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RESEARCH REPORT

Internet-based Science Learning: A review of journal publications

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Internet-based science learning has been advocated by many science educators for more than a decade. This review examines relevant research on this topic. Sixty-five papers are included in the review. The review consists of the following two major categories: (1) the role of demographics and learners' characteristics in Internet-based science learning, such as demographic background, prior knowledge, and self-efficacy; and (2) the learning outcomes derived from Internet-based science learning, such as attitude, motivation, conceptual understanding, and conceptual change. Some important conclusions are drawn from the review. For example, Internet-based science learning is equally favorable, or in some cases more so, to learning for female students compared to male students. The learner's control is essential for enhancing students' attitudes and motivation toward learning in Internet-based science learning environments. Nevertheless, appropriate guidance from teachers, moderators, or the Internet-based learning environment itself is still quite

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crucial in Internet-based science learning. Recommendations for future research related to the effects of Internet-based science learning on students' metacognitive reflections, epistemological development, and worldviews are suggested.

Keywords: *Science learning; Literature review; Internet; Web; Technology-based learning environment*

Introduction

Over the past decade, the Internet has become commonplace in various aspects of educational practices, and it has made a considerable impact on teaching and learning at all levels of schools (Heller, Tsai, & Underwood, 2010; Jonassen, Peck, & Wilson, 1999; Knezek & Christensen, 2002). Educational researchers have advocated that Internet-based instruction can provide learners with distant yet highly interactive, richly broad, individualized, and inquiry-oriented learning activities, thus promoting their knowledge construction and meaningful learning (e.g., Chou & Tsai, 2002; Tsai, 2001a).

In many different disciplines, the Internet has been largely utilized by teachers to improve students' learning outcomes (e.g., Hug, Krajcik, & Marx, 2005; Riffell & Sibley, 2005); science is no exception. Consequently, Internet-based science instruction has been increasingly implemented, and students' learning processes and outcomes of Internet-based science learning environments (ISLEs) have been increasingly highlighted by educators and researchers in science education (Tsai, 2001b). ISLEs have been implemented in various forms, such as the utilizations of online resources (and searching), simulation/animation, virtual reality, discussion forums, video-conferencing, online game-based learning, web 2.0 applications (e.g., blog, wiki), or combinations of different forms.

Numerous studies have been conducted to investigate how students learn science in ISLEs and how they benefit from ISLEs. A few reviews have been done previously about general trends of Internet-based education or educational technologies (Linn, 2003; Moos & Azevedo, 2009; Tallent-Runnels, Thomas, Lan, & Cooper, 2006; Winn, 2002). For example, Winn (2002) suggested that the foci of educational technologies have shifted from emphasizing content, format, interaction, to creating 'learning environments.' Moos and Azevedo (2009) emphasize reviewing the role of computer self-efficacy in computer-based learning. In reviewing empirical studies about implementing Internet-based courses, Tallent-Runnels et al. (2006) synthesized findings in four areas: course environments, learners' outcomes, learners' characteristics, and institutional and administrative factors. Most previously published reviews did not focus on the potential effects of Internet or educational technologies on teaching or learning in any particular discipline. Linn's (2003) review is one of the few articles that discussed the trends of advancement in technology, including computer and Internet, and their applications in the content and learning environments for science education. However, Linn's (2003) paper did not set out to be a systemic or comprehensive review of empirical evidence about students' learning. A more thorough review will be helpful to get potential insights for implementing ISLEs and to suggest possible directions for further research. Therefore, this paper aims to review relevant research regarding ISLEs.

This review addressed the following two questions: (1) what characteristics (or demographics) of the learners can play essential roles during science learning in ISLEs? and (2) what are the major outcomes attributed to learning in ISLEs? Guided by the above questions, we categorized the reviewed studies into two major categories. The first category included studies that explored the role of learners' demographics or characteristics in Internet-based science learning. Learners' characteristics included prior knowledge and self-efficacy. The second category included studies that examined the effects of ISLEs on students' learning outcomes. Both outcomes in general to learning and outcomes specific to science education are considered in this review. Attitude, motivation, conceptual understanding, conceptual change, argumentation, general cognitive skills, cognitive skills specific to science inquiry, and person-to-person interaction are areas of outcomes reviewed in this category. Details of the selecting procedures and the analytical framework for coding relevant studies are discussed in the methodology section.

The aforementioned categories of learner's characteristics and learning outcomes have been widely researched in traditional learning settings and are worth further investigation in ISLEs. For example, students' demographics and prior knowledge have been continuously emphasized and examined in prior research in science learning in a traditional learning environment (Catsambis, 2006; Cuevas, Lee, Hart, & Deaktor, 2005; Hewson, 1982). Nonetheless, Internet-based learning environments, such as online information searching systems and online discussion forums, may challenge students due to their abundant resources, variety of interactions, dynamic interfaces, and diverse categories of online learning tasks (Tsai, 2009). These challenges may result in learning outcomes different from those in traditional learning environments. In addition, some of the learning outcomes examined in this review, such as conceptual understanding, conceptual change, argumentation, and cognitive skills specific to science inquiry, were tailored to learning in science education.

Methodology

The Social Sciences Citation Index (SSCI) database was the literature source for this review. The goal of this study was to review SSCI journal articles regarding ISLEs published from 1995 to 2008. SSCI is one of the highly recognized databases that indexes core journals in social sciences including science education and educational technology. The searching time period was set after 1995 because we believed prior to 1995 Internet technology was not mature enough to be widely utilized for educational research. Also, with an attempt to review studies that are potentially more consistent in their quality, this study focuses solely on journal articles. Thus, research published in any types of publications other than journal articles, such as in conference proceedings, unpublished dissertations, books or book chapters were not included. To this end, the research papers of this study were identified by following procedures in three major stages. In the first stage, the researchers searched the electronic database by using ISLE keywords. In this stage, the searching engine systematically identified journal articles with the desired keywords. To be included, each study should include at least one keyword regarding science learning and at least one keyword related to Internet technology. The keywords for science learning included *science learning, learning science, science teaching, teaching science, science education, science instruction, biology learning, chemistry learning, physics learning, biology teaching, physics teaching, chemistry teaching, biology education, physics education, chemistry education, biology instruction, physics instruction,* and *chemistry instruction*. The keywords used for the Internet technology included *Internet, web, on-line, online,* and *technology*. The two sets of keywords were combined by using the Boolean logic 'AND.'

