The control group students followed their own learning strategy such as highlighting, memorization, or taking notes to prepare for their test for thirty minutes. Students in the two experimental groups' created concept maps using computers for thirty minutes.
Students in the individual group created concept maps and studied independently using computers. Students in the collaborative group, however, created concept maps together using computers. The experimental groups' students saved their files on their computer-server and printed out their concept maps to use them during their study time. Finally, all three groups of students turned in their study notes and concept maps prior to taking a test.

Materials and Instruments

The study essays were selected by the classroom teacher from the Prentice Hall Science textbook for eighth grade that was adopted by the school district (Padilla, Miaoulis, & Cyr, 2002). The contents of the four essays to be studied by students were validated by a subject matter expert and the teacher established that they met the state curriculum and that the students had not been exposed to those essays or the topics of those essays in school prior to the study. The four short essays, "Tools of Modern Astronomy," "Characteristics of Stars," "Lives of Stars," and "Star Systems and Galaxies" were each one page long and consisted of expository text without illustrations or graphics. Students were given 50 minutes to study each essay.

The comprehension test consisted of 40 computer-based multiple-choice items from the Prentice Hall test bank that was provided with the eighth grade textbook adopted by the participating school district. The multiple choice comprehension test items were selected and validated by both the teacher and researchers as appropriate for this study. Items were criterion referenced to concepts in the essays that students studied during their experimental study time. Ten item multiple choice comprehension tests were administered on each of the four days for ten minutes after treatment. Scores were totaled for each student to provide the 40 item total. For the purpose of scoring students' responses to the comprehension test items, one point was given for a correct answer, and no credit was given for incorrect or unanswered questions. Internal consistency was established at .82 (coefficient alpha) for the comprehension test.

All participants were asked to fill out a Learning Strategy Questionnaire in the last minutes of the fourth day. The Learning Strategy Questionnaire was a student self-report instrument developed by the researchers. Students in all three groups were asked to describe the steps that they took to prepare for the test. Students in both experimental groups were asked to explain how they felt about making concept maps that showed interrelationships among concepts during study time and to discuss how making concept maps helped them learn content. The individually-generated concept mapping group answered the following other questions: When you created concept maps on a computer during study time, do you think that working by yourself helped you learn the content better than if you had worked with others? Why or why not? The collaboratively-generated concept mapping group answered the following questions: When you created concept maps on a computer during study time, do you think that working with others helped you learn the content better than if you had worked by yourself? Why or why not?

Data Sources and Analyses

The four data sources included: (a) comprehension test scores, (b) student responses on the Learning Strategy Questionnaire, (c) students' study notes, and (d) the video recording of classroom activities. Comprehension test scores were analyzed quantitatively. Students' study notes, the video recording, and responses on the Learning Strategy Questionnaire were analyzed qualitatively to explain quantitative results and to provide insight into participants' attitudes and study strategies.

A one-way analysis of variance (ANOVA) using "treatment" as the independent variable and "comprehension test scores" as the dependent variable was administered among the control, individual, and collaborative groups. The researchers summarized student responses to the Learning Strategy Questionnaire and triangulated those self-reports with researchers' and teachers' observation and students' study notes. The researchers examined students' study notes and identified strategies employed. Content analyses approaches as described by Emerson, Fretz, and Shaw (1995) were applied to the researcher's journal entries, the video recording during study time, and students' response to the Learning Strategy Questionnaire. For focused coding analyses, the researcher independently compiled and numbered the contents according to the categories that emerged (Merriam, 1998). To analyze the video recording, the researcher watched the video several times and independently identified categories of student behaviors.

Results

Results of data analyses provided answers to the research questions regarding the effects of individually generated computer-based concept mapping, and collaboratively generated computer-based concept mapping. ANOVA (Analysis of Variance) revealed that means differed across groups. A .05 level was used for determining significance. Levene's Test of Equality of Error Variances was applied and groups were found to be homogenous.

