Ninth-Grade Student Engagement in Teacher-Centered and Student-Centered Technology-Enhanced Learning Environments

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ABSTRACT: Engagement has been viewed as an important construct to understand students' learning performances in classroom settings. Taking an interactive perspective, the study investigates ninth graders' cognitive, emotional, and behavioral engagement in teacher-centered (TC) and student-centered (SC) technology-enhanced classrooms. 54 students from two science classes in Taiwan participated in this study. Multiple sources of data were collected during a 3-week instructional unit. The statistical results showed that although students in the SC class reported having significantly higher emotional engagement, the emotional engagement level had no impact on students' learning achievement. Analyses of qualitative data showed that students in both classes spent a majority of class time on cognitive involvement in learning activities, but there were qualitative differences

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in cognitive and behavioral engagement between the two classes. One type of activities that did not occur in the TC class was making reflections in which students in the SC class self-assessed what they did. In addition, the SC class usually interacted through group discussions provoked by the simulations, whereas the TC class frequently interacted through initiation–response–evaluation sequences and engaged in student-initiated discussions. The findings suggest that both instructional approaches promoted students' conceptual understanding and provided students with different opportunities to engage in science learning. *Sci Ed* **91:**727–749, 2007

INTRODUCTION

Many researchers in educational technology advocate the importance of integrating technologies into science teaching and learning (Kozma, Russell, Jones, Marx, & Davis, 1996; Linn & Hsi, 2000). Extensive use of technology in classrooms has the potential to support students' exploration of scientific ideas (de Jong & van Joolingen, 1998) and to enable student-centered learning (Brush & Saye, 2000; M. J. Hannafin & Land, 1997). Many studies on the effectiveness of technology-enhanced learning have used students' understandings about scientific concepts and their reasoning skills as primary measures (White & Frederiksen, 1998; Wu, Krajcik, & Soloway, 2001). Relatively little research has directed at investigating student engagement in technology-enhanced classrooms, in spite of the fact that student engagement has been viewed as an important construct to understand and predict students' learning performance (Fredricks, Blumenfeld, & Paris, 2004; Greenwood, Horton, & Utley, 2002; Lau & Roeser, 2002; Singh, Granville, & Dika, 2002).

In addition, past studies have found that when some teachers integrate technology into instruction, their use is to sustain their existing practice and to support a teacher-centered instructional approach (Cuban, Kirkpartick, & Peck, 2001). This finding is somewhat disappointing because technology is expected to transform the way science is taught (Dwyer, Ringstaff, & Sandholtz, 1991). Yet, in a technology-based classroom, a teacher-centered approach that emphasizes direct guidance, lectures, and demonstrations of teaching materials is sometimes more effective than a student-centered approach that allows students to do self-paced learning and to freely interact with technological tools. For example, having examined the impact of two instructional approaches of computer-assisted instruction (CAI) on student science learning, Chang (2003) found that students in teacher-directed CAI classrooms performed significantly better than those in student-centered CAI classrooms on achievement and attitude measures. In addition, some studies showed that students under a learner-controlled environment performed more poorly on cognitive tasks than on teacher-directed or program-controlled situations (R. D. Hannafin & Sullivan, 1996; Morrison, Ross, & Baldwin, 1992). However, little is understood about how students interact with class members and technological tools in classrooms with different instructional approaches. Thus, the purpose of the study is to investigate ninth-graders' engagement in teacher-centered and student-centered technology-enhanced classrooms where students used computer simulations to learn concepts about force and motion.

Following Herrenkohl and Guerra (1998) and Nystrand and Gamoran (1991), we take an interactive perspective to investigate students' engagement in technology-enhanced learning environments. In this study, engagement refers to students' involvement and participation in learning activities (Ryan & Patrick, 2001) and involves behavioral, emotional, and cognitive aspects (Fredricks et al., 2004). In addition to characterizing students' engagement, we are also interested in possible interactions among engagement, conceptual understanding, and students' achievement level. Thus, the research questions are as follows: (1) Which instructional approach does support students to develop better conceptual understandings about force and motion? (2) In what ways do students in two classes emotionally, cognitively, and behaviorally engage in technology-enhanced learning activities? (3) How do students' achievement levels interact with their conceptual understanding and engagement in the two classes?

THEORETICAL BACKGROUND

Engagement has long been viewed as a useful indicator of the quality of school learning and a predictor of student achievement level (Capie & Tobin, 1981; Nystrand & Gamoran, 1991; Tobin & Capie, 1982). Student engagement in classrooms contributes to their cognitive development (Greenwood et al., 2002; Lee & Anderson, 1993), and student-engaged time has a significantly positive correlation with their academic achievement measured by standardized tests (Capie & Tobin, 1981; Tobin & Capie, 1982). Although the concept of engagement has garnered much research attention in years, it was defined and measured in various ways in research literature. For example, Tobin and his colleagues defined engagement as students' involvement in learning activities (Capie & Tobin, 1981; Tobin & Capie, 1982). They regarded it as a quantitative construct that was related to the amount of time when students demonstrated cognitive behaviors such as attending, recalling, comprehending, and planning. On the other hand, Lee and Anderson (1993) focused on students' cognitive process as well as their motivational status and employed qualitative methods (e.g., classroom observations and informal interviews) to measure "students' engagement in classroom tasks with the goal of achieving better understanding of science in specific situations" (p. 590).

Having reviewed definitions and measures of engagement in the existing educational research, Fredricks et al. (2004) indicated that engagement is a multifaceted construct and implies behavioral, emotional, and cognitive participation in learning experiences. Behavioral engagement refers to involvement in classroom and extracurricular activities, such as positive classroom behaviors (Greenwood et al., 2002; Skinner & Belmont, 1993) and the amount of time spending on homework (Singh et al., 2002). Emotional engagement includes positive and negative emotions to school, teachers, or academic activities (Lau & Roeser, 2002). Cognitive engagement involves students' intellectual investment and effort to understand complex ideas and use thoughtful strategies (Blumenfeld & Meece, 1988; Corno & Mandinach, 1983). This multidimensional definition allows for richer characterizations of how students learn. Therefore, this study focuses on the three aspects of student engagement and aims at understanding how instructional approaches and students' achievement levels have impact on students' engagement.

Previous research has shown that instructional variables such as task design are closely related to student engagement. When students work in small groups or when tasks are procedurally complex, students demonstrate lower cognitive engagement (Blumenfeld & Meece, 1988; Nystrand & Gamoran, 1991). Nystrand and Gamoran (1991) also found a negative effect of small-group time on engagement and suspected that small-group time may have failed to include solving challenging problems collaboratively but instead involved answering textbook questions and filling out worksheets. These findings suggest that a student-centered approach that provides students with many opportunities to work and interact with peers in groups may not increase students' engagement in learning if the learning tasks are not well designed.

The issue of whether students engage more in a student-centered learning environment was also explored by researchers who were interested in learner control and choice. In a student-centered learning environment, students are expected to take an active role in their learning and the responsibilities of planning, organizing, and synthesizing the subject content. They have more choices about what they learn and how they learn, but do they engage more in such a learning environment? Findings from previous studies suggest that the answer is yes and no.

It has been known that greater perceived control results in a higher level of intrinsic motivation (Enzle & Anderson, 1993) and positive emotion (Patrick, Skinner, & Connell, 1993). In Flowerday and Schraw (2003), when a group of college students were given choices on how to complete a reading task, their emotional engagement was significantly higher than the no-choice group. However, Flowerday and Schraw also found that short-term choice had no effect on cognitive engagement measured by students' performances on the task. When students were given a choice of how long to study, they spent less time on learning and performed more poorly on cognitive tests than students who worked through the materials in the order and time frame given by the researchers. Similarly, several studies showed that students under a learner-controlled environment performed more poorly on cognitive tasks than on other controlled situations, such as teacher-directed (Chang, 2003) and program-controlled environments (R. D. Hannafin & Sullivan, 1996). Taken together, these studies indicate that there is a close relationship between student engagement and instructional approaches and that an instructional intervention may have different effects on different aspects of engagement.