In the second stage, two researchers then manually and systematically screened the article titles and abstracts and confirmed that the selecting articles: (1) must be using Internet-based environment(s) for learning, (2) should be related to science education, and (3) must provide empirical evidence or evaluation. For instance, studies those simply describing the design of learning environment without the support of empirical data were excluded from this review. The studies simply using computers without any Internet application were also excluded from this review. During the screening process, any inconsistent decisions between the two researchers were then discussed and resolved by involving a third researcher. Finally, 240 papers were identified as the initial research sample pool of this review.

In the third stage, the paper selection and identification process was guided by an analytical framework strongly tied to the two research questions for this review (see Table 1). This framework was developed by three rounds of panel discussions by nine experts in science education and educational technology after referring to some review articles in educational technology (Hartley, 2007; Lin & Hsieh, 2001; Linn, 2003; Tallent-Runnels et al., 2006). In addition to reviewing some common areas in education, such as cognitive domain, affective domain, and demographics of the learners (e.g., Tallent-Runnels et al., 2006), the panel agreed on the importance of tailoring some review areas to the outcomes unique to science learning. The framework was then finalized by two senior researchers in the field. As mentioned previously, the first category in the framework emphasizes the relationship between learner's characteristics and learning in ISLEs. The second category focuses on the outcomes resulted from learning in ISLE; both outcomes general to learning and outcomes specific to science education are considered. Areas of studies associated with each sub-category are shown in Table 1.

Each author in this study was asked to review one or two sub-categories regarding ISLEs by examining each paper of the paper pool. Because the scope of this review focused on students not on teachers, the research team excluded studies about teacher learning or professional development. Each author identified papers for the assigned categories and sub-categories, and one additional researcher also validated the selected papers in the final stage. Finally, for the first category in this review (learner's characteristics and demographic), there are a total of 13 papers (listed in

Table 1. Major categories, sub-categories, and associated areas for studies about ISLEs

Major category	Sub-category	Associated areas of studies
Demographics and learner's characteristics	Demographics	Gender; ethnicity; social economic status
	Prior knowledge (ability)	Prior domain knowledge of science; prior general ability; metacognitive ability
	Self-efficacy	Internet self-efficacy; academic self-efficacy; self-efficacy for self-regulated learning
Learning outcomes	Attitude	Attitude toward school science; attitude toward learning in ISLEs
	Motivation	Motivation to learn sciences
	Conceptual understanding	Gains in conceptual understanding
	Conceptual change	Conceptual change
	General cognitive skills	Self-regulated learning skills, problem-solving skills, visual-spatial ability
	Cognitive skills specific to science inquiry	Ability of scientific argumentation; data-processing and interpretation skills; scientific process skills
	Interaction	Student–student interaction; student–instructor interaction

Appendix A). For the second category (learning outcomes) we examined, there are a total of 52 (listed in Appendix B).

In sum, the studies were identified and selected through a systematic process and with set criteria. There is no intended bias to the selection of the studies. The fact that a relatively high proportion of studies by Asian researchers were included (in Appendices) was simply a result of the systematic selection process.

Learner's Demographics and Characteristics in Respect to Learning in ISLEs

Demographics

In this review, demographic backgrounds were discussed in terms of learner's gender, ethnicity, and socio-economic status (SES). Across multiple studies, a consistent observation was that utilizing online learning resources in ISLEs was equally favorable, or in some cases more so, to learning for female students compared to male students (Cantrell, Pekcan, Itani, & Velasquez-Bryant, 2006; Herman & Kirkup, 2008; Joo, Bong, & Choi, 2000; Mayer-Smith, Pedretti, & Woodrow, 2000). For example, Mayer-Smith et al.'s (2000) study indicated that secondary school female students performed as well as or better than male students while learning in ISLEs in a self-paced collaborative way. Joo et al. (2000) even found that junior high school female students were superior to male students in self-regulated learning and cognitive strategy when engaging in ISLEs and also outperformed males on written examinations, although in this same study males reported having used computers for longer periods compared to females.

Gender issues in ISLEs in relation to online discussions were examined, and different engagement patterns and participation preferences between genders were found (e.g., Chuang, Hwang, & Tsai, 2008). It seems that male students were more active in participating online science forums than female students; nonetheless, some other research results also indicated that online group social supports may encourage more female learners to participate in the science community. For instance, on the one hand, Chuang et al. (2008) found that male students preferred to be involved in the process of discussion, preferred to show critical judgments, enjoyed the process of negotiation, and engaged in reflective thoughts more than female students. Male students seemed to demonstrate better adaptability to the constructivist-oriented ISLEs. On the other hand, Herman and Kirkup (2008) reported that online discussion in ISLEs could effectively support women to return to science, engineering, and technology careers. In a short online university course aimed at empowering women who were returning to employment in science, engineering, and technology after a career break, women were positively disposed to adopt the ISLE due to the influence of group social expectations (Herman & Kirkup, 2008). In other words, if female students are in a group where the group members expect them to utilize new technology (for learning), they will try to adopt it.

It is interesting that there is no report of technical-related difficulties for either gender when learning with ISLEs. Based on the studies above, two preliminary trends should be noted regarding gender differences and Internet-based science learning. First, it seems that male students did not perform as well as female students in a self-paced or self-regulated ISLE. It could be the case that at younger age, about middle- and high school, female students possessed better self-regulated skills or strategies than male students. Second, despite research of traditional learning and online learning both found female students enjoy the social support in learning; female students may still be less comfortable with activities that may result in conflicts among the classmates (Chuang et al., 2008). Male more than female students are in favor of online science activities that require negotiations among the participants and that requires expressing critical judgments.

Not only the gender issue but also the roles of SES and ethnicity played in students' science learning with simulation-based ISLEs were explored in Cantrell et al.'s (2006) study. In an engineering design curriculum, students went through an iterative inquiry process in which they discussed their design, evaluated the design variables in the online simulation system, and then constructed the design prototypes. Overall, after the students engaged in the design projects, the achievement gap for science concepts decreased largely for low SES students as well as for Hispanic and Black students (Cantrell et al., 2006). Cantrell et al. also found that Asian students outperformed students in other ethnic groups in terms of the state science assessment. The research suggested that the design project and the simulation-based ISLE together provided new learning opportunities. The learning effects of the design projects were more impressive for some special groups than others. However, as a result of our paper selection process, it appears that not many studies have addressed the roles of SES and ethnicity in ISLEs.

