

The Interplay Between Different Forms of CAI and Students' Preferences of Learning Environment in the Secondary Science Class

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ABSTRACT: This evaluation study investigated the effects of a teacher-centered versus student-centered computer-assisted instruction (CAI) on 10th graders' earth science student learning outcomes. This study also explored whether the effects of different forms of computer-assisted instruction (CAI) on student learning outcomes were influenced by student preferences of learning environment (PLE). A total of 347 10th-grade senior high school students participated in this nonequivalent control group quasiexperiment. During a one-week period, one group of students ($n = 216$) were taught by a teacher-centered CAI (TCCAI) model whereas the other group of students ($n = 131$) were subject to a student-centered CAI (SCCAI) method. Results showed that (a) no statistically significant difference on students' earth science achievement was found for either group; (b) TCCAI group had significantly better attitudes toward earth science than did the SCCAI group; furthermore (c) a significant PLE-treatment interaction was found on student attitudes toward the subject matter, where the teacher-centered instructional approach seemed to enhance more positive attitudes of less constructivist-oriented learning preferences students, whereas the student-centered method was more beneficial to more constructivist-oriented learning preferences students on their attitudes toward earth science in a computer-assisted learning environment. © 2005 Wiley Periodicals, Inc. *Sci Ed* **89**:707–724, 2005

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INTRODUCTION

Computer-assisted instruction (CAI) is deemed as a powerful instructional method in the secondary classroom as a result of great advances in modern computer technology over the past decade. The teaching standard proposed by the recent science education standards in the USA also describes that

Other teaching strategies rely on teachers, texts, and secondary sources—such as video, film, and computer simulations. (National Research Council, 1996)

Conducting scientific inquiry requires that students have easy, equitable, and frequent opportunities to use a wide range of equipment . . . Some equipment is general purpose and should be part of every school's science inventory, such as . . . computers with software for supporting investigations. (National Research Council, 1996)

Science educators in Great Britain have compiled a report entitled "Beyond 2000: science education for the future" (Millar & Osborne, 1998), which emphasizes the use of a variety of instructional methods as the following:

Seeing the science course as a series of short periods of more intensive learning of new ideas (using a range of methods including teacher exposition, practical work, video resources, computer software, reading about science, CD-ROMs, the Internet and so on) (Millar & Osborne, 1998)

The latest science and life technology curriculum standards in Taiwan (Ministry of Education, 2003) state specifically that

Students should be able to use computers and Internet for the collection and analysis of data and make reports. Students should be able to integrate the use of computers into information communication and transmission. (Ministry of Education, 2003)

Despite constant support for using computers or implementing CAI in the secondary science classroom, the recent *TIMSS* (Third International Mathematics and Science Study) *1999 International Science Report* (Martin et al., 2000), published by the International Association for the Evaluation of Educational Achievement (IEA), specifically noted that very few secondary students reported frequent use of computers in any of the science subjects, and only in Israel and in the USA did at least 20% of students report using computers almost always or regularly in science classes. Wang and Chan (1995) have pointed out that isolation from human interaction and large capital investment were the major disadvantages of CAI, whereas the lack of time, too little computer hardware and software, and the lack of teachers' experience and skills in educational technology were the major inhibitions of CAI implementation among many secondary schools throughout the world (Wang & Chan, 1995).

Even with widespread optimism about the usage of CAI in the science classroom, confounding research findings on the comparative effectiveness of CAI versus traditional instruction are present in the science education literature. Some research found that CAI was effective in improving students' science achievement or their attitudes toward science (Chang, 2001a, 2001b, 2002; Ferguson & Chapman, 1993; Levine, 1994; McCoy, 1991; Yalcinalp, Geban, & Ozkan, 1995). On the other hand, other researchers have found that the CAI approach has no significant effects on cognitive achievement or science learning (Morrell, 1992; Olugbemiro, 1991; Wainwright, 1989). Christmann, Badgett, and Lucking (1997) also reported a meta-analysis, comparing traditional instruction versus traditional

instruction supplemented with CAI effects on the academic achievement of sixth graders through twelfth graders across eight curricular areas. They found that higher academic achievement among students receiving *traditional instruction supplemented with CAI* was found with an overall mean effect size of 0.209 reported. Effect sizes were largest for science (0.639) and most highly negative for English (−0.420) (Christmann et al., 1997).

The aforementioned mixing research results perhaps stemmed from some unknown factors that might have revolved around the CAI treatment and students' characteristics or their preferences of learning environment in the science classes. For example, Windschitl and Andre (1998) have recognized that the epistemological beliefs of learners significantly interact with the type of learning environment or treatment in determining their science achievement using computer simulation as an instructional tool. They showed that students with more sophisticated epistemological (constructivist) beliefs perform better when allowed to explore in a constructivist learning environment and students with less developmentally advanced (traditional-objectivist) beliefs learned more with an objectivist treatment (Windschitl & Andre, 1998). However, the interaction effects concerning students' affective domain was not under evaluation in the above study.