In addition to the instructional variables, students' characteristics also interact with their cognitive and emotional engagement in classrooms. Lee and Anderson (1993) found that students in the same classroom demonstrated different patterns of task engagement and experienced and interpreted the academic tasks differently, even though they were taught by the same teachers using the same curriculum materials. This is similar to the observation made by Gallagher and Tobin (1987) about differential engagement; while some students in classrooms seemed to be overly engaged most of the time and answered a majority of questions asked by teachers, remaining students were passively engaged or disengaged. Greenwood et al. (2002) suggested that student achievement level might be one of the student characteristics that interact with engagement. They found that although students' engagement showed no significant differences among the high-, middle-, and low-achieving groups, the low-achieving group showed significantly more inappropriate behaviors. Greenwood et al. (2002), therefore, concluded that students' engagement was "differentially accelerated by instructional situations and interventions" (p. 328).

In summary, the studies reviewed above show the importance of treating engagement as a multidimensional concept and considering all three aspects of engagement (i.e., behavioral, emotional, and cognitive engagement). Engagement should be viewed beyond the behavior of individual students and indeed involves interactive processes among students, teachers, and the learning environment (Herrenkohl & Guerra, 1998). However, none of the studies investigated all three aspects of engagement and little is known about students' engagement in technology-enhanced classrooms. Thus, this study examines students' behavioral, emotional, and cognitive engagement in classrooms with different instructional approaches and investigates possible interactions among engagement, conceptual understanding, and students' achievement level. We used a self-report questionnaire to measure students' emotional engagement and analyzed discursive interactions between a teacher and her students in two technology-enhanced science classrooms. Below we provide a detailed account of the research design.

RESEARCH DESIGN

Setting

This study was conducted in a public junior high school (grades 7 through 9) located in Taipei city, serving approximately 2500 students. The school was one of the largest public junior high schools in the district and drew students from a majority of middle and upper-middle class families with a wide range of educational backgrounds. About one third of the students commuted to the school from across the Taipei city because the school graduates scored high on the senior high school entrance examination.

Fifty-four ninth graders in two classes participated in the study. Both classes were taught by the second author who held a master degree in science education and had taught science at junior high schools for 3 years. Before the study was conducted, the teacher had taught the two classes for a year during which she used computer simulations and animations occasionally and took a teacher-centered approach in both classes. She frequently asked questions to check on students' knowledge, modeled problem-solving processes, invited students to express their own ideas, and discussed conceptual questions raised by students. Prior to the study over 70% of the class instruction involved lectures, recitations, and guided discussion.

Student-Centered and Teacher-Centered Classes

Of the two science classes in the study, one class was randomly assigned as the student-centered (SC) class and the other, the teacher-centered (TC) class. In the SC class (25 students, 11 males), the teacher used minilectures and class discussions to introduce key ideas about force and motion. Students then used computers to manipulate simulations and worked in pairs to complete learning tasks at a computer laboratory. Each student pair could have different learning progress and take different approaches to learning tasks. The teacher provided support and guidance when she noticed students were having difficulty doing a task or when students asked for help. The design of learning activities was to encourage manipulation rather than simple acquisition of knowledge (M. J. Hannafin & Land, 1997; Pedersen & Liu, 2003).

In the TC class (29 students, 15 females), the key concepts about science were also introduced by the teacher's lectures and class discussions, but students did not have opportunities to use computers. Instead, the teacher used a projector linked to a laptop to demonstrate the simulations and guided students to complete the series of learning activities. Although the teacher was an authority and the focus of attention who delivered instruction, students actively participated in the teacher-guided discussion, volunteered their ideas to questions, and asked questions about the content.

In each class, students were categorized by the science scores they received in the previous semester as high (top 33%), medium (34th–67th percentile), and low (68th percentile and below) achievers. In addition, to collect detailed information about students' conversation and engagement, six students in each class were nominated by the teacher for intensive observation. Among the 12 focus students, 6 were female. The 12 focus students were identified as representing three achievement levels (high, medium, and low) based on their science performance records from the previous year. To understand how students' achievement levels interacted with their engagement, all focus students were formed into pairs and worked with another student who was at a similar achievement level.

Description of Physlets®

The computer simulations used in this study were Physlets® created by Wolfgang Christian at the Davidson College (http://webphysics.davidson.edu/Applets/Applets.html). Physlets are scriptable Java applets and interactive simulations that can be integrated into a variety of Internet-based applications (Christian, 1999). Physlets contain several features that help students visualize abstract concepts about force and motion. First, Physlets provide microworlds that allow students to explore scientific phenomena that are impossible, difficult, or time consuming to accomplish with actual laboratory or real-life experiences (Cox, Belloni, Dancy, & Christian, 2003). For example, students can manipulate unseen forces such as friction, mass, and speed in Physlets to explore ideas about Newton's laws.

Second, Physlets include one or more variables involved in a system or a scientific phenomenon and allow students to manipulate these variables and to see the effects on the system. This feature helps students identify relations among components of a system, test "what if" questions and explore a wide range of variables rapidly (de Jong & van Joolingen, 1998).

Third, Physlets provide multiple linked representations to enhance student understanding of concepts. Each Physlet presents learners with a number of representations simultaneously (see Figure 1) that allows students to learn a novel representation such as a velocity time graph by viewing familiar representations such as a simulation of two running dogs. This feature supports students to extend their experience and knowledge about motion to scientific representations such as line graphs. In addition, Physlets allow a representation changed by manipulating its connected representation or description. For example, when students increase the velocity of a running dog (Figure 1), the position–time (x–t) and velocity–time (v–t) graphs would change to reflect the movement of the dog. This

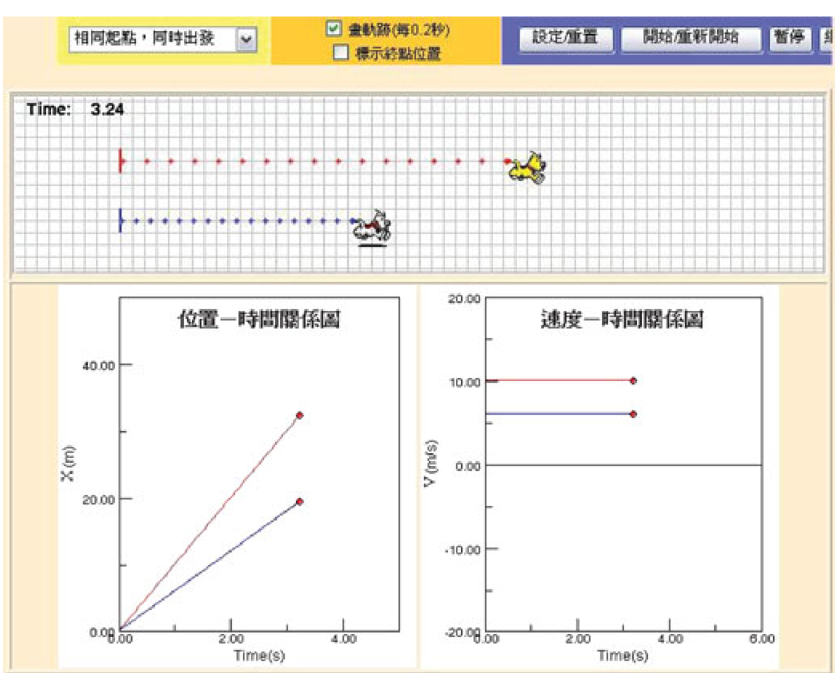


Figure 1. Multiple representations provided by a Physlet. [Color figure can be viewed in the online issue, which is available at www.interscience.wiley.com.]

feature enables students to visualize and correctly make conceptual connections between representations (Wu & Shah, 2004).