Descriptive statistics for the experimental groups' were respectively: individual group, n = 31, mean = 26.29, SD = 4.49; collaborative group, n = 31, mean = 23.19, SD = 6.20; and the control group, n=12, mean = 19.67, SD = 7.11. The one-way ANOVA results indicated that a significant difference existed among the individual, collaborative, and control, groups on the mean scores of the comprehension posttest, F =6.25 ($p < .05$ level) as seen in Table 2.

Table 2. One Way ANOVA Summery Table

Source	Df	Mean Square	F	Significance
Group	2	203.81	6.25	.00*
Error	71	2315.89		

*p < .05.

Tukey's HSD post hoc test revealed that the group that generated concept maps individually significantly outscored the group that did not generate concept maps (control group), while the group that generated concepts maps collaboratively did not differ significantly in its performance when compared to the other groups (see Table 3). The effect size between the control and individual groups was 1.11. The effect size between the control and the collaborative groups was 0.53. The effect size between the individual and collaborative groups was 0.57.

Table 3. Tukey HSD Post Hoc Test Results

Tukey HSD (I) Group	(J) Group	Mean Difference	Significance	Effect Size/Cohen's *d*
Control	Individual	6.62*	.00*	1.11
Control	Collaborative	3.53	.17	0.53
Individual	Collaborative	3.10	.09	0.57

*p < .05.

Therefore, our first research hypothesis that middle school students who collaboratively or individually generate computer-based concept maps perform better on a comprehension test than those who do not generate computer-based concept maps is only partially accepted. Although students who individually generated concept maps scored higher than the control group, students who collaboratively generated concept maps did not score significantly higher than the control group on the comprehension test. Also, there was no significant difference between the groups of students who individually and collaboratively generated concept maps. Therefore, the second hypothesis that middle school students who collaboratively generated computer-based concept maps performed better on a comprehension test than those who individually generated computer-based concept maps is rejected. Qualitative data provided insight regarding quantitative findings, students' attitudes toward concept mapping, and the strategies that students chose to employ while studying.

Table 4. Survey Result of Learning Strategy during Study Time

Category	**Control Group**	**Individual Group**	**Collaborative Group**
Feeling about *CM	None	85% say helpful and fun. Some students think better than worksheet on paper or regular class activity. 15 % No response	87% say helpful and fun. Some students think better than worksheet on paper or regular class activity.13 % No response
Sense that CM helps with content learning.	None	87% think concept maps help with learning the science content. 13 % No response	97% think concept maps help with learning the science content. 3 % No response
Opinion of working with group	None	None	50% think working with a group is helpful and useful. 40 % did not like group work and preferred to work alone. 10 % No response
Opinion of working individually	None	70% think that studying by themselves is helpful and useful. 19% preferred to work in a group. 11 % No response	None
Steps taken to prepare for test	Read the whole handout and some students took notes and underlined parts.	Generated and studied their concept maps and tried to understand relationships among the bubbles.	Generated and studied their concept maps and tried to understand relationships among the bubbles.
Previous exposure to concept mapping	None	12% had created concept maps before. 100% did not know Inspiration™ program before	9% had created concept maps before. 100% did not know Inspiration™ program before

*CM = concept mapping

Attitudes toward concept mapping for science concept learning were positive whether the students were working individually or collaboratively (see Table 4). Generating concept maps using the computer program, Inspiration™, provided students with a useful learning strategy and a positive experience. An interesting observation by both the teacher and the researchers was that the students in the individual group were more positively engaged in their studying than were the students who studied collaboratively. The teacher and researchers observed students in the collaborative groups spending excessive time competing for control of the mouse and students complained vocally about having to share the keyboard and work collaboratively. Only 50% of students in the collaborative group thought that working with peers was helpful for studying and learning science concepts. Students' negative attitudes toward collaboration may have influenced their comprehension of concepts being studied and might explain why the students in the individual group performed better than the students in the collaborative group.

The study strategy chosen by students in the control group when they prepared for the test was to simply read the handout, while the students in the two experimental groups' created and studied the relationships between bubbles on their concept maps and links that they created during study time. Students who created concept maps expressed that creating those maps and studying relationships between bubbles and links were quite helpful and fun for learning science.