Constructivist teaching has been expanding in the area of science education for the past 20 years. Baird and Northfield (1992) illustrated more than 80 techniques that are closely related to the constructivist teaching approach, such as cooperative learning, group discussions, hands-on activities, concept mapping, conceptual change, problem solving, and inquiry-oriented approaches, all of which involve active participation of students in learner-centered activities. However, not every student could value the student-centered character of the constructivist model and appreciate the essence of the constructivist teaching approach (Baird & Northfield, 1992). In previous studies (Chang & Barufaldi, 1999; Chang, Hua, & Barufaldi, 1999), we found that student perceptions toward constructivist teaching demonstrated frustration; they realized its advantages in terms of stimulating and increasing their thinking skill. Yet, students did not see this type of instruction as being promising because it seemed that it would not help them perform better on forthcoming exams. It is then hypothesized by us that students' perceptions or preferences of computer-based learning environment may account for the aforementioned indecisive research results found in student attitudes or science achievement between different forms of CAI implementation in the science classroom.

Students' preferences toward learning environments, to a certain extent, represent their epistemological beliefs. Tsai (2000b) and Tsai and Chuang (2005) showed that students' preferences toward learning environments were significantly related to their epistemological beliefs. Students who preferred more constructivist-oriented learning environments tended to hold more sophisticated epistemological (constructivist) beliefs (Tsai, 2000b; Tsai & Chuang, 2005), a finding likely consistent with that revealed by Windschitl and Andre (1998). Educators have concluded that learners' epistemological beliefs may affect their learning approaches, reasoning modes, and decisions when processing or acquiring information (Hofer, 2001; Hofer & Pintrich, 1997; Tsai, 1998, 1999). As the exploration about epistemological beliefs may be complicated and difficult for high school students, this study used student preferences for learning environments as an important factor that may influence student performance on different forms of CAI instruction.

Furthermore, while previous studies and meta-analyses have primarily focused on the comparative efficacy of CAI versus traditional instruction (Chang, 2001a, 2001b; Kulik & Kulik, 1986, 1991), there have been relatively fewer examples of research exploring how various teaching methods of CAI interact with student preferences of learning environment in the secondary classroom. In previous studies, Chang (2001b, 2002) evaluated the comparative efficacy of CAI versus traditional instruction in the secondary science classroom.

The results revealed that CAI seemed unanimously brought forth (marginally) significantly greater gains in students' science achievement than did the traditional teaching approach supplemented with regular computer-Internet usage, yet confounding findings on student attitudes toward the earth sciences subject also existed in the previous investigations. Recently, Chang (2003, 2004) have further demonstrated that instruction which stresses the teacher's role in teaching multimedia CAI can lead to improved student science achievement and attitudes toward the subject matter. However, student preferences of learning environment were not under considerations at the time of above investigation and analysis (Chang, 2003, 2004). Therefore, in this paper, this issue is further addressed by investigating the possible interaction effects between student preferences of learning environment and treatment (teacher-centered CAI, TCCAI vs. student-centered CAI, SCCAI) on student earth science learning outcomes including achievement and attitudes in a computer-assisted learning environment of some secondary science classes in Taiwan.

METHOD

Participants

The participants involved in the study included 347 10th-grade senior high school students attending eight earth science classes and two earth science teachers who taught the above classes at a public suburban senior high school located in the central region of Taiwan. There were eight classes of about 43 students each—a total of 167 males and 180 females. The students were typical 10th-grade students. Their mean age was about 16, and the gender mix was approximately equally distributed among the classes. The study took place at the commencement of the spring semester in March 2002. One of the participating teachers held an equivalent master's degree in earth science and had 13 years of experience teaching the subject. The other teacher had a master's degree in geophysics and had taught earth science for 5 years. The senior teacher had five classes and the junior teacher had three classes available respectively during the course of study. Since these two teachers have participated in this series of CAI studies (Chang, 2002, 2003), each teacher is supposed to employ and practice both instructional strategies to make the comparison more appropriately. We randomly assigned three of senior teacher's classes to the TCCAI group and two of his classes to the SCCAI group. The same random assignment was also carried out on the junior teacher's three classes. As a result, there were five classes with a total of 216 students including 110 females and 106 males receiving the TCCAI approach while three classes with a total of 131 students including 70 females and 61 males were taught by the SCCAI scheme.

Software

The software employed in this study was designed and written using an authoring package, AUTHORWARE version 4.0 (Macromedia Inc., San Diego, CA), which supported multimedia functions and nonlinear representations. Topics covered in the multimedia software included *Typhoon and the Debris-Flow Hazards*. At the end of July 1996, Typhoon Herb roared through Taiwan causing heavy rain over the course of 3 or 4 days that resulted in the loss of many lives and extensive property damage from flooding, landslides, and a large-scaled debris-flow hazard. The CAI program was designed to help students to become more knowledgeable about the hazards. This kind of earth science topic is closely related to students' daily lives since most students in Taiwan experience typhoons or natural hazards around their neighborhood.

At the start-up screen of the computer program, students were first shown a video clip of the debris-flow hazard that occurred in Nan-Tou province of Taiwan in 1996. Then, through guided inquiry provided by the computer program, students were asked to identify facts associated with the natural hazard and find out possible factors that might cause this hazard. Students were subsequently encouraged to prepare and implement their plans by analyzing and investigating the research questions, i.e., the factors causing the debris-flow hazard and collect necessary information in association with the debris-flow hazard. Students also need to go through a virtual field trip to conduct geological investigations provided by the CAI and to find out the solutions to the debris-flow hazard problems. Finally, students prepared final reports of their work and presented project results to their classmates. The structure of the computer program was based upon a virtual, private research office comprising the following seven learning sections (LS): a *tables-and-graphs* LS, a *news-report* LS, a *newspaper* LS, a *bookshelf* LS, a *computer* LS, a *virtual-field trip* LS, and an *evaluation* LS.