In this study, Physlets were modified for local use. We embedded the Chinese version of Physlets (http://www.phy.ntnu.edu.tw/demolab/) into HTML documents to create Physlet-based activities. Each activity included Physlets, guiding questions, and problems for group or class discussions.

The Instructional Unit

A 3-week instructional unit was designed to engage students in constructing understandings about motion and force. The unit took up nine 45-minute class periods and contained 11 learning activities with Physlets (Table 1). We followed White's inquiry cycle (White & Frederiksen, 1998) to guide students' use of Physlets. Each activity began with a question given by the teacher. Students then used the questions to formulate hypotheses through group work (SC class) or class discussions (TC class). Next, students developed strategies and procedures to carry out experiments with Physlets. In the SC class, students manipulated the simulations by themselves, while in the TC class the teacher demonstrated several experiments with Physlets. Finally, students analyzed the simulated results and made conclusions. In the TC class, the analyses of simulated results were substantially supported by the teacher and students were guided to generate appropriate conclusions through class discussions. In the SC class, students worked in groups to analyze the results; the conclusions students made may be inaccurate and they may not realize the errors until class discussions at the end of each class period.

TABLE 1
The Instructional Unit

Class	Period	Description
1	Classroom instruction	Introducing position, distance, displacement, path, velocity
2	Classroom instruction	Identifying and describing motion using position–time (x–t) and velocity–time (v–t) graphs
3	Classroom instruction	Describing changing motion and introducing acceleration and acceleration–time (a–t) graphs
4	Physlet-based activities	Activity 1: Identifying the differences between speed and velocity Activity 2: Constructing and interpreting x–t and v–t graphs
5	Physlet-based activities	Activity 3: Matching a v–t graph with the motion of a car Activity 4: Predicting positions of two moving objects Activity 5: Visualizing and graphing trajectories of moving points
6	Physlet-based activities	Activity 6: Identifying and visualizing changes of velocity Activity 7: Analyzing the process of free fall
7	Classroom instruction	Introducing Newton's first and second laws
8	Physlet-based activities	Activity 8: Newton's first law Activity 9: Newton's second law
9	Physlet-based activities	Activity 10: Visualizing and describing the effects of combined forces Activity 11: Using given information about force applied to predict changes in velocity and direction of motion

Data Collection

To examine students' engagement in the two classes, multiple sources of data were collected during the unit including classroom video recordings, field notes, students' worksheets, computer activity recordings, achievement tests, and self-report questionnaires.

Every class period was videotaped by a digital camcorder. During the whole-class activities, the camcorder was used to record class discussions and conversations between the teacher and students. When students worked in groups, the camcorder was pointed to the three focus student pairs to capture their gestures and actions (their seats close by each other), and their discussions were recorded by three digital audio recorders placed on their desks. Field notes were also taken to capture classroom activities. The classroom video and audio recordings illustrated students' cognitive and behavioral engagement in the learning activities and were later analyzed by a coding scheme that considered the nature of learning activities and the structure of classroom discourse.

Computer activity recordings captured activities on a computer screen and conversations of focus student pairs in the SC class. We installed a screen-capturing tool, Camtasia Studio, in students' computers to record their learning processes during all Physlet-based activities. The recordings were saved as video files that allowed detailed analyses of students' conversations and use of computer simulations.

An achievement test was designed to assess students' conceptual understandings about force and motion. The test consisted of 32 items that were adapted from the Force Concept inventory (Hestenes, 1992) and the Junior Mechanics Concept inventory (Cheng, 2002). The reliability coefficient was estimated at 0.94 using the Kuder–Richardson formula 20 (KR-20). The test was administered as the pretest, posttest, and delayed posttest to assess, respectively, initial understanding, changes, and retention of conceptual understanding up to 6 weeks later.

After the two classes completed the instructional unit, a self-report questionnaire was used to measure emotional engagement that involves students' emotions, anxiety, and interests to technology-based learning activities. The questionnaire was adapted from Huang (2002) and Flowerday and Schraw (2003) and consisted of 30 items using a 5-point Likert scale that ranged from strongly agree to strongly disagree. Examples of items include "I enjoy using computers to learn," "I feel anxious when using computers," and "I think that computers can help me learn." Internal-consistency reliability of the questionnaire, computed using Cronbach's alpha, was .91. Test–retest reliability assessed using the intraclass correlation coefficient was .83.

Data Analysis

The quantitative data (i.e., the achievement tests and the questionnaire) were analyzed by SPSS 11.0 (the Statistical Package for the Social Sciences). We used paired t tests to determine whether statically significant differences existed between the means of the two classes. To identify whether statistically significance differences existed among the three subgroups (high-, medium-, and low-achieving levels) in the two classes, we also conducted 2 (instructional approach) $\times$ 3 (achievement level) two-way ANOVA tests.

Students' cognitive and behavioral engagement was examined by analyzing the qualitative data including classroom video recordings, field notes, and computer activity recordings. We first transcribed the video recordings into text format. Each class period was then segmented into episodes. Within each episode, a classroom activity centered on the same conceptual theme (Jordan & Henderson, 1995). These transcripts were imported into a database and organized by the NVivo analysis software (QSR International, Doncaster, Victoria, Australia).

TABLE 2
The Categories for Analyzing Student Engagement

Activity	Interaction With Subject Matter	Cognitive Level	Cognitive Engagement	Behavioral Engagement
1. *Manipulating simulations*: Students manipulate variables on Physlets to test their ideas and solve problems	High	Varied	Yes	Yes
2. *Solving problems*: Students use physics concepts, equations, and mathematical techniques to solve problems	High	Varied	Yes	Yes
3. *Making reflections*: Students self-assess what they have done or go back to revise the answers they made on the worksheets	Varied	High	Yes	Yes
4. *Asking for help*: Students ask questions to clarify their confusion	Varied	Low	Yes	Yes
5. *Filling out worksheets*: Students answer the questions and complete worksheets without conversations about the questions and relevant concepts	Low	Low	Ambiguity	Yes
6. *Off-task*: Students demonstrate inappropriate behaviors or are in conversations indicating that they do not pay attention to the task at hand	None	Low	No	No

Because of the complex nature of student engagement, we conducted two levels of coding to characterize students' cognitive and behavioral engagement. In the first level of coding, we categorized classroom activities into six types (Table 2). For each type of the activities, we then analyzed its level of cognitive challenge and to what extent it allowed students to interact with subject matter. According to the cognitive level and interaction with subject matter, we identified the first four types of activity as cognitive engagement. One example of cognitive engagement was when students purposefully manipulated simulations in order to answer questions posted by the teacher or on the worksheets. If students just filled out worksheets without conversations about the questions and relevant concepts, they were identified as "behavioral engaged." Disengagement was coded when students were off task. This level of coding was to identify major learning activities and to provide an overview about what students did in the two classrooms. To further analyze the nature of students' engagement and their learning practices, in the second level of coding, we examined classroom discourse involved in the activities.