Prior Knowledge (Ability)

Prior knowledge, in this study, refers not only to students' prior domain knowledge of science but also to prior domain-general cognitive (such as spatial visualization) and metacognitive abilities. In the following, we present findings in each of these sub-categories respectively.

The relationship between prior knowledge and students' performance in ISLEs is complex. For instance, Downing, Moore, and Brown (2005) found that college students' domain expertise played an important role in their online information searching performance in science; domain expertise helped to search more relevant information in ISLEs. In another study, Lin and Tsai (2008) found that high school students' existing views about the nature of scientific knowledge guided their evaluative standards and searching strategies when processing science information in ISLEs. The students who perceived scientific knowledge as more tentative utilized more sophisticated evaluative standards, such as cautiously validating the information in open-ended ISLEs. These two studies highlighted the importance of prior domain knowledge and existing views of nature of science (NOS) in online searching activities.

Some researchers have been particularly interested in the effects of ISLEs on students with low prior knowledge or low abilities. As an example, Muller, Bewes, Sharma, and Reimann (2008) revealed that students with low prior knowledge benefited most from the inclusion of misconceptions in multimedia ISLEs, in companion with the discussion of those misconceptions between the students and a tutor. In the same study, the ISLEs, and high prior knowledge learners' gains were not diminished by such an approach (Muller, Bewes et al., 2008). In another study, however, Wu and Huang (2007) found that low-achieving high school students benefited less from the student-centered instructional approach offered by ISLEs. The researchers argued that the low-achieving students needed more guidance from the teacher when engaging in ISLE activities (Wu & Huang, 2007).

Researchers also investigated the role of students' prior general ability in learning with ISLEs. Regarding students' spatial visualization ability (SVA), Downing et al. (2005) examined the effects of SVA and of its interaction with domain expertise on college students' online information-seeking behaviors about biology. A significant main effect of SVA was found on the time required to find the first relevant article on the search topic, although no significant interaction was found between SVA and domain expertise. Downing et al.'s (2005) results were consistent with prior research results (e.g., Vicente, Hayes, & Williges, 1987) that students with low SVA generally have longer mean execution times than those with high SVA in a hierarchical database system.

Metacognitive ability indicates the ability of knowing about and regulating an individual's cognitive activities in learning processes or simply defined as the ability of knowing about knowing (Flavell, 1979). Before they were directed to an ISLE system, a group of high school students' metacognitive strategies were first examined by Tsai, Lin, and Yuan (2001). Then, a concept mapping ISLE was developed where these students used it for science learning. The results showed that students reporting more critical thinking and regulation management strategies, that is, those with more sophisticated metacognitive strategies, were more willing to use such ISLE. This implies that metacognition may enhance students' usage and learning in ISLEs, an assertion made by Tsai (2001b).

Finally, in some other studies, the ISLEs were utilized as a potential way of examining or diagnosing students' prior knowledge (Chang, Barufaldi, Lin, & Chen, 2007; Tsai & Chou, 2002). Tsai and Chou (2002) developed two-tier diagnostic online tests to probe high school students' alternative conceptions in physics. Chang et al. (2007) further reported a significantly positive correlation between high school students' prior domain knowledge and problem-solving abilities via an ISLE for earth sciences.

In sum, we seem to be able to conclude from the results of multiple studies that higher levels of prior knowledge, including higher levels of prior domain knowledge, more sophisticated views of the NOS, higher levels of SVA, and higher levels of metacognitive abilities, can help students complete some learning tasks in ISLEs and help them perform better in those tasks. However, it is still arguable whether students of low prior knowledge or abilities can benefit more than their counterparts when engaging in ISLEs (Muller, Bewes et al., 2008; Wu & Huang, 2007). Nevertheless, these studies also shared similar ideas. Teacher's guidance for ISLEs, for instance, can be crucial for low-achieving students during the learning process (Wu & Huang, 2007). Explicit presentation and discussion of science misconceptions, perhaps induced by teacher or virtual tutor, can also benefit students with low prior knowledge (Muller, Bewes et al., 2008). This could stem from the fact that some tasks in ISLEs may require high levels of cognitive demands than traditional learning activities. Therefore, additional training or guidance from expert or teacher is necessary for students with low prior knowledge in order for them to take full advantages from the engagement in Internet-based science learning activities.

Self-efficacy

'Self-efficacy' typically refers to an individual's beliefs, expectations, and perceived capability to perform a task (Bandura, 1993, 1996). Students' beliefs of self-efficacies in ISLEs may include their perceived capabilities for the use of the Internet (i.e., Internet self-efficacy), perceived capabilities for learning achievement or school performance (i.e., academic self-efficacy), and perceived capabilities for self-regulated learning (i.e., self-efficacy for self-regulated learning).

Researchers suggested that Internet self-efficacy may be an essential variable to predict students' information-seeking in ISLEs. Two studies supported that Internet self-efficacy was significantly positively correlated with students' sophistication of adopting online information searching strategies and achievements as well as their search-based learning performances in science (Joo et al., 2000; Tsai & Tsai, 2003). In addition to Internet self-efficacy, Joo et al. (2000) further explored the roles of students' academic self-efficacy and self-efficacy for self-regulated learning (self-efficacy for SRL) in junior high school students' learning in ISLEs. The results revealed that students' self-efficacy for SRL was highly correlated with their academic self-efficacy and their use of cognitive and self-regulated strategy (Joo et al., 2000). In their statistical model, Joo et al. also found that Internet self-efficacy can predict search outcomes but not learning performance; whereas academic self-efficacy was positively correlated with learning outcomes but not correlated with search performance. In other words, Internet self-efficacy is relatively independent from academic self-efficacy in predicting search outcomes in ISLEs (Joo et al., 2000), highlighting the importance for researchers to consider Internet self-efficacy and academic self-efficacy as separate constructs in research.