The *tables-and-graphs* LS contains mainly data tables, charts, and animations including local maps, geological maps, topography maps, animated weather satellite images, and precipitation data tables and information for data analysis and interpretation. The *news-report* LS covers all the relevant TV news reports in video format on a debris-flow hazard event, which occurred in Nan-Tou province of Taiwan in 1996. The *newspaper* LS reports headline news in print on the debris-flow hazard. The *bookshelf* LS consists of science textbooks explaining the occurrences of natural hazards and introducing basic geoscience concepts such as those in geology and meteorology for further references and readings. The *computer* LS comprises a series of video CDs presenting the local geological and weather characteristics. The *virtual-field trip* LS permits learners to conduct several geological investigations virtually in order to understand facts and information in association with the debris-flow hazard and get an insight into this natural event. Finally, an *evaluation* LS contains 10 randomly selected test items from a pool of 30 multiple-choice items to examine students' understanding of science concepts and help them reflect upon their own learning outcomes. A complete summary of the key elements, primary interfaces, and major functions of the LSs included in the multimedia CAI software can also be found in Chang (2003).

To summarize, the multimedia CAI that was developed and employed in this study provided:

- large amounts of information and data on the subject of debris-flow hazards (represented in different formats such as video, graphics, animation, and sound); and
- the multimedia resources including information and data on the debris-flow hazards can be accessed through various paths or different routes.

During its development, a class of forty 10th-grade students enrolled in an earth science course first tested the software during the spring semester of 1998. The software was then revised according to the suggestions and comments from participating students and teachers. The first revision was, for the most part, to improve the quality of text, charts, maps, video, and sound embedded in the LSs. The software was then used with 159 10th graders in a pilot study (Chang, 2001a) in the following semester. The results of the above pilot study showed that the software had promise in supporting students' learning of earth science in terms of improving their earth science achievement, especially on the knowledge and comprehension levels of Bloom's (1956) cognitive domain.

The software was subsequently improved once again based on the second evaluation (the above pilot study) and was completed during the autumn of 1999. The second revision was mainly focused on the improvement of interfaces among various LSs in order to make the

navigations between different LSs more smoothly. Details of the design, development, and components of the software and two subsequent main studies evaluating the comparative efficacy of the CAI versus traditional instruction can also be found in Chang (2001b, 2002). The results of the above main evaluation studies suggested that the CAI produced marginally significantly greater gains in students' earth science achievement than did the traditional teaching approach supplemented with regular computer-Internet usage; however, the CAI effects on student attitude toward the earth sciences subject were indeterminate in the previous investigations.

Following the aforementioned main evaluation studies, Chang (2003, 2004) has also explored how various teaching formats of CAI influence student science learning outcomes in the secondary classroom and found that CAI implementation which specifically lays emphasis on the teacher's role in the computer-based learning environment could not only significantly help the students' grasp of earth science concepts, but also greatly improve their attitude toward earth science. However, student preferences of learning environment were not taken into account in the previous investigations due to available time and efforts of those studies. Therefore, this study took further steps and attempted to determine whether the effects of different models of computer-assisted instruction (CAI) on 10th graders' earth science learning outcomes were influenced by student preferences of learning environment with the aims at exploring the possible implementation models of future computer-based instruction within secondary science classrooms of Taiwan.

Forms of CAI

The teacher-centered CAI (TCCAI) scheme in the current study is a mixture of whole-class presentation, interactive discussions among the teacher and students, and classroom activities using the CAI software. The instruction emphasized direct guidance and presentation, occasional demonstrations, and clear explanations of important concepts to the students given by teachers in the earth science classroom/lab. The whole-class presentation was implemented using a combination of a high-speed laptop computer and a high-resolution liquid crystal display (LCD) projector to display the CAI contents on a large screen in front of a whole class (Figure 1). Besides, class discussions between the teacher and the students and among students were also embedded in this teaching format. It is noted that the whole-class presentation was intended to be interactive in nature in order to ensure maximum interactive



Figure 1. The TCCAI setting.

discussions by the teacher and the students. The key feature of this instruction was providing students with clear and detailed instructions and explanations.

As alluded to earlier, the earth science class began with the teacher launching the start-up screen of the CAI software, i.e. the video clip of some massive property damages resulting from flooding and a large-scaled debris-flow hazard that occurred in Nan-Tou province of Taiwan at the end of July 1996. The virtual research office was subsequently displayed in front of the whole class for the teacher to address facts associated with the natural hazard and lecture on possible factors that might cause this hazard. Then the students learned debris-flow hazard topics being taught through the whole-class presentation and teacher–student discussion teaching strategies. Classroom activities using the software were deemed as important components of the teacher-centered instruction. During one activity, for example, students were first exposed to a diagram on a large white screen showing precipitation tables and charts, which illustrated the local precipitation data during the period of Typhoon Herb passing through Taiwan. After observing various precipitation charts and tables, students were asked to interpret data and give explanations through teacher–student discussions. Finally the teacher made clear explanations concerning the characteristics of Typhoon Herb and the weather system in Taiwan. Details of the TCCAI approach can also be found in Chang (2003).