TABLE 3
The Categories for Analyzing Classroom Discourse

Potential	Reciprocity Between Participants	Contiguity of Talk
Discourse sequence		
Discussion: Classroom discourse involves back and forth dialogues where students have some input into and control over the discourse	High	High
Questioning: Classroom discourse involves a simple question-and-answer session, or an initiation–response–evaluation pattern	Low	Low
Describing: Classroom discourse is monologic and involves a low degree of reciprocity between conversants such that the teacher or a student describes ideas, provides information, or provides answers to simple questions	Low	Low
Discourse structure		
Uptake: The teacher (or a student) follows up on student (or group member) answers and incorporates these answers into subsequent questions	High	High
Evaluation: The teacher (or a student) substantially responds to a student (or group member) question, ask follow-up questions, and together work on the answers or related topics	Varied	Varied
Repeated question: The teacher (or a student) repeats questions to gather student (or group member) attention	Low	Varied
Repeated statement: The teacher (or a student) repeats previous descriptions or statements to ensure the correctness of its content	Low	Low

Classroom discourse involved in the activities was analyzed by its sequence and structure (Table 3), which were two different sets of categories used to code each class episode. For example, in an episode, the class engaged in a question-and-answer session and the teacher repeated a question several times to direct students' attention to critical features of a task. This episode was coded as "questioning" for the sequence and "repeated question" for the structure. A sequence or a structure that supported a higher level of reciprocity and contiguity of talk allowed students to have input into and control over the discourse and help them cognitively engaged in the task at hand (Nystrand & Gamoran, 1991). Reciprocity was defined as mutual exchange of ideas among participants and contiguity of talk depended on the extent to which a topic was sustained across conversation turns. For example, when class members had genuine dialogues about a topic that was initiated by student interest and not preplanned by the teacher (e.g., discussion), the reciprocity between the participants was high because all participants had contribution to the discussion. In addition, when the teacher or a student picked up on the substance of another student's response (uptake), the conversation was continued and the contiguity was established between receding and succeeding dialogues. This level of coding allowed us to take a close look at students' learning practices in each activity without simplifying students' engagement into only two types (i.e., cognitive and behavioral).

In addition to the discourse sequences and structures, the content of discourse (concept, technology, or task), the nature of questions generated by class members (related to concepts, simulations, or questions on worksheets), and the initiator of a discourse session were also analyzed. Three researchers analyzed the same set of data, and the interrater agreement among three coders was 0.89.

After the transcripts were coded, we reviewed the coded transcripts and identified the range of variation and counted the frequencies of occurrence of data. We then generated analytical notes, searched for assertions about students' engagement, and compared similarities and differences between students' engagement in the two classes. Assertions were validated by confirming evidence from the data corpus (Erickson, 1998).

FINDINGS

Conceptual Understandings

Students' conceptual understandings about force and motion were assessed by the achievement tests (Table 4). Paired two-sample t tests for means within a class showed statistically significant differences between the means of pretest and posttest (TC class: $t\ (28) = 9.234$, $p < .01$; SC class: $t\ (24) = 7.634$, $p < .01$) and between the means of pretest and delayed posttest (TC class: $t\ (28) = 9.341$, $p < .01$; SC class: $t\ (24) = 6.340$, $p < .01$). These results indicate that in both classes, students developed significantly better understandings about force and motion after engaging in the series of technology-enhanced learning activities. Yet, comparisons between the two classes showed no significant differences between the means of the two classes in the pretest, posttest, and delayed posttest (pretest: $t\ (53) = .684$, $p = .497$; posttest: $t\ (53) = .734$, $p = .465$; delayed posttest: $t\ (53) = .664$, $p = .509$). These results suggest that prior to the instruction students in the two classes had a similar level of prior knowledge and that both instructional approaches supported students to learn concepts about force and motion.

The test items were categorized based on the concepts involved (i.e., velocity, acceleration, free fall and gravity, and combined force). The statistical comparison results of students' performance on test items showed that the TC class performed significantly better on items that involved concepts of free fall and gravity, whereas the SC class received higher scores on items relating velocity and combined force. As we will present later in more detail, some of the student-initiated questions and features in Physlets seemed to provoke productive discussions about concepts that may contribute to differential learning outcomes.

To examine whether the instructional approaches had different effects on students with different achievement levels, 2 (instructional approach) × 3 (achievement level) two-way ANOVA tests were employed. We used gain scores as dependent variables to avoid the impact of individual differences on the level of content knowledge at the start of the study (Table 4). Gain scores were defined as the difference between pretest and posttest scores (Gain 1), and the difference between pretest and delayed posttest scores (Gain 2). The results of ANOVA tests showed no statistically significant impact of either instructional approach or achievement level on Gain 2, but a significant two-way interaction ($F(2, 48) = 4.709$, $p = .014 < .05$) was found when the dependent variable was Gain 1. These tests were followed by simple main effect tests on each instructional approach. In the TC class, the three achievement groups showed no significance difference on Gain 1 ($F(2, 26) = 1.754$, $p = .193$), whereas in the SC class there existed a significant difference among the three groups ($F(2, 22) = 3.867$, $p = .036 < .05$). Post hoc tests showed that in the SC class the high- and medium-achieving groups performed significantly better than the low-achieving group (high-low, $p = .013 < .05$; medium-low, $p = .034 < .05$).

TABLE 4
Descriptive Statistics of Students' Scores on the Achievement Tests

	Pretest (A)		Posttest (B)		Delayed Posttest (C)		Gain 1 (B−A)		Gain 2 (C−A)	
	TC Mean (*SD*)	SC Mean (*SD*)	TC Mean (*SD*)	SC Mean (*SD*)	TC Mean (*SD*)	SC Mean (*SD*)	TC	SC	TC	SC
Achievement (Total)	60.8 (11.9)	58.5 (12.5)	80.3 (11.3)	77.4 (17.2)	77.1 (11.2)	74.5 (16.9)	19.5	18.9	16.3	16.0
High achiever	64.5 (6.4)	67.3 (9.0)	86.6 (9.3)	87.6 (8.0)	83.5 (7.8)	82.6 (16.3)	22.1	20.3	19.0	15.3
Medium achiever	64.9 (11.3)	51.5 (12.1)	79.1 (8.2)a	75.6 (7.5)	77.3 (6.7)	71.3 (12.8)	14.2	24.1	12.4	19.8
Low achiever	48.5 (3.6)	48.8 (4.8)	71.0 (10.1)	60.4 (10.1)	65.8 (9.2)	55.8 (11.6)	22.5	11.6	17.3	7.0

The statistical results suggest four main findings. First, students' conceptual understandings about force and motion were significantly improved in both classes. It appears that neither one of the instructional approaches was better than another in terms of helping students learn the concepts. Second, compared to high- and medium-achieving groups, low-achieving students benefited less from the student-centered instructional approach (Table 4) and might need more guidance from the teacher when engaging in technology-enhanced learning activities. Third, high-achieving students could gain substantial understanding in either one of the learning environment, whereas medium-achieving students seemed to improve more in the student-centered learning environment (Table 4). The fourth finding is that the effects of instructional approach on different achieving groups did not last long. Although a significant difference between the means of pretest and posttest was found among the three achieving groups in the SC class, there was no interaction or main effect on the Gain 2 scores.

Emotional Engagement

To compare students' emotional engagement in the two classes, we conducted a paired sample t test between the means of the SC ($M = 89.82$) and TC classes ($M = 80.58$) using the total score on the self-report questionnaire as an outcome measure. This difference was statistically significant (t (53) $= -3.355$, $p = .002 < .01$). Students in the SC class reported having higher emotional engagement in a technology-based learning environment. The results of item analyses showed that students in the SC class reported having significantly lower anxiety level, higher confidence, and more positive attitude toward using computers for learning. It seems that choice and opportunities to use simulations and manipulate variables could have positive impact on students' emotional engagement (Flowerday & Schraw, 2003).

To examine whether students' emotional engagement and instructional approach interacted with their performance on the achievement posttest, we divided students into three groups by their scores on the questionnaire: highly engaged, engaged, and less engaged. We performed a 2 (instructional approach) $\times 3$ (emotional engagement level) two-way ANOVA test on the achievement posttest. No significant difference was found (interaction effect: $F(2, 37) = .078$, $p = .925$; main effects: $F(1, 37) = 1.531$, $p = .224$; $F(2, 37) = 1.381$, $p = .264$). This result suggests that emotional engagement level in computer-based learning had no impact on students' achievement.