Summary for the Roles of Demographics and Characteristics

Most studies about prior knowledge or self-efficacy focused on utilizations of online resources like information-seeking or searching. Those studies found that higher levels of prior domain knowledge help students find more relevant information, and higher levels of SVA help them reduce the time required to find information related to biology. In addition, students' views of the nature of scientific knowledge and Internet-self efficacy also affect how sophisticated the strategies utilized for searching information in ISLEs. Few studies examined other types of ISLEs and future studies are needed to examine how the roles of student prior domain knowledge, prior experience, and self-efficacy beliefs play in other formats of ISLEs such as online discussion forums, virtual reality, and game-based learning.

Differences in ISLEs can be found between low and high achievers, between genders, and between students with different ethnic backgrounds. Research exploring student demographic variables in Internet-based science learning focused more on gender issues than any other demographic variables such as age, SES, and ethnicity. It is still not known whether any relationships exist among student SES status, student access to the Internet, and science learning. In addition, it seems that little attention has been paid to culturally sensitive content for Internet-based science learning.

Learning Outcomes Derived from ISLEs

Attitude

Attitude is commonly defined as a preference to respond positively or negatively toward people and things. ISLE researchers have examined not only learners' attitudes toward science but also attitudes toward the use of the Internet or computers. In general, studies reported students' positive attitudes toward the ISLEs (Chiu, 2002; Hsu, 2006; Jang, 2006; Shin, 2002; Simons & Klein, 2007; Tsai et al., 2001). For example, when implementing team teaching together with Internet-assisted learning in seventh-grade science classes, students preferred it to traditional learning (Jang, 2006). In another study, learning via ISLE helped students develop positive attitudes toward school science and also positive attitudes toward using and learning about computers, regardless whether it was in collaborative or individual settings (Chiu, 2002). One potential reason for students' positive attitude toward the ISLEs was the fact that those learners were able to control their learning pace in ISLEs (Chiu, 2002; Shin, 2002).

Students' achievement levels were also relevant to their attitudes toward the ISLEs. Simons and Klein (2007) found that high-achieving students in their study expressed more positive attitudes toward working on the problem-based ISLEs than low-achieving students. Nevertheless, Cole and Todd (2003) found high logical-thinking ability (college) students expressed less enthusiasm for online science homework while low ability students were more positive. Thus, based on these two studies, it is still inconclusive whether high-achieving students have more positive attitudes toward Internet-based science learning. The difference in conclusion may also come from the variations of learning tasks and experiences in ISLEs for different studies.

Motivation

Motivation is an internal state that will engage students in active learning science and encourage sufficient effort for knowing science (Reeves & Reeves, 1997). Only one study reviewed had embedded instructional design in an ISLE for promoting students' intrinsic motivation and then provided direct evidence for that matter (Wang & Reeves, 2006). Wang and Reeves' (2006) study showed evidence of students' interests in learning sciences, cognitive engagement, enthusiasm, and behavior engagement with the tasks while using the animation/visualization ISLE. Students stated that visualization through video and animation, and learner control of the learning process may promote motivation (Wang & Reeves, 2006).

A few studies of students' usage or behaviors suggested that the ISLEs were motivating. For example, Freasier, Collins, and Newitt (2003) found that college students in a homework tutorial ISLE were motivated to take more online homework quizzes voluntarily, beyond the course requirement. The students found the Internet-based science learning system helpful because it was easily accessible, allowing practice in a non-threatening environment, and allowing self-paced learning. Wang (2008) also found that the middle school students in his study spent more time in the Internet-based formative assessment system than a normal web-based test. The result suggested that the challenge and game-like features of the formative assessment appear to promote students' motivation. In addition, Riffell and Sibley (2005) combined the web-based course and face-to-face lectures together and studied the effect of this blended learning on college students' biology learning. It was found that the blended course motivated learners to preview their learning materials before the course and engendered more interactions with their peers more frequently than the traditional lectures.

Conceptual Understanding

Science educators have conducted several studies to examine the effects of ISLEs on students' conceptual understanding. Numerous studies reported improvements in students' conceptual understanding derived from ISLEs. Those ISLEs that resulted in gains of conceptual understanding included online homework (Arasasingham, Taagepera, Potter, Martorell, & Lonjers, 2005; Penn, Nedeff, & Gozdzik, 2000; Taraban, Anderson, Hayes, & Sharma, 2005), online formative assessment (Wang, 2008; Wang, et al., 2006), online resources for inquiry (Hoffman, Wu, Krajcik, & Soloway, 2003; Hug et al., 2005), synchronous and asynchronous communication or discussion environments (Kubasko, Jones, Tretter, & Andre, 2008), virtual reality (Hansen, Barnett, & MaKinster, 2004; Sancho et al., 2006; Shim et al., 2003; Sun, Lin, & Yu, 2008), simulations (van der Meij & de Jong, 2006; Wu & Huang, 2007), online systems for project-based learning (Barak & Dori, 2005; ChanLin, 2008; Lin, Cheng, Chang, & Hu, 2002), and integrated online systems for science learning (Mistler-Jackson & Songer, 2000; Williams & Linn, 2002).

Improvements in students' conceptual understandings were evaluated for different areas of science learning. In terms of the results of science examinations, for instance, Taraban et al.'s (2005) found that online homework improved students' grades on undergraduates' in-class tests. While examining different types of science concepts, Hansen et al. (2004) pointed out that construction of three-dimensional virtual reality models best facilitated college student understandings of spatially related astronomical concepts. In the same study (Hansen et al., 2004), traditional instruction techniques best facilitated student understandings of fact-oriented astronomical knowledge. The high school students in Lin et al.'s (2002) study who undertook Internet-based science projects by using online resources had higher scores for short-answer questions than those who had experienced more traditional teaching; while students who experienced the latter had higher scores in multiple-choice tests. Finally, in a different kind of comparative study, Kubasko et al. (2008) engaged students in inquiry-based projects in which students can interact with scientists online on different communication modes. They found that both synchronous and asynchronous interactions with scientists in ISLEs can improve high school learners' understanding of the studied science topics. However, asynchronous instruction enabled the students to ask significantly more *inquiry* and *interpretation* questions of scientists (Kubasko et al., 2008). In sum, it seems that traditional instruction may facilitate the acquisition of fact-based science knowledge; while ISLEs may help students not only conceptualize the scientific knowledge but also communicate science ideas.