In contrast, the student-centered CAI (SCCAI) approach was based on students' self-paced learning using the CAI software with their own individual computers (PCs) in a modern computer lab (Figure 2). The instructional method stressed students' self-paced learning using the multimedia CAI program with their own PCs in a modern computer classroom. The students could freely navigate through a variety of learning sections and acquire their own knowledge and understandings about the debris-flow hazards via guided directions provided by the program or the classroom teacher. It is noted, however, both TCCAI and SCCAI were taught three hours a week and received the same instructional software, the same hands-on activities and data, and the same assignments. Both groups also had the same learning objectives, i.e. topics and principles introduced in the software, and had equal opportunities to practice their learning objectives.

Preferences of Learning Environment (PLE)

To assess students' preferences of learning environments, a Chinese version of the Constructivist Learning Environment Survey (CLES) originally developed by Taylor and Fraser



Figure 2. The SCCAI setting.

(1991) was administered. The original CLES contains the following four scales (seven items for each scale): negotiation, prior knowledge, autonomy, and student-centeredness scales (Taylor & Fraser, 1991). Of which the student-centeredness scale is most related to the investigation of the current study since this scale measures student preferences of the extent to which there are opportunities for students to experience a student-centered learning environment.

CLES includes two forms: one is actual form (or perceived form), assessing the extent of the agreement between actual learning environments and constructivist learning environments, and the other one is preferred form, assessing the matches between students' views about ideal learning environments and constructivist ones. Only the preferred form was administered in this study. Taylor and Fraser (1991) reported the reliability to be 0.63 for the student-centeredness scale of preferred form of CLES. Tsai (2000b) surveyed 1,176 Taiwanese 10th graders (16-year-olds) and reported 0.70 for the same scale of preferred form. The reliability was estimated at 0.68 with participants in the current study. The following question is the sample item cited from CLES instrument: In this class, I prefer the teacher to show the correct method for solving problems (student-centeredness scale, preferred form, stated in a reverse manner).

Each CLES item has a five-point Likert scale with categories ranging from "very often" (5) to "never" (1). For their responses on the items presented in a constructivist view, the five-point Likert scale was scored with a five point "very often" response down to a one point "never" response, whereas students' responses on those statements presented in a traditional or nonconstructivist way were scored in a reverse manner. The scores for every student's responses on the student-centeredness scale in the preferred form of CLES were used as indicators to display their preferences of constructivist learning environments; hence, every student had different scores to show their preferences toward such environments.

Learning Outcomes

To measure student earth science learning outcomes in terms of earth science achievement and student attitudes toward the subject matter, we constructed and developed the *Earth Science Achievement Test (ESAT)* and the *Attitude Toward Earth Science Inventory (ATESI)*. The Earth Science Achievement Test (Chang 2001a) is a 30-question multiple-choice test designed to measure students' earth science achievement. A panel of specialists, including three university professors and three high school teachers, established the content validity of ESAT. These specialists checked the degree of equivalence between the content of the software program and the ESAT items and established that the nature of the test items is in alignment with the important concepts introduced in CAI software. The reliability coefficient of 0.74–0.78 was reported in the previous studies and was estimated at 0.77 for the present sample of the study, using the Kuder–Richardson formula 20 (KR-20).

The Attitude Toward Earth Science Inventory (Chang & Mao, 1999) consists of 30 items intended to investigate students' attitudes toward earth science. The Cronbach's alpha was estimated to be around 0.90 in previous studies and was calculated at 0.93 with the present sample of this study. The detailed construct, validity, and reliability of the ESAT and ATESI can be found in Chang (2001a) and Chang and Mao (1999), respectively. The test and survey were administered immediately before and after the 3-h course.

Procedure

A nonequivalent control group quasiexperimental design involving eight intact classes was adopted (Campbell & Stanley, 1966). Random assignment of individual students to

new classes is not likely in the educational system of Taiwan; intact class set is the unit of the experimental design. As alluded earlier, five intact classes ($n = 216$) were randomly assigned to the TCCAI group; three classes ($n = 131$) were randomly assigned to the SCCAI group. The ESAT and ATESI were administered to both groups immediately before and after the 1-week intervention. The design is illustrated in Figure 3.

One group of students ($n = 216$) were taught by the TCCAI model whereas the other group of students ($n = 131$) were subject to the SCCAI scheme. During the 1-week period, each group received an equal amount of instructional time and was provided with the same instructional materials and assignments. We also attempted to make relevant resources, that is, topics and principles introduced in the TCCAI and SCCAI, available to students in both groups. The earth science topics taught for the two groups of students during this period of time included Typhoon Herb and the debris-flow hazards. Research dealing with classroom-based treatment within a regular school setting usually encounters a variety of difficulties, such as few schools and teachers willing to participate, strict regulations set by the school administration, and random assignment of students to classes. Under these and other limitations, we attempted to make every effort not only to implement different forms of CAI in the regular earth science classrooms but also to try to establish equivalence between the TCCAI and SCCAI to evaluate the relative effectiveness of different instructional formats.