Cognitive and Behavioral Engagement

Analyses of the classroom video recordings show that students in both classes spent a majority of class time on cognitive involvement in learning activities (TC: 68.3%; SC: 65.2%), approximately one fifth of class time on behavioral engagement (TC: 19.1%; SC: 18.6%), and relatively low amount of time on disengaged behaviors (TC: 12.6%; SC: 16.1%). Although students in the TC class seemed more cognitively engaged and exhibited fewer disengaged behaviors, the quantitative difference of cognitive engagement between the two classes was small. This may partially explain why there was no significant difference between the two classes on the achievement posttest scores.

Learning Activity. We analyzed the types of learning activities to understand in what learning activities students were engaged. We counted the number of instances of the learning activities, and the percentage in Figure 2 was calculated by dividing the number

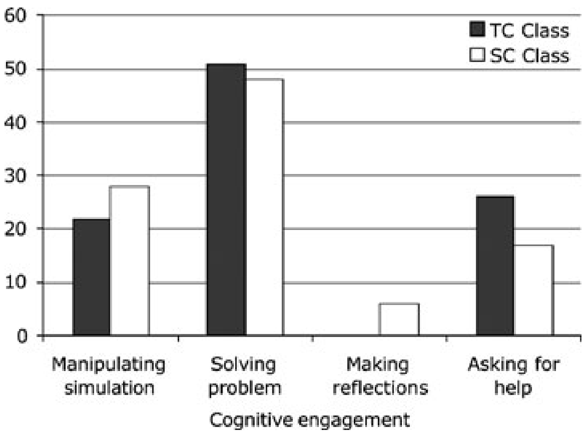


Figure 2. The activities that supported cognitive engagement in the two classes. The percentage was calculated by dividing the number of instances of an activity by the total number of instances of all activities.

of instances of an activity by the total number of instances of all activities. Figure 2 shows that the most engaging activity in the two classes was solving problems posted on the simulations and worksheets. In addition, compared to the SC class, students in the TC class asked for the teacher's help more frequently. This may be because in the TC class the teacher was the focus of attention while in the SC class students could share ideas with group members and generated answers through group discussions. One type of learning activities that did not occur in the TC class was making reflections in which students in the SC class went back to revise the answers they made on the worksheet. Because students were not given correct answers until the class discussion at the end of each lesson, they self-assessed what they did and became aware of their learning.

Discourse Sequence and Structure

Although the activities in which students engaged were similar in the two classes, analyses of classroom discourse showed qualitative differences between the two classes (Figure 3). Analyses of the discourse sequences in the two classes showed that a vast proportion of questions in the TC class were asked by the teacher in recitation and that students in the TC class usually engaged in simple question-and-answer and initiation–response–evaluation (IRE) sequences. In the SC class, students frequently described their ideas and provided information to their group members, and their conversations also involved question-and-answer sessions when the group members had disagreement or confusion about the tasks. One common feature in discourse sequences between the two classes was that discussions did not happen very often (Nystrand, 1997); less than 15% of the discourse sequences were discussion.

Analyses of discourse structure indicated that in general, the levels of reciprocity and contiguity of talk were low in the two classes. Class members in the two classes seldom follow up other members' answers so the frequency of uptake was not high (Figure 3). Evaluations always occurred during the question-and-answer and IRE sessions in the TC class, and students in the SC classes frequently evaluated each other's idea by giving a brief response (e.g., you're right; I don't think so) or repeating their previous statement. What follows are two examples.

Excerpt 1: (TC class 916-0913) The projector screen shows a velocity versus time graph. The teacher asks students about the line on the graph.

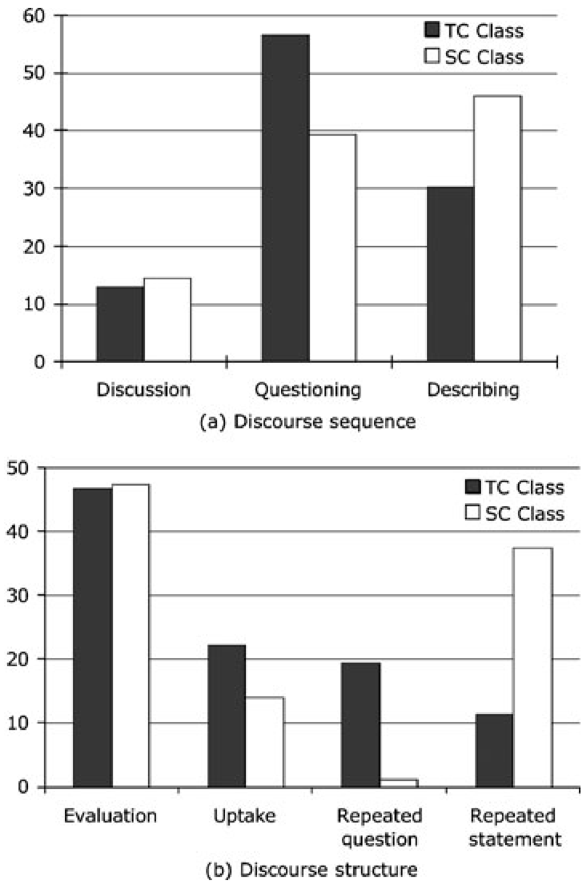


Figure 3. (a) The percentage of discourse sequences and (b) the percentage of discourse sequences structures in the two classes. The total percentage for each category (i.e., discourse sequence and discourse structure) was near 100%.

Teacher:	What does this horizontal line mean?
Hong:	Constant velocity.
Chia-Hua:	Constant velocity.
Teacher:	Very good, it shows the car is moving in constant velocity.

Excerpt 2: (SC class 917-910-336) Su-Lee and Shan-Lin is doing the fourth Physlet-based activity: Predicting positions of two moving objects. Su-Lee is controlling the mouse.

Su-Lee:	Wait, let's press the button once. Restart, okay. [The cars on the simulation start running.] At the start point, the velocities of the cars are the same. Then this car [yellow car] runs faster. Look, there's a long distance between them at the start point. Wait for the end. See, the red car is behind it [yellow car] now.
Shan-Lin:	So. . . it [yellow car] runs faster.
Su-Lee:	Yeah, it runs faster and faster.

The first excerpt is a typical example of an IRE sequence. A preplanned question was asked by the teacher; students then gave responses and the teacher provided a low-level evaluation by repeating the correct answer. Sometimes when students in the TC class did not provide appropriate responses, the teacher restated the question. This is why the frequency

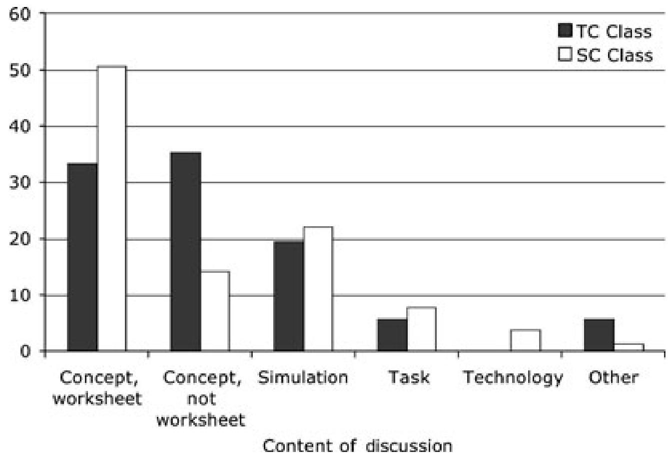
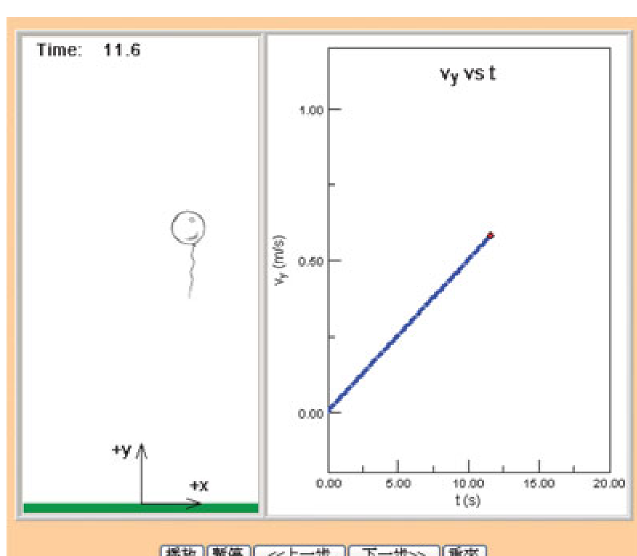