In some studies, researchers collected multiple sources of qualitative data, such as students' artifacts, interviews, classroom observation data, or online archived discussions, in order to uncover to which extent students develop conceptual understandings through Internet-based learning. For instance, Hoffman et al. (2003) found that students did not necessarily develop deeper or more accurate understanding in science when engaged in online inquiry activities. Factors such as students' use of adequate search strategies, adoption of assessment strategies to online information, and the quality of online resources obtained by students were essential to more successful development of science conceptual understandings.

Still some other studies, however, concluded that there was no significant difference in conceptual understanding between students engaged in ISLEs and those by traditional teaching settings (Dantas & Kemm, 2008; Hsu & Thomas, 2002; Woodrow, Mayer-Smith, & Pedretti, 2000). For example, Hsu and Thomas (2002) found no significant difference in the conceptual understanding between the college students using simulation-based ISLEs and those who received traditional instruction. Hsu and Thomas suggested that the guidance from instructor is crucial for students' performance. Two studies also reported no significant differences in college science learning performance between the student group using online homework and the group using traditional paper-based homework (Bonham, Deardorff, & Beichner, 2003; Cole & Todd, 2003). Both studies suggested that simply changing the homework media from traditional paper and pencil to the Internet, without further modifications in the pedagogical content such as providing additional support or feedback, resulted in no better conceptual outcome. This conclusion suggests that on the one hand, traditional methods with appropriate pedagogies can still be effective if implemented properly. On the other hand, ISLEs with little implementation of sophisticated pedagogies may produce no better results than traditional learning environments. As Kozma (1994) suggested, whether learning media will influence learning depend largely on whether educational technology designers have rooted instructional designs in '*cognitive and social processes*' (p. 8) that facilitate knowledge construction.

Conceptual Change

Compared to research on student conceptual understanding using ISLEs, relatively fewer studies have investigated the effects of ISLEs on conceptual change. Most of the studies of conceptual change revealed positive effects of the ISLEs (Hsu, 2008; Hsu, Wu, & Hwang, 2008; Muller, Bewes et al., 2008; Muller, Sharma, & Reimann, 2008; She & Lee, 2008). For instance, Hsu et al. (2008) reported that high school students who experienced an ISLE about the causes of seasons (including use of videos, animations, simulation, and online concept-mapping) had reduced misconceptions about the topic. In addition, in this same ISLE, the student-centered approach was more effective than the teacher-guided approach in altering high school students' alternative conceptions of seasonal change (Hsu, 2008). Muller, Bewes et al. (2008) examined the effects of different multimedia ISLE treatments (diagrams, animations, live action demonstrations, and graphs) on student conceptual change. They revealed that by including video-based interactive dialogs about alternative conceptions of Newton's laws of motion, the multimedia-based ISLEs fostered conceptual change for college freshmen students who began with varying levels of prior knowledge. In a similar study, with different online streaming video, Muller, Sharma et al. (2008) studied the effects of dialog involving alternative conceptions of Newton's first and second laws. Muller, Sharma et al. (2008) found that the college students who watched the online video with alternative conceptions invested greater mental effort and achieved higher posttest scores than those who received a standard lecture-style presentation in the video. In another study, She and Lee (2008) developed an adaptive ISLE, called the scientific concept construction and reconstruction

(SCCR), for middle school students. Their study revealed that the students who used the SCCR outperformed students who received traditional instruction not only in understanding of 'combustion' concepts but also in scientific reasoning. Moreover, the success rate for conceptual change for the experimental group was very high (above 75%) in most learning events. In other words, the students with SCCR made significant progress in conceptual change.

General Cognitive Skills

Three kinds of cognitive skills, self-regulated learning skills, problem-solving skills, and visual-spatial ability, were found in the reviewed studies of ISLEs, where these were considered as outcomes from ISLEs. One study (Ng & Gunstone, 2002) reported the effects of the Internet-based science activities on self-regulated learning. Ng and Gunstone investigated high school students' usage of the Internet resources for research on science topics. In the study, most students perceived that the activities promoted self-regulated and independent learning. However, some students expressed the need for more background information and more help from others to understand the searched information, due to the unedited and unstructured nature of online information.

Problem-solving in science is a complex cognitive task which involves domain-specific knowledge, effective organization of information, and procedural skills (Eylon & Linn, 1988). Both Pedaste and Sarapuu (2006) and Oliver and Hannafin (2000) intended to examine how particular ISLEs facilitated problem-solving and reached different conclusions. The results of Pedaste and Sarapuu's (2006) study demonstrated an improvement of high school students' problem-solving as well as analytical skills resulting from an ISLE. More specifically, Pedaste and Sarapuu (2006) concluded that ISLEs that presented certain supportive information for guiding tasks and enhancing learning process awareness improved students' ability in analyzing tables and figures. Nonetheless, during the open-ended problem-solving activity in an ISLE, Oliver and Hannafin (2000) found that few middle school students in the study used relevant tools in the ISLE for higher-order or critical thinking such as organizing information, seeking patterns in the data, or justifying their ideas. Students tended to use lower-order tool functions, such as information collection, more frequently. In addition, students rarely followed conceptual scaffoldings embedded in the ISLE to evaluate evidence or their own ideas. Thus, Oliver and Hannafin argued that the tools provided by ISLE alone are not sufficient to sustain problem-solving unless the students adopt strategic and sophisticated usage of the tools.

Visual-spatial ability is essential for scientific practices, but only one study in our literature pool investigated the effects of ISLEs on students' spatial orientation and visualization. In the study conducted by Piburn et al. (2005) study, both the college students in control and experimental groups studied the laboratory manual in geological sciences, and the experimental group utilized two additional multimedia instructional modules delivered on the Internet. The results showed the multimedia instructional modules via ISLEs successfully supported the development of spatial abilities. Piburn et al. (2005) found greater improvement in the experimental group than the control group in both spatial orientation and spatial visualization.