Care was taken to ensure that an appropriate comparison was attained between the TCCAI and SCCAI instructional methods. For example, the virtual office provided by the multimedia CAI program was furnished with books, geologic maps, and precipitation data tables and charts etc. for data analysis and interpretation for the SCCAI group. The teacher in the TCCAI groups also presents very similar instructional materials to the students by giving lectures and undertaking comparable data-analysis activities in the lecture classroom. Besides, the geological photos and detailed field-trip documentation, which were supplied by the virtual-field trip learning section for the SCCAI group, were also clearly presented and explained by the teacher during the regular classroom sessions for the TCCAI group. Explicitly, not only was the scope of the content covered by the two treatments deemed equivalent relative to the posttest but also the overall learning time of the two groups was the same.

Data Analysis

A number of variables, such as grade level (10th grade) of earth science students and the equivalent instructional content and duration, were held constant. The major independent variable was the format of instruction (TCCAI vs. SCCAI) and the dependent variables were student earth science learning outcomes in terms of earth science achievement and student attitudes toward earth science subject.

To further understand how the two groups would be affected by the intervention, we carried out univariate analysis of covariance (ANCOVA) on posttest scores with the pretest

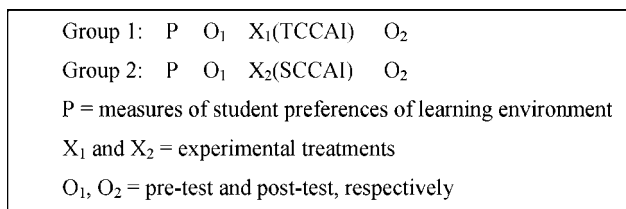


Figure 3. The quasiexperimental design employed by the study.

as the covariate on the achievement and attitude measures respectively to determine any significance between the two groups. Moreover, this study investigated the possible interaction between students' PLE and the use of instructional treatments; therefore, this study used the following variables as predictors in regression models to predict students' learning outcomes (including achievement and attitude):

1. pretest score
2. instructional treatments (TCCAI vs. SCCAI)
3. PLE score
4. instructional treatments \times PLE

Consequently, two regression models using the variables above were constructed to explain the learning outcomes of achievement and attitude separately. For the regression model of predicting student achievement, the achievement pretest score was included, whereas for the attitude model, the attitude pretest score was used for the regression analysis. This way of evaluating the interaction between instructional conditions and students' certain perceptions was similar to that used by several researchers (Tsai, 2000a; Windschitl & Andre, 1998).

Several assumptions of the ANCOVA were first tested to ensure that they were met in the analysis of covariance for the present study. The measures of each dependent variable were determined to be independent. The Kolmogorov–Smirnov tests show that distributions of posttest scores were normal ($p = 0.02$). The Levene's tests of the homogeneity of variance indicated that the error variance for each dependent variable is equal across groups ($p = 0.909$ for the ESAT posttest scores and $p = 0.198$ for the ATESI posttest scores). The Box's M test of equality of covariance matrices revealed that the observed covariance matrices of the dependent variables were also equal across groups ($p = 0.555$). The homogeneity of group regression assumption was also examined, and the results indicated that the assumption of parallelism of the regression planes was tenable because the F ratio yielded nonsignificant values for the covariate by treatment interaction effects for each covariate ($p > 0.05$). Therefore, the results of assumption tests permit use of the univariate analysis of covariance for this study.

Assumptions for the linear regression model were also checked to ensure that they were met in the analysis of regression model for the present study. The measures of each dependent variable were determined to be independent. The histogram of the standardized plot implied no violation of the normality assumption, and the standardized residual plots also indicated that assumptions of the linear regression model are tenable.

To meet contemporary calls for improvement in the interpretation and reporting of quantitative research in education (Rennie, 1998; Thompson, 1996), this study reports practical significance (effect magnitudes) along with statistical significance test. The effect size index eta squared (η^2) or f was used since it is more appropriate for the analysis of variance or covariance (Cohen, 1988). According to Cohen's rough characterization (1988, pp. 284–288), $f = 0.1$ is deemed as a small effect size, $f = 0.25$ a medium effect size, and $f = 0.4$ as the large effect size (for interpreting η^2 , $0.01 =$ “small,” $0.059 =$ “medium,” and $0.138 =$ “large”). Besides, measures of association or how much of the variability in the dependent variable is associated with the variation in the independent variable are used for examining proportion of variance such as R^2 in the regression analysis. This kind of data presentation method is quite important in terms of interpreting research results. Researchers have cautioned the insufficiency of using only the result of statistical significance testing in statistical inference (Cohen, 1988; Daniel, 1998; McLean & Ernest, 1998). This is mainly because the computation of statistical significance is related to the sample size involved in

TABLE 1
Descriptive Statistics of Students' Pretest and Posttest Scores on the ESAT and ATESI by Treatment

Treatment	Achievement (ESAT)		Attitude (ATESI)	
	Pretest <i>Mean (SD)</i>	Adjusted Posttest <i>Mean (SD)</i>	Pretest <i>Mean (SD)</i>	Adjusted Posttest <i>Mean (SD)</i>
TCCAI (<i>n</i> = 216)	62.03 (10.50)	66.33 (10.45)	108.92 (14.38)	107.94 (14.79)
SCCAI (<i>n</i> = 131)	61.38 (10.34)	65.60 (10.85)	108.89 (13.48)	105.86 (12.47)

the analysis. Moreover, it is quite common to observe a statistical significance with a large sample size, even if there was little practical effect actually. Therefore, to protect against statistical significant finding in terms of large sample size for the current study, effect magnitudes were also reported along with statistical significance test. Tests of the assumptions for the ANCOVA and multiple regression were undertaken using SPSS 11.5 (Statistical Package for Social Sciences version 11.5).