Discussion and conclusions

The findings provide further evidence that individually-generating concept maps during study time positively influences science concept learning and that computer-based concept mapping can be facilitative. But findings do not support the assumption that collaborative learning is more effective than learning individually. Students enjoyed Inspiration software which supported their construction of concept maps for science learning and helped them capture their quickly evolving ideas and organize them for meaningful learning. These findings provide evidence that constructivist learning theory is correct regarding learners' needs to organize and represent concepts visually and explore interrelationships among concepts. However, in this case, social construction of meaning using concept maps was no more effective than application of a self-selected study strategy.

The Positive Effect of Concept Mapping on Learning

These findings replicate previous research results (Cifuentes & Hsieh, 2003a, b; Cifuentes & Hsieh, 2004, Hsieh & Cifuentes, 2003; Hsieh & Cifuentes, 2006). It extends the research by providing evidence that individually-generating concept maps on computers is more effective than either independent, unguided study, or collaboratively-generating concept maps. However, the findings do not support Fischer, et al's (2002) assumption that collaborative knowledge construction is more effective than individual knowledge construction. Qualitative findings suggest that the reason that students in the collaborative group did not score significantly higher than the control group on achievement might have been lack of a disciplined, supportive collaborative working environment.

Cifuentes and Hsieh (2004) previously demonstrated that distraction of computers and software and the difficulty of visualization can contribute to lack of the effectiveness of computer-based visualization. Students in the school setting of this study were not motivated to collaborate with each other and were distracted by each other, the computers, and the software. Most of the participants did not have computers at home and the school district had limited technical facilities. The participating students learned concept mapping using computers for the first time in the context of this study. In addition, according to their own self-report, most students had had few opportunities to develop collaborative learning skills in their young school careers. With computer skills, concept mapping, and collaboration all new to the students, the combined tasks challenged them. To be effective, all three components of the experiment required sophistication on the part of learners.

Perhaps more experienced learners would produce a different result. Findings indicate that teachers should train their students in computer-based concept mapping and facilitate adoption of concept-mapping as an independent study strategy. Deciding whether to adopt a computer-based individual concept mapping strategy or a computer-based collaborative concept mapping strategy might be based upon characteristics of the learners and the learning context. For example, a teacher should ask the following questions prior to implementing concept mapping: Do students feel comfortable and competent working on computers during class time? Do students already know how to work collaboratively during study time? Do students know how to work collaboratively on computers? If the answer to any of the questions is "no," as was the case in this study, then teachers should only recommend such a strategy after students have been sufficiently trained on computers, on collaboration, and on computer-based collaboration. Until that time, students should be encouraged to develop concept maps individually. If the answer to these questions is "yes," then the teacher might consider encouraging students to generate concept maps collaboratively.

Recommendations for Future Study

Study limitations are that generalizations to populations beyond the sample of this study should be made conservatively because a nonrandomized, quasi-experimental design was used, a small number of students participated, and groups were of unequal size. Therefore, it is recommended that these findings be replicated in a study with a larger group of students who are randomly selected for placement in equal-sized groups. However, we acknowledge that this is quite difficult in the naturalistic classroom environment.

Chiu, Wu, & Huang, (2000) have found that when students have computer skills and collaboration skills, they can work together effectively on computers. Therefore, the researchers suggest that this study be replicated in another school context, where students have technical skills and support, the atmosphere is conducive to collaboration, and students have a history of collaborative experience in school. They predict that under these circumstances, the outcomes of collaboratively-generated concept mapping may be more positive. Researchers might investigate whether individually or collaboratively computer-generated concept maps differentially affect learners with specific characteristics such as those listed above.

Given that participants in this study were distracted by members of their group, both the classroom teacher of those students and the researchers think that an investigation comparing collaborative groups versus collaborative pairs is of interest. Collaborative pairs might be less distracting than collaborative groups. Further studies might be conducted to compare the effect of individually and collaboratively generating concept maps on the quality of those maps.

Possible qualitative factors might include— propositions, hierarchical relationships among sub-concepts, cross links, and examples (Novak & Gowin, 1984). In order to conduct a study using quality of concept maps as a dependent variable, training in future studies should specifically prepare study participants to generate concept maps that include quality factors identified in concept mapping literature.

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