Cognitive Skills Specific to Science Inquiry

Under the sub-category of cognitive skills specific to science inquiry, studies were found in investigating students' scientific argumentation skills (Bell & Linn, 2000; Clark & Sampson, 2007, 2008; Walker & Zeidler, 2007), data processing and interpretation skills (Sancho et al., 2006), and scientific process skills (Chiu, 2002). Scientific process skills involve identifying variables, hypothesizing, operationally defining, designing investigations, and graphing and interpreting data (Chiu, 2002).

Scientific argumentation is used to make more valid claims and to persuade others in the scientific community, and it is central to science inquiry (Clark & Sampson, 2007). While students rarely engaged in discussing, evaluating, or debating on issues in conventional science classes (Clark & Sampson, 2008), some researchers believed ISLEs can offer adequate opportunities for scientific argumentation. In a series of ISLEs designed to promote students' scientific argumentation (Bell & Linn, 2000; Clark & Sampson, 2007; Walker & Zeidler, 2007), the students are found to be prompted to explore evidence regarding conflicting viewpoints, gather additional data, organize arguments, debate and discuss the issues, and finally form their own viewpoints.

Two studies (Bell & Linn, 2000; Walker & Zeidler, 2007) explored the possible connections between middle and high school students' views of the NOS and argument construction in ISLEs. Bell and Linn's (2000) study showed a moderate consistency between NOS and quality of arguments made in ISLEs. However, in Walker and Zeidler (2007), it was revealed that the students needed explicit instruction in evaluating evidence and forming arguments in ISLEs. Even though the study treatment emphasized NOS, the high school students did not make explicit reference to aspects of NOS due to the open-ended nature of the debate (i.e., genetically modified food) discussed in ISLEs. Although Walker and Zeidler (2007) suggested that NOS embedded online scaffolding in ISLEs may help the students to apply NOS views in judging the claims, further investigation in this area is needed to prove this proposition. With a different research focus, Clark and Sampson (2007, 2008) introduced the personally seeded approach for ISLEs. Through this approach, the middle school students first constructed their own principles based on the data, and then the principles became the seed comments for online argumentation. Both studies resulted in similar conclusions wherein personally seeded discussions in ISLEs supported advanced levels of scientific arguments (Clark & Sampson, 2007, 2008).

Studies also examined the ISLE effects on other potential skills related to science inquiry. Sancho et al. (2006) showed that college students acquired non-manual skills (e.g., data reading, calculations, interpretation of the results, deployment of an analytical protocol, and reporting results) after working through the ISLEs with virtual laboratories. In another study, Chiu (2002) found that high school students in both team settings and individual settings of ISLEs showed significant gains in their scientific process skills; no significant difference between the two settings of ISLEs were found. ISLEs, used either in collaborative or individual manner, can help the students acquire scientific process skills.

Interaction

Moore (1989) makes a distinction between three types of interactions in educational settings: learner–content interaction, learner–instructor interaction, and learner–learner interaction. Most studies reviewed for interaction in ISLEs in this paper focused on learner–learner interactions. All of the studies in this sub-category adopted content analysis or qualitative methods to explore student–student or student–teacher interactions in ISLEs.

Three studies identified potential factors that may influence online interactions for science learning, although the learning environments varied. Factors include the values of the learning settings perceived by students, details of the online posting requirements for online discussions, and the kind of information displayed during video-conferencing for science learning. First, Furberg and Ludvigsen (2008) analyzed chronologically selected extracts from a sequence of two secondary school students' interactions. They found a sudden change in the students' interaction trajectories due to the influence of institutional aspects. Thus, they suggested that it is essential to be highly aware how students orient their talk and interaction toward more or less school values, expectations, and demands embedded in the school setting. The values and expectations embedded in 'doing school' (i.e., good performance in school) play an important role in the interactions of the implemented ISLEs.

Guan, Tsai, and Hwang (2006) examined the role of interaction conditions for an online high school physics forum. Two conditions were set for the online discussion. The first condition required the students to reply to others' discussion before posting any message (called 'required,' R-condition); whereas, the other condition did not set the requirement (called 'non-required,' NR-condition). The results showed fewer participants of the R-condition strayed from the topic under discussion in comparison to the NR-condition; however, a larger percentage of message content containing metacognitive components (such as regulation or self-awareness) was found in the NR-condition. The study concluded that the preliminary requirement that the learners reply fostered the cognitive-oriented interactions (e.g., clarification or inference), but it did not necessarily induce metacognitive-oriented interactions. The study (Guan et al., 2006) also highlighted the crucial role of moderator in maintaining the online discussion quality. Finally, the different display modes on college student interactions in a video-conferencing ISLE were studied by Saw et al. (2008). They found that there were more interactions in the graphic display mode than in the video display mode. The graphic display mode, which involves the simultaneous interaction with the teacher and instructional materials, produced higher student engagement. The study highlighted the contribution of the teacher-initiated interactions in the graphic display mode.

Nevertheless, studies also suggested pitfalls of having students interact in ISLEs. The major two problems revealed were off-topic discussions and information overload. Despite reporting fruitful interactions among the students in online discussions, Guan et al. (2006) also reported that the students tended to post irrelevant messages after a few rounds of online discussions. Lipponen, Rahikainen, Lallimo, and Hakkarainen (2003) suggested that in a highly interactive ISLE for middle school students, the participants have connections with each other, and members are likely to mutually influence each other. However, extensive and widespread exchange of messages can result in heavy information load.

Summary for the Effects of ISLEs

Taken as a whole, ISLEs generally led to improved outcomes in the affective domain for students such as attitudes and motivation. Learners may find that learning through ISLEs engenders very different experiences, and the novelty effect of ISLEs may foster the students' favorable attitudes and motivation. This review has also concluded that factors, such as the following, made the learning environment more motivating or attractive to students: providing visualization, being as learner-centered to confer responsibility on the students, designing challenge, and providing game-like activities. In particular, the flexibility of learners' control is essential for promoting students' attitudes and motivation toward learning in ISLEs (Chiu, 2002; Shin, 2002; Wang & Reeves, 2006). Future research should address if some students feel uncomfortable or anxious for learning in ISLEs. Also, although it is believed that Internet-based environment can motivate students, few studies systematically observed motivated behaviors and measured students' motivation levels during the course of using ISLEs.