RESULTS

The descriptive statistics of students' pretest and adjusted posttest scores on the ESAT and ATESI by treatment are summarized in Table 1. Before reporting the results examining differential learning outcomes by different forms of computer-assisted instruction (CAI), we first need to determine the equivalence of incoming achievement and attitudes among groups. An ANOVA was computed on the pretest data and found all of them to be not significant ($p > 0.05$).¹ Thus, the groups all started out with approximately the same degree of incoming earth science achievement and attitudes. Besides, given the nested nature of the data, we have also examined the variances between individual classrooms. The Levene's tests of the homogeneity of variance indicated that the error variance for each dependent variable is equal across classrooms ($p = 0.416$ for the ESAT pretest, $p = 0.959$ for the ESAT posttest scores; $p = 0.110$ for the ATESI pretest, $p = 0.337$ for the ATESI posttest scores). Therefore, data analysis disaggregating to the student level is deemed appropriate for the current study.

This study further conducted ANCOVA tests on posttest scores with the pretest as the covariate on the achievement and attitude measures respectively to determine any significance between the two groups. A univariate analysis of covariance on the ESAT posttest scores with students' pretest scores as the covariate was conducted (see Table 2 results). The results revealed that the treatments did not play a role in student achievement outcome, $F(1, 341) = 0.587$, $p = 0.444$, $\eta^2 = 0.002$, $f = 0.045$, as shown in Table 2. However, the univariate analysis of covariance performed on the ATESI posttest scores with students' pretest measures as the covariates indicated that students in the TCCAI group attained better attitude than those in the SCCAI group did after the instructional treatments, $F(1, 341) = 4.393$, $p = 0.037$, $\eta^2 = 0.013$, $f = 0.115$, as illustrated in Table 2. According to Cohen's rough characterization (1988, p. 284–288), $f = 0.1$ is deemed as a small effect size.

As stated previously, this study further examined the possible interaction between instructional treatments and PLE orientations. Table 3 shows the results for the regression

¹An ANOVA test was also performed on student PLE data and there were no significant differences between groups and classes ($p > 0.05$).

TABLE 2
An Analysis of Covariance Summary for Student Achievement and Attitude

Dependent Variables	Univariate ANCOVA						
	<i>df</i>	<i>SS</i>	<i>MS</i>	<i>F</i> (1, 341)	<i>p</i> -Value	η^2	<i>f</i>
Achievement	1	43.218	43.218	0.587	0.444	0.002	0.045
Attitude	1	346.725	346.725	4.393*	0.037	0.013	0.115

* $p < 0.05$.

model of predicting the achievement outcomes by using achievement pretest scores, treatment conditions, PLE, and treatments \times PLE as predictors. The regression analysis revealed that the pretest score was the only significant predictor in explaining students' learning outcomes in achievement ($t = 13.5$, $p < .01$), suggesting the importance of prior knowledge in subsequent learning. No statistical interaction between instructional treatments and PLE orientations on the achievement outcomes was found.

A similar regression analysis was conducted on student attitude outcomes, illustrated in Table 4. Results showed an adjusted R square (R^2) = 0.604, F (4, 342) = 130.296, $p < 0.001$. Hence, about 60% of the outcome variance may be accounted for by the following variables: attitude pretest scores, treatment conditions, PLE, and treatments \times PLE. According to the regression model, it is plausible to find that student (attitude) pretest score was a significant variable in predicting their attitude outcomes. In addition, the instructional treatments also showed their significance in student attitude, and TCCAI students tended to display better attitudes toward the subject matter than SCCAI did ($t = 2.6$, $p < 0.05$). More importantly, there was a statistical interaction between instructional approaches (TCCAI vs. SCCAI) and student PLE orientations in determining student attitude outcomes ($t = 2.05$, $p < 0.05$). The interaction suggested that the teacher-centered instructional approach seemed to increase more positive attitudes of less constructivist-oriented leaning preferences students, whereas the student-centered method was more benefit to more constructivist-oriented leaning preferences students.

To better understand the interaction examined above, we plotted subjects' attitude outcome variable against with subjects' PLE data whose scores were one standard deviation above and below the mean to best illustrate the obtained interaction. This is shown in Figure 4. The figure showed the LCO students (less constructivist-oriented, one standard

TABLE 3
Regression Model Testing the Interaction Between Instructional Treatments and Student PLE on Achievement

Dependent Variable	Predicting Variables	<i>B</i>	<i>S.E.</i>	β	<i>t</i>	<i>p</i> -Value
Achievement	Ach. Pretest	0.60	0.04	0.59	13.50**	0.00
	Treatment	2.31	2.90	0.11	0.80	0.43
	PLE	0.51	1.17	0.02	0.44	0.66
	Treatment \times PLE	1.19	1.95	0.08	0.61	0.54
	Constant	26.29	3.56		7.39**	0.00

$R^2 = 0.352$; adjust $R^2 = 0.344$.

** $p < 0.01$.

TABLE 4
Regression Model Testing the Interaction Between Instructional Treatments and Student PLE on Attitude

Dependent Variable	Predicting Variables	<i>B</i>	<i>S.E.</i>	β	<i>t</i>	<i>p</i> -Value
Attitude	Att. Pretest	0.77	0.04	0.78	21.68**	0.00
	Treatment	7.76	2.99	0.27	2.60*	0.01
	PLE	-0.68	1.25	-0.02	-0.55	0.59
	Treatment \times PLE	4.12	2.01	0.21	2.05*	0.04
	Constant	17.05	4.82		3.54	0.00

$R^2 = 0.604$; adjust $R^2 = 0.599$.