Figure 4. An analysis of the content of class discussions in the two classes.

of repeated question was higher in the TC class (Figure 3). On the other hand, students in the SC class interacted differently. Instead of asking preplanned questions, they stated their ideas or described what they saw in simulations when working in groups. In the second excerpt, Su-Lee described the motions of two cars in the simulation, and Shan-Lin signaled his agreement by repeating Su-Lee's observation "it runs faster." Thus, discourse in the SC class contained a high proportion of repeated statement (Figure 3).

The Content of Discussions. When the two classes engaged in thoughtful discussions, their focuses were slightly different (Figure 4). While students in the SC class mainly focused on the concepts directly related to the questions on worksheets, students in the TC class discussed conceptual questions on the worksheets as well as those that were not directly related to the worksheet questions. The excerpt below is an example.

Excerpt 3: (TC class 916-0923) The TC class is doing Activity 6: Identifying and visualizing changes of velocity. Students are viewing an animation of a moving balloon and a v–t graph that shows the balloon is moving with constant acceleration. Some students do not know why it is constant acceleration. [Color figure can be viewed in the online issue, which is available at www.interscience.wiley.com.]



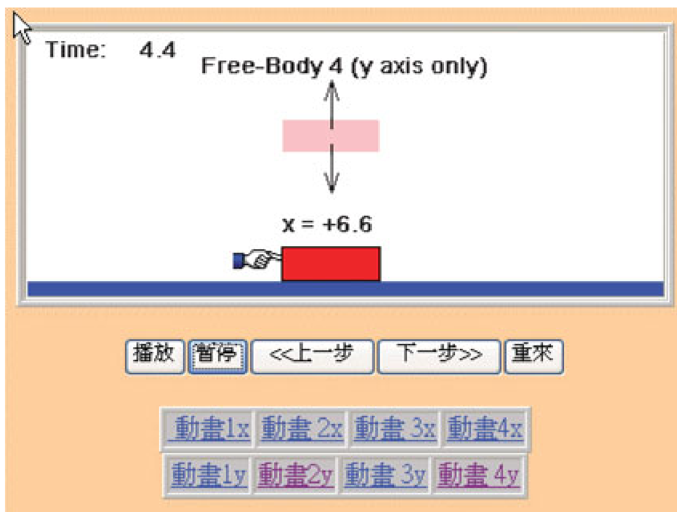
Shien:	Teacher, should air buoyancy be higher [when the balloon is moving up]?
De-Yu:	Air resistance becomes lower.
Teacher:	Air resistance is. . .
Students:	Lower.
Ping:	Why?
Shien:	Why? Because its [the balloon] volume becomes larger.
De-Yu:	Because air pressure is low.
Chia-Hua	Yeah.

In Activity 6, the animation of a moving balloon was to help students learn about changes of velocity. When watching the animation, Shien was confused about the phenomenon and initiated a discussion about air buoyancy and air resistance. The teacher and several students followed up on Shien's question and provided their ideas. The discussion involved scientific concepts (e.g., air resistance and air pressure) that were not what the teacher intended to teach. Thirty-seven percent of the discussions in the TC class were centered on conceptual questions that were not listed on the worksheets or preplanned by the teacher, and over 85% of these questions were raised by students. This high percentage suggests that student-initiated questions played a substantial role in provoking discussions among class members in the TC class.

In addition, the teacher selectively used student-initiated questions to identify students' possible confusions and took the opportunity to enhance their cognitive engagement and conceptual understanding. For example, in the TC class, there were three episodes involved open discussions about free fall and gravity. In the first episode (Physlet-based Activity 7), after viewing an animation of the process of free fall, one student used two classmates with different weights as an example and asked the teacher whether the weight of the falling body affected the terminal velocity. Several students began to talk about their ideas and the teacher did not provide an answer during the episode but told them that they would explore more about the topic in the next activity. In the second episode of free fall, the teacher revisited the question and invited students to apply Newton's laws of motion to explain why all objects regardless of weight free fall with the same acceleration. In the third episode (Activity 10), after watching an animation the teacher wanted to ensure that students understood the relationship between acceleration and gravity so she had a student draw a free-body diagram on the blackboard showing the force acting upon a falling object. One student raised a question about the direction of force and believed that there was a force "pushing" the object. The class started discussing whether the arrow should start from the object or point toward it and which way was better to show the direction of gravity. The three episodes were not initially designed in lesson plans. Under the teacher's guidance, students in the TC class had multiple opportunities to explore ideas about free fall during Physlet-based activities. This might explain why compared to the SC class, the TC class performed significantly better on items that involved concepts of free fall and gravity. These episodes also show that student-initiated questions could change the flow of lessons and possibly affect the learning outcome when class members took them as opportunities to learn.

We also found that students in the SC class raised conceptual questions that were not listed on the worksheet (13% among all the questions discussed). Yet, a majority of them were asked during the first three activities. Students seemed to realize that these questions could not be answered without support from the teacher or other resources, so during the last five Physlet-based activities, target students in the SC class turned all their attention to the worksheet questions.

Although student-initiated questions were fewer in the SC class and students spent most of their time answering questions designed by the teacher, they engaged in rich discussions about concepts when using Physlets. Through manipulating simulations, students examined their predictions, clarified confusion, and reinforced concepts developed during previous activities. The excerpt below is an example.



Excerpt 4: (SC class 917-923) An animation shows an object moving with constant speed toward the right. Students are asked to determine the horizontal (*x* axis) and vertical (*y* axis) forces applied on the object. They have to choose two animations from 8 animations (1x to 4x and 1y to 4y) to represent motion in two dimensions. [Color figure can be viewed in the online issue, which is available at www.interscience.wiley.com.]

So-Hang:	Click on play, play.
Shuen:	Okay, let's play it.
So-Hang:	Very weird.
Shuen:	It [the object] doesn't go up or down. This of course is balanced.
So-Hang:	We should choose 4s [4x and 4y], right?
Shuen:	Yes, because the two forces are balanced. The combined force is zero. This means constant velocity.
Shuen:	[Writing down the conclusion] The first answer is, the combined force [in the *x* axis] is zero, moving with constant velocity. The second answer is, the combined force [in the *y* axis] is zero. . .
So-Hang:	No, it's not constant velocity [in the *y* axis].
Shuen:	It's at rest.
So-Hang:	Wait, do you see it stop?
Shuen:	Up and down, do you see it go up or down?
So-Hang:	But the object is moving.
Shuen:	But look at here [animation 4y]. Does it [the object on the animation 4y] go down?
So-Hang:	No, so 4y is wrong.
Shuen:	The combined force is zero, it means no up and down movement. Let's write it down. The combined force, going down, is zero.