Moreover, although diverse findings were revealed in previous studies, it was found that, in general, ISLEs could be used to improve learners' conceptual understanding, conceptual change, and other non-conceptual learning outcomes, for example problem-solving or argumentation skill. Moreover, many studies already have been conducted to explore the effects of ISLEs on student conceptual learning outcomes, while only a relatively few studies addressed learners' conceptual change in ISLEs, and even fewer studies investigated non-conceptual learning outcomes such as argumentation, problem-solving and process skills. One possible explanation is that the measurement of argumentation, problem-solving and other cognitive skills are challenging. It is even more challenging if the measurements are tailored for a particular science content area. In almost all of the studies reviewed in these sub-categories, researchers had to design the particular measurements or analytical framework for the intended cognitive skills. For example, coding for quality of argumentations or problem-solving is multi-faceted and resides in the discourse among students. Therefore, researchers need to develop extensive codes. Another possible reason for the small number of studies may relate to the fact that designing adequate ISLEs for promoting these cognitive skills is fairly complex (Linn, 2000). Publicly available Internet-based resources for supporting these cognitive skills are rare and the learning environments accompanied by well-developed science content and sufficient guidance are even more scarce. More sophisticated ISLEs are needed to be shared within the science education community.

This review has revealed that even though the ISLEs, in general, allow more learner control, the guidance from teachers, moderators, or the system itself is still quite crucial (e.g., Guan et al., 2006; Pedaste & Sarapuu, 2006; Saw et al., 2008). In addition, the expectations from others or from the learning context may shape the students' ideas, behaviors, and learning in ISLEs (e.g., Furberg & Ludvigsen, 2008; Herman & Kirkup, 2008).

This review also found that there is little research addressing the impact of ISLEs on more advanced aspects of learning. Educators advocated that Internet-based learning environments, if used properly, can promote students' metacognition and epistemological development (e.g., Tsai, 2004). Therefore, more research should be undertaken to explore the role of ISLEs in the development of students' metacognitive reflections, epistemological understandings, or worldviews.

Finally, as for Internet-based interactions, some issues are still worth further investigation. For example, whether or how an individual's learning is improved in the processes of online discussion. Moreover, people who visit the online discussion forum without posting any comments or any further messages might still benefit from reading the messages on the forum. It could be interesting to investigate to what extent those various learners indeed benefit from reading discussion messages and what may hinder them from posting messages on the forum. More research about learner–content interaction in ISLEs is necessary.

Final Concluding Remarks

This paper provides a review of some current research about Internet-based science learning from 1995 to 2008. Major conclusions are summarized in Table 2. For example, the use of ISLEs may not always help students gain better conceptual understandings in science. Although we set the year from 1995, all of the papers qualified for this review were formally published after 1999. Most of the studies reviewed utilized online resources or online searching, simulation, virtual reality, or discussion forums as the main features of ISLEs. Recent applications for web 2.0 technology, such as blog or wiki (Huang, Yang, & Tsai, 2009), should be integrated as a part of ISLEs in the future. Also, some attempts to incorporate game-based learning with ISLEs should be made. We are fully aware that the original decision of limiting the search in SSCI database can miss some potential studies published in formats other than journal articles. Future studies can focus on one particular review topic and expand the search to other databases such as ERIC or PsychInfo.

Moreover, this paper also found that almost all of the ISLE studies in this review were conducted with middle school, high school and college students. The only exception is the research undertaken by Herman and Kirup (2008), studying adult

Table 2. Summary of major findings in each sub-category

Sub-category	Major findings
Demographics and learner's characteristics	
Demographics	• Some studies reported that female students outperformed male students in self-paced or self-regulated learning environments. • Female students can benefit from the social support in online discussions; however, more male than female students enjoyed negotiation, expressing critical judgments, or expressing reflective thinking. • Studies addressing the relationship between ethnicity or SES differences and learning in ISLEs are rare.
Prior knowledge (ability)	• Students' prior domain knowledge, prior views of the nature of science, prior general knowledge and metacognition may impact their performance in ISLEs. Although, more studies investigated the role of prior domain knowledge. • Low-achieving students do not necessarily benefit the most in ISLEs. • ISLEs can be carefully designed to probe students' prior domain knowledge (such as alternative conceptions).
Self-efficacy	• Internet self-efficacy can predict students' online searching strategies and searching outcomes.
Learning outcomes	
Attitude	• Studies reported positive attitudes toward ISLEs and positive attitudes toward science. • Potential factors influencing students' attitudes toward ISLEs: sense of control of the learning pace in ISLEs, achievement level, and logical-thinking abilities.
Motivation	• Studies suggested some features of the ISLEs may be motivating: visualization, learner control/self-paced environment, non-threatening environment, game-like features (for assessment), and blended courses.
Conceptual understanding	• Many studies reported gains in science conceptual understanding after learning with ISLEs, such as online homework, online assessment, online resources for science inquiry, online synchronous and asynchronous communication, virtual reality, simulations, and online systems for project-based learning or science integration. • Some studies, however, also reported no significant differences in conceptual gains between learning with ISLEs and learning in traditional settings.
Conceptual change	• Studies who have tailored the ISLEs for conceptual changes successfully reduce students' misconceptions or alternative conceptions.
General cognitive skills	• Online information searching activity for science issues can promote self-regulated learning. • ISLEs can promote development of visual-spatial abilities. • In terms of problem-solving skills, ISLE can improve students' analytical skills; but students may tend to use online functions supporting lower-order cognitive skills while solving problems in ISLEs.

Table 2. (*Continued*)

Sub-category	Major findings
Cognitive skills specific to science inquiry	• Certain ISLEs can promote students' ability of scientific argumentation, data-processing and interpretation skills, and scientific process skills. • Some moderate relationships between students' argumentation skills and views of nature of science when engaged in learning in ISLEs are found.
Interaction	• Identified factors that may influence online interactions for science learning include the values of the learning settings perceived by students, details of the online posting requirements for online discussions, and the kind of information displayed during video-conferencing for science learning. • Not all online interactions have positive effects on learning. Online postings can be irrelevant to the science topics and extensive online interactions can result in information overloading.

women. As ISLEs become more mature and widespread, science educators should pay more attention to younger learners (such as elementary school or pre-school children) or more senior learners (adults, teachers, employees). Internet technology can allow learners at different levels and/or different locations to experience group learning that otherwise may not be practical or possible. The potential of ISLEs should be extended to learners beyond formal schooling to include museums, municipal educating institutions such as botanical and zoological gardens, and other resource institutions in society.