* $p < 0.05$, ** $p < 0.01$.

deviation below PLE mean) receiving the teacher-centered strategies appeared to increase more positive attitudes compared to students taught by the student-centered instruction; while the MCO individuals (more constructivist-oriented, MCO, one standard deviation above PLE mean) seemed to benefit more from the student-centered approach in comparison with subjects learning from the teacher-centered condition.² Here, we also find that the differences between the treatments seem to be greater for the LCO individuals and lesser for the MCO students.

DISCUSSIONS AND IMPLICATIONS

The goal of this study was to investigate the effects of a teacher-centered versus student-centered computer-assisted instruction (CAI) on 10th graders' earth science student learning outcomes. It was found that there were no statistically significant differences on students' earth science achievement for either group. However, TCCAI group had significantly better attitudes toward earth science than did the SCCAI group with small size of effect concerning practical significance. It may be because the classroom teacher played a more important role in the TCCAI group by integrating human interactions and discussions sensibly within the classroom culture, which could not possibly be fully achieved through individual student's self-paced learning with his or her own computer. The emergence of the role of the teacher as an important factor in computer-aided instruction is perhaps an unsurprising finding. Fraser and Tobin (1989) synthesized some exemplary practice studies and reported that the biggest differences between classes of exemplary and nonexemplary teachers were closely related to classroom variables such as involvement, teacher support, order and organization. Therefore, the interactive and well-organized teaching strategies embedded in the TCCAI here might have some possible positive impacts on learners in light of the current study. It is noted, however, that the practical significance (effect size) found for the treatment effect is only small. Future replication studies concerning treatment effects might be needed to further substantiate the findings.

Another important goal of this current study was to explore whether the impacts of different models of CAI on Taiwanese 10th-grade students' earth science learning outcomes were

²Fifty-five LCO students (31 in TCCAI group and 24 in SCCAI group) were chosen based on their PLE scores (15 points) which were one standard deviation below the mean score (19.14 points), while 61 MCO students (33 in TCCAI group and 28 in SCCAI group) students were selected based on their PLE scores (23 points) which were one standard deviation above the mean score. The posttest scores shown in Figure 4 are the means (attitudes toward earth science) by the breakdown of treatment groups by student PLE orientations.

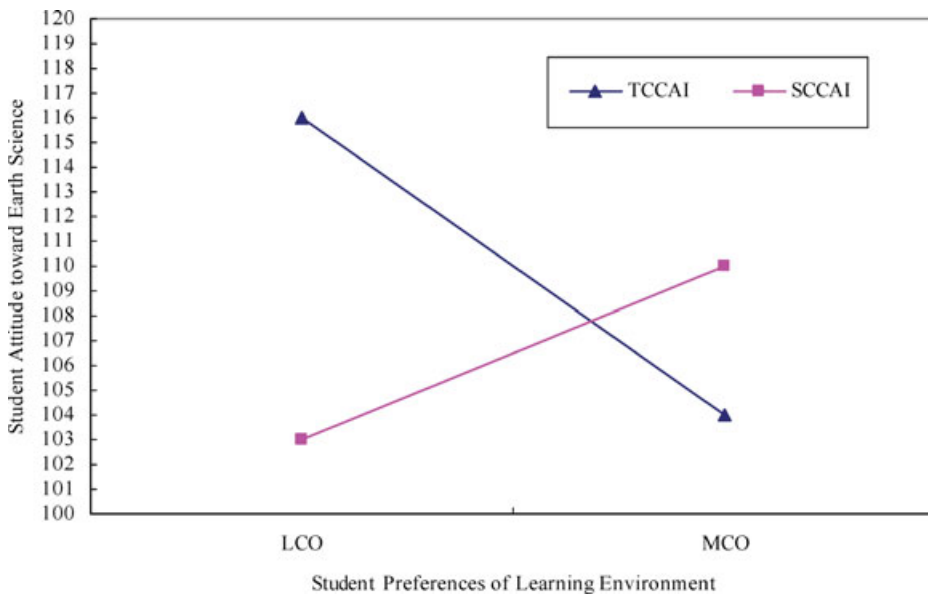


Figure 4. PLE-Treatment interaction on student attitudes toward earth science.

influenced by student preferences of learning environment in a senior high school of Taiwan. The results of the study showed that only interaction effect between student PLE and the treatment variable on student attitudes toward subject matter is statistically significant. The teacher-centered instructional approach seemed to increase more positive attitudes of less constructivist-oriented students, whereas the student-centered method was more benefit to more constructivist-oriented students. It may be because the learning environment supported by either the teacher-centered or student-centered instructional approaches matches specifically with students' preferences of learning environments. The interactive effect between the treatment and student preferences of learning environment, therefore, was reflected in students' posttest scores on the attitudes measures. Explicitly, when the treatments matched students' preferences of computer-assisted learning environment, students seemed to develop better attitudes toward the subject, and the reverse was also held true for the mismatched situation.