So-Hang:	But these two forces [on the animation 4y] are equal. Let's play it again.
Shuen:	Yes, these two are equal. Together with the animation 4x, it shows constant velocity [in the *x* axis].
So-Hang:	But. . .
Shuen:	The combined force is zero. It [The object] stays here. It doesn't run up or down. It stays along the line.
So-Hang:	Oh, okay, I got it. But you can't say it's at rest. At rest means no movement.
Shuen:	Okay, up and down. The combined force toward up and down is zero, so there is no up and down movement. That's it.

Independence of motion in two dimensions was a difficult concept for the ninth graders to understand. In this excerpt, Shuen tried to explain to her partner that when the combined force applied to an object is zero, it moves with constant velocity or is at rest. Yet, So-Hang did not realize the independence and insisted that the object in the animation was moving. Through the discussion, Shuen articulated her ideas and used the terms "up and down" or "staying along the line" to differentiate between motions in two dimensions.

The excerpt shows that in the SC class, students' use of animations supported their cognitive engagement in learning. Without animations, it could have been even more difficult for the two students to discuss ideas about "moving" and "at rest." Through manipulating simulations and playing animations, students could examine their existing ideas, negotiate meanings, articulate their ideas about combined force, and explore the relationships between force and motion.

Differences Among Achieving Groups in the SC Class. We compared students' engagement across the three target groups in the SC class and found that all the groups spent a majority of class time on cognitive involvement in learning activities (high: 63.3%; medium: 62.6%; low: 62.0%). The high-achieving group was more behaviorally engaged than other groups (high: 28.1%; medium: 23.1%; low: 16.7%) and similar to what was found in Greenwood et al. (2002), the low-achieving group demonstrated more disengaged behaviors (high: 8.6%; medium: 14.2%; low: 21.3%).

Among the four types of activities in which students engaged, all groups spent a majority time on solving problems (high: 49.3%; medium: 51.3%; low: 48.5%). Compared to the medium-achieving group, the high- and low-achieving groups asked for help more often (17.6% and 17.7%), but the nature of help that the two groups sought from their peers and the teacher was different. The high-achieving group asked more questions about task; over 50% of their questions were to look for confirmation about what they were supposed to accomplish in a task. The low-achieving group sought help for completing tasks as well as for checking the correctness of answers to worksheets questions; they usually looked for answers from the group sitting next to them but seldom asked why and how the answers were generated.

In addition, analyses of discourse sequence and structure showed that the high-achieving group engaged in discussions about concepts, challenged each other's ideas, and asked for explanations. Excerpt 4 shown previously is one example of the high-achieving group's discussions. On the other hand, the low-achieving group's conversations contained more repeated statements and fewer uptakes, as shown in Excerpt 2.

Topics discussed among the group were also different among the three achieving groups in the SC class (Figure 5). Discussions in the high- and medium-achieving groups involved more scientific concepts, whereas discussions in the low-achieving focused more on procedures to complete a task and on technical issues of simulations. This suggests that low-achieving students needed more guidance to direct their attention toward the

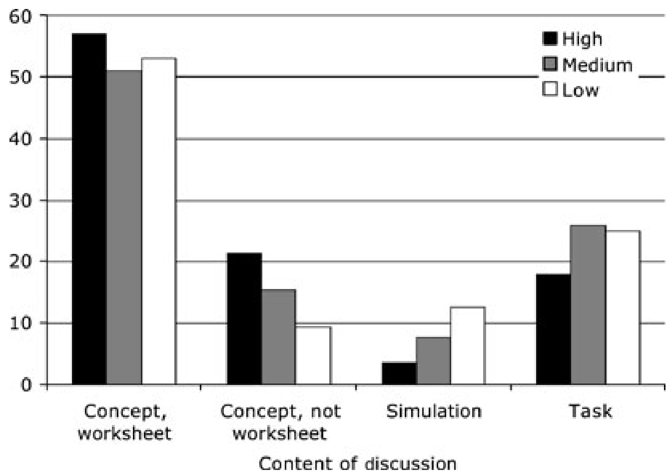


Figure 5. An analysis of the content of class discussions among three achieving groups in the SC class.

conceptual aspect of a task. They also needed support to engage in productive discourse that included discursive features such as evaluating each other's ideas, following up on answers, negotiating meanings, and asking for explanations. Engaging fewer conceptual discussions, low-achieving students did not gain as much as high- and medium-achieving students (Table 4).

DISCUSSION AND CONCLUSIONS

Engagement has been viewed as an important construct to understand students' learning performances in classroom settings. As Salomon, Perkins, and Globerson (1991) argued, "although intelligent computer tools offer a partnership with the potential of extending the user's intellectual performance, the degree to which this potential is realized greatly depends on the user's volitional mindful engagement" (p. 4). To understand how students learn scientific concepts in technology-enhanced learning environments, this study investigates ninth graders' cognitive, emotional, and behavioral engagement in teacher-centered and student-centered classrooms by taking an interactive perspective.

Research on student engagement has reported mixed findings for choice and student-centered learning (Chang, 2003; R. D. Hannafin & Sullivan, 1996; Morrison et al., 1992). This study provides evidence that different instructional approaches do not lead to significant differences in students' performances on achievement tests. Rather, different instructional approaches provide students with different opportunities to engage in science learning. In this study, students in the SC class reported having significantly higher emotional engagement, made reflections about what they did, and centered their discussions on the content of simulations, while students in the TC class interacted through initiation–response–evaluation sequences, discussed student-initiated questions, and explored difficult concepts under the teacher's guidance.

In addition, the role of computer simulations was different in the two classes. In the TC class, simulations displayed the content, provoked student-initiated questions, and allowed students to visualize phenomena. In the SC class, simulations were used to negotiate meanings, clarify confusions, examine predictions, and reinforce concepts developed during previous activities. The findings suggest that instructional approaches shape students' learning experiences and allow them to engage in different learning activities such as making reflections, holding a positive attitude toward learning, raising conceptual questions, and generating thoughtful discussions about the content learned. Teachers should consider the question of "what are desirable learning activities" when deciding the implementation of instructional approach.

Another significant finding of this study is that students' achievement levels could interact with instructional approaches. Low-achieving students benefited more from the teacher-centered instructional approach; in the TC class, they improved as much as the high-achieving groups did. Yet, in the SC class, the high- and medium-achieving groups performed significantly better than the low-achieving group. In addition, the low-achieving group in the SC group demonstrated more disengaged behaviors and engaged in fewer conceptual discussions; disengagement seemed to have a negative impact on learning achievement (Nystrand & Gamoran, 1991). These findings suggest that one instructional approach does not meet all students' needs and that structured instruction might be more helpful for low-achieving students.

There are reasons that might cause the significant interaction effect between instructional approach and achievement level. Compared to students in the TC class, low-achieving students in the SC class did not receive direct support from the teacher that could constantly draw their attention to the content. They also had fewer opportunities to listen to or engage in thoughtful discussions about concepts. Therefore, learning environments should provide guidance or ongoing scaffolds to enhance low-achieving students' engagement. Teachers might also consider combining different instructional approaches for learning topics to support students with different achieving levels.

The analyses of differences among the achieving groups suggest ways to enhance student engagement. First, low-achieving students tended to ask for help from students sitting next to them rather than the teacher. Appropriate seat arrangement and group composition could help low-achieving students have timely support from their peers (Krajcik, Czerniak, & Berger, 1999). Second, when high-achieving students were cognitively engaged, they raised conceptual questions, evaluated each other's ideas, followed up on answers, negotiated meanings, and asked for explanations. Teachers, technological tools, and instructional materials could use coaching strategies or provide semantic guidance to engage low-achieving students in similar dialogue sequences (Polman & Pea, 2001).