It is expected that ISLEs will continue to be developed, examined, and enhanced in the next decade. This paper may shape some grounding conceptual frameworks and insights for researchers in this field.

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Appendix A. Studies about Learner's Characteristics (Category 1)

Sub-category	Author(s) and year	Purpose of study	Subject/topic	Sample	Research method/ design	Internet-related technology utilized
Demographics	Cantrell et al. (2006)	To examine the roles of gender, ethnic and social economic levels in science learning behavior and science achievement	Physics	434 seventh- and eighth-grade students	Mixed: experimental, interview	Simulation
Demographics	Chuang et al. (2008)	To investigate the role of gender in learners' perceptions of Internet-based learning environments	Physics	109 high school students	Quantitative: survey	Discussion forum
Demographics	Herman and Kirkup (2008)	To report women's experiences in an online forum course	Science, engineering, and technology	113 women in an average age of 42	Mixed: survey, interview	Discussion forum
Demographics; Self-efficacy	Joo et al. (2000)	To examine the gender effects and the relationships between self-efficacy beliefs and performance in web-based instructional contexts	Science	152 eighth-grade students	Quantitative: survey; correlational	Online resources and searching
Demographic	Mayer-Smith et al. (2000)	To explore if technology enriched science classrooms are gender dependent	Physics	132 secondary high school students (grade nine to twelve)	Mixed: survey, interview, observation	Online resources and searching; visualization/animation
Prior knowledge	Downing et al. (2005)	To examine the effects of students' spatial visualization ability and domain expertise on students' information-seeking	Biology	35 college students	Mixed: experimental, content analysis	Online resources and searching
Prior knowledge	Chang et al. (2007)	To examine students' domain-specific knowledge and reasoning skills as well as attitudes toward science topics	Earth sciences	263 tenth-grade students	Quantitative: correlational	Online testing

Appendix A. (Continued)

Sub-category	Author(s) and year	Purpose of study	Subject/topic	Sample	Research method/ design	Internet-related technology utilized
Prior knowledge	Muller, Bewes et al. (2008)	To examine the effects of four online multimedia treatments on student conceptual learning regarding Newton's first and second laws of motion	Physics	364 college students	Quantitative: experimental	Visualization
Prior knowledge	Lin and Tsai (2008)	To explore the relationships between learners' views about the nature of scientific knowledge and their evaluative and searching strategies in web-based science learning environments	Science	486 high school students	Quantitative: survey	Online resources and searching
Prior knowledge	Tsai and Chou (2002)	To develop a networked two-tier test system to diagnose students' prior knowledge	Physics	555 eighth-grade students; 599 tenth-grade students	Quantitative: correlational	Online testing
Prior knowledge	Wu and Huang (2007)	To investigate ninth graders' cognitive, emotional, and behavioral engagement in teacher-centered and student-centered technology-enhanced classrooms	Physics	54 ninth-grade students	Mixed: observation; survey; experimental	Simulation/animation
Prior knowledge	Tsai et al.(2001)	To develop a web-based concept map as a testing system and examine its relations with student motivation and learning strategies	Physics	38 high school students	Mixed: content analysis, survey	Online testing
Self-efficacy	Tsai and Tsai (2003)	To examine the role Internet self-efficacy played on online information searching strategies and learning achievements in science	Physics/STS issues of nuclear energy	Eight college freshmen with mixed levels of Internet self-efficacy	Qualitative: survey, case studies, think-aloud, observation	Online resources and searching

Appendix B. Studies about Learning Outcomes (Category 2)

Sub-category	Author(s) and year	Purpose of study	Subject/topic	Sample	Research method/design	Internet-related technology utilized
Attitude	Chiu (2002)	To investigate whether a collaborative team setting benefits secondary science learning in a network supported environment	Earth science	94 tenth-grade students	Quantitative: experimental	Online resources (database) and searching
Attitude	Cole and Todd (2003)	To compare the computer-based online homework assignments, and traditional homework assignments	Chemistry	200 college students	Mixed: experimental; interview	Online resources (database) and animation
Attitude	Hsu (2006)	To present the development and evaluation of a web-based lesson	Physics	58 eighth-grade students	Quantitative: experimental	visualization/ animation
Attitude	Jang (2006)	To investigate students' attitudes and performance about the web-assisted learning with team teaching	Natural science	128 seventh-grade students	Mixed: experimental; interview	Online resources (database) and searching
Attitude	Shin (2002)	To investigate the user-perceived pedagogical effectiveness of a virtual reality learning system	Earth science	410 participants (including secondary students, college students, teachers, and others)	Qualitative: survey	Online resources/ multimedia
Attitude	Tsai et al. (2001)	To develop and evaluate a web-based concept map testing system for science students	Physics	38 eleventh-grade students	Mixed: content analysis, survey	Online testing
Attitude	Simons and Klein (2007)	To investigate the effects of web-aided instructional simulation on student conceptual change, problem solving and transfer	Metrology	117 college students	Quantitative: experimental	Simulation/ animation
Motivation	Riffell and Sibley (2005)	To evaluate the effectiveness of a hybrid course format	Biology	187 college students	Quantitative: experimental, survey	Online resources (database) and searching

Appendix B. (Continued)

Sub-category	Author(s) and year	Purpose of study	Subject/topic	Sample	Research method/design	Internet-related technology utilized
Motivation	Freasier et al. (2003)	To develop a web-based homework quiz-tutorial system to motivate students' learning	Chemistry	40–60 college students for each year	Quantitative: correlational	Online resources (database) and animation
Motivation	Wang and Reeves (2006)	To design a web-based learning environment to promote students' motivation of learning science	Earth science	27 tenth-grade students	Mixed: survey; interview; observation	Visualization/ animation
Motivation; conceptual understanding	Wang (2008)	To compare multiple formats of online formative assessments	Biology	165 fifth-grade students	Quantitative: experimental	Online testing
Conceptual understanding	Arasasingham et al. (2005)	To examine whether an implementation of a web-based instructional software program could change learning outcomes in courses with very large enrollments	Chemistry	248 college students	Quantitative: experimental	Visualization
Conceptual understanding	