The results might be better explicated from both practical and pedagogical views. Maybe it is because the blend of the software with the whole class teaching format (TCCAI) provided less-constructivist students with systematic instructional content, organized presentation sequence, as well as human touches, all of which might have led to better improve pupils' attitudes toward earth science. On the other hand, the student self-paced learning scheme in front of individual computers (SCCAI) might have met more-constructivist students' needs in terms of providing them with the opportunities to individually and virtually conduct their own science investigations and work on their own problems instead of depending upon the teacher's explanations. In that case, more-constructivist students assumed the role of "knowledge pursuer," resulting in more or less development of those affective domains.

The results of the present study are, to a certain extent, in line with a previous study (Windschitl & Andre, 1998), which found that college student epistemological beliefs concerning learning environment influence their achievement when used a computer simulation as an instructional tool. They showed that students with more sophisticated epistemological beliefs (constructivist-oriented) learned more with a constructivist treatment and students

with less developmentally advanced beliefs learned more with an objectivist treatment. Tsai's (2000a) study indicated a related finding that open-ended inquiry-type instruction was especially beneficial to students having epistemological views more oriented to constructivist views of science, when their cognitive outcomes were compared to those with less mature epistemological views. The current study suggests that PLE-treatment interaction might also exist in student attitudes toward earth science in a computer-assisted learning environment; therefore, a future study exploring the relationships between student epistemological beliefs and their learning outcome in the affective domain might be much more fruitful.

The observed interaction between student PLE and treatment, as illustrated in Figure 4, shows some patterns. This figure displays that the effects of PLE-treatment interaction on student earth science attitude outcomes appear to diverge on different student PLE. The differences between treatments seem to be greater for the LCO individuals and much restricted for the MCO students in students' earth science attitudes. This finding suggests that PLE X treatment interaction is mainly caused by the outcome performance of less constructivist-oriented students in either group. These students seem to be more motivated by the teacher-centered scheme and less provoked by the student-centered approach. Why would such results be obtained? One explanation is that the LCO individuals preferred teacher's control over instruction and enjoyed structured computer-based learning environment. As a consequence, these students may have been more easily and rapidly to attend to the successful components provided by the teacher-centered scheme. In contrast, the same PLE students receiving the student-centered approach might have difficulty to sift through a large amount of information and data on the debris-flow hazards and get lost and frustrated under such conditions. Therefore, the potential benefit of the student-centered approach would be attenuated for this group of students that struggled to endure within the free-navigated and self-paced learning environment.

The aforementioned results are perhaps not very surprising, since Taiwanese students are generally quiet and passive learners and not inclined to enjoy self-learning very much. Besides, the teacher-centered teaching method has prevailed in the science classrooms for so long and students in Taiwan are quite familiar with the traditional method of classroom instruction (Chang and Mao 1999). The results might also shed some light on previous studies in this series which found that CAI emphasizing the teacher's role can result in increased student science achievement and attitudes (Chang, 2003, 2004). It would have become clearer if student PLE were taken into account in the aforementioned investigations. Future research conducted on the effectiveness of computer-based instruction should examine student PLE along with student learning outcomes.

The results of the current study, along with previous studies in the series, might also have some further instructional implications regarding the use of computer technology and the implementation of future computer-based instruction within secondary-science classrooms. Since the teacher-centered CAI is a relatively inexpensive, simple and portable teaching method compared with individual computer usage in the computer lab, the methodology can be reproduced for other subject areas or in situations where funding is low and resources are scarce such as the lack of uptake of computers for secondary science classes; the large screen could also be replaced with an interactive whiteboard leading to further interaction between the teachers and students.

Moreover, as the science class is usually a mixture of diverse students' orientations or preferences, the TCCAI using the multimedia software, a laptop computer, and a large screen might also be followed by students doing the follow up work at their own paces (SCCAI) in schools which have sufficient computer access for students. Namely, interactive whole class teaching could integrate the software with other teaching methods using either a large

screen or an interactive whiteboard, with options for students to do the follow-up work at their own pace in a computer room, and other possibilities. For instance, some “learning sections” could also be studied individually or in pairs in a computer room, such as the text-based *bookshelf* LS and the test-based *evaluation* section. In this combination way, the computer-assisted instruction might be beneficial to more students and accommodate students with various PLE orientations in the secondary science classroom.

The findings of this study also revealed that more attention should be paid to the interaction of students and learning environments, be it computer based or not, and that the mere introduction of a teacher-centered or student-centered software/instruction does not necessarily guarantee that all students will benefit from it. This study also suggests that teachers and those involved in CAI implementation should recognize the limitations of approaches under different forms of computer-based learning environments. A more detailed investigation concerning what worked and what did not for each group of students is needed in this area, so that designers of learning environments and practitioners can benefit from this type of future research.

In conclusion, a significant PLE-treatment interaction was found on student attitudes toward the subject matter and the interaction is possibly and primarily due to the outcome performance of less constructivist-oriented students as a result of the current study. Future replication studies concerning PLE-treatment interactions might be needed to further substantiate the findings. In addition, more evidence is needed by conducting studies employing longer treatments and larger samples or from studies that draw on qualitative data-collection methods. A further study is also needed to see if there are differential impacts on students’ learning outcomes between the treatments and PLE in the secondary school to additionally extend the conclusions. These issues are currently being examined with the development of a new battery (instrument) of science classroom learning environment and the design of entirely distinct teacher–student centered instructional methods.

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