In addition to cognitive and behavioral engagement, this study examines students' emotional engagement in technology-enhanced classrooms. The statistical results show that choice and opportunities to use simulations and manipulate variables could have positive impact on students' emotional engagement but the emotional engagement level in computer-based learning had no impact on students' achievement (Flowerday & Schraw, 2003). Because of the qualitative nature of cognitive engagement, this study does not explore the possible relationships between emotional and cognitive engagement. Neither does the study consider the long-term changes of emotional engagement when students learn science (Sansone & Thoman, 2005). Future research could consider using multiple instruments to measure emotional engagement over time and focus on the interactions among the three aspects of engagement.

REFERENCES

Blumenfeld, P. C., & Meece, J. L. (1988). Task factors, teacher behavior and students' involvement and use of learning strategies in science. Elementary School Journal, 88, 238–249.

Brush, T., & Saye, J. (2000). Implementation and evaluation of a student-centered learning unit: A case study. Educational Technology Research and Development, 48(3), 79–100.

Capie, W., & Tobin, K. (1981). Pupil engagement in learning tasks: A fertile area for research in science teaching. Journal of Research in Science Teaching, 18(5), 409–417.
Chang, C. Y. (2003). Teaching earth sciences: should we implement teacher-directed or student-controlled CAI in the secondary classroom? International Journal of Science Education, 25(4), 427–438.
Cheng, R.-F. (2002). Junior high school students' conceptual understandings about force and motion. Unpublished master's thesis, National Taiwan Normal University, Taipei, Taiwan.
Christian, W. (1999). Physlets: Delivering media-focused problems anytime anywhere. Computer Physics Communications, 121–122, 569–572.
Corno, L., & Mandinach, E. B. (1983). The role of cognitive engagement in classroom learning and motivation. Educational Psychologist, 18(2), 88–108.
Cox, A. J., Belloni, M., Dancy, M., & Christian, W. (2003). Teaching thermodynamics with Physlets in introductory physics. Physics Education, 38(5), 433–440.
Cuban, L., Kirkpartick, H., & Peck, C. (2001). High access and low use of technologies in high school classrooms: Explaining an apparent paradox. American Educational Research Journal, 38(4), 813–834.
de Jong, T., & van Joolingen, W. R. (1998). Scientific discovery learning with computer simulations of conceptual domains. Review of Educational Research, 68(2), 179–201.
Dwyer, D. C., Ringstaff, C., & Sandholtz, J. H. (1991). Changes in teachers' beliefs and practices in technology-rich classrooms. Educational Leadership, 48, 45–52.
Enzle, M. E., & Anderson, S. C. (1993). Surveillant intentions and intrinsic motivation. Journal of Personality and Social Psychology, 64, 257–266.
Erickson, F. (1998). Qualitative research methods for science education. In B. J. Fraser & K. G. Tobin (Eds.), International handbook of science education (pp. 1155–1173). Dordrecht, The Netherlands: Kluwer.
Flowerday, T., & Schraw, G. (2003). Effect of choice on cognitive and affective engagement. Journal of Educational Research, 96(4), 207–215.
Fredricks, J. A., Blumenfeld, P. C., & Paris, A. H. (2004). School engagement: Potential of the concept, state of the evidence. Review of Educational Research, 74(1), 59–109.
Gallagher, J. J., & Tobin, K. (1987). Teacher management and student engagement in high school science. Science Education, 71(4), 535–555.
Greenwood, C. R., Horton, B. T., & Utley, C. A. (2002). Academic engagement: Current perspectives on research and practices. School Psychology Review, 31(3), 328–349.
Hannafin, M. J., & Land, S. M. (1997). The foundations and assumptions of technology-enhanced student-centered learning environments. Instructional Science, 25, 167–202.
Hannafin, R. D., & Sullivan, H. J. (1996). Preferences and learner control over amount of instruction. Journal of Educational Psychology, 88, 162–173.
Herrenkohl, L. R., & Guerra, M. R. (1998). Participant structures, scientific discourse, and student engagement in fourth grade. Cognition and Instruction, 16(4), 431–473.
Hestenes, D. (1992). Modeling games in the Newtonian world. American Journal of Physics, 60, 440–454.
Huang, S.-J. (2002). Development of an attitude survey to gauge junior high school students' attitude toward computer-based learning. Unpublished master's thesis, National Kaohsiung Normal University, Kaohsiung, Taiwan.
Jordan, B., & Henderson, A. (1995). Interaction analysis: Foundations and practice. Journal of the Learning Sciences, 4(1), 39–103.
Kozma, R. B., Russell, J., Jones, T., Marx, N., & Davis, J. (1996). The use of multiple, linked representations to facilitate science understanding. In S. Vosniadou, E. D. Corte, R. Glaser, & H. Mandel (Eds.), International perspective on the psychological foundations of technology-based learning environments (pp. 41–60). Mahwah, NJ: Erlbaum.
Krajcik, J. S., Czerniak, C. M., & Berger, C. (1999). Teaching children science: A project-based approach. Boston: McGraw-Hill.
Lau, S., & Roeser, R. W. (2002). Cognitive abilities and motivational processes in high school students' situational engagement and achievement in science. Educational Assessment, 8(2), 139–162.
Lee, O., & Anderson, C. W. (1993). Task engagement and conceptual change in middle school science classrooms. American Educational Research Journal, 30(3), 585–610.
Linn, M. C., & Hsi, S. (2000). Computers, teachers, peers: Science learning partners. Hillsdale, NJ: Erlbaum.
Morrison, G. R., Ross, S. M., & Baldwin, W. (1992). Learner control of context and instructional support in learning elementary school mathematics. Educational Technology, Research and Development, 40, 5–13.
Nystrand, M. (1997). Opening dialogue: Understanding the dynamics of language and learning in the English classroom. New York: Teachers College Press.

Nystrand, M., & Gamoran, A. (1991). Instructional discourse, student engagement, and literature achievement. Research in Teaching of English, 25(3), 261–290.

Patrick, B. C., Skinner, E. A., & Connell, J. P. (1993). What motivates children's behavior and emotion? Joint effects of perceived control and autonomy in the academic domain. Journal of Personality and Social Psychology, 62, 625–633.

Pedersen, S., & Liu, M. (2003). Teachers' beliefs about issues in the implementation of a student-centered learning environment. Educational Technology Research and Development, 51(2), 57–76.

Polman, J. L., & Pea, R. D. (2001). Transformative communication as a cultural tool for guiding inquiry science. Science Education, 85, 223–238.

Ryan, A. M., & Patrick, H. (2001). The classroom social environment and changes in adolescents' motivation and engagement during middle school. American Educational Research Journal, 38(2), 437–460.

Salomon, G., Perkins, D. N., & Globerson, T. (1991). Partners in cognition: Extending human intelligence with intelligent technologies. Educational Researcher, 20(3), 2–9.

Sansone, C., & Thoman, D. B. (2005). Does what we feel affect what we learn? Some answers and new questions. Learning and Instruction, 15, 507–515.

Singh, K., Granville, M., & Dika, S. (2002). Mathematics and science achievement: Effects of motivation, interest, and academic engagement. Journal of Educational Research, 95(6), 323–332.

Skinner, E. A., & Belmont, M. J. (1993). Motivation in the classroom: Reciprocal effects of teacher behavior and student engagement across the school year. Journal of Educational Psychology, 85(4), 571–581.

Tobin, K., & Capie, W. (1982). Relationships between formal reasoning ability, locus of control, academic engagement and integrated process skill achievement. Journal of Research in Science Teaching, 19(2), 113–121.

White, B. Y., & Frederiksen, J. R. (1998). Inquiry, modeling, and metacognition: Making science accessible to all students. Cognition and Instruction, 16(1), 3–118.

Wu, H.-K., Krajcik, J. S., & Soloway, E. (2001). Promoting understanding of chemical representations: Students' use of a visualization tool in the classroom. Journal of Research in Science Teaching, 38(7), 821–842.

Wu, H.-K., & Shah, P. (2004). Exploring visuospatial thinking in chemistry learning. Science Education, 88, 465–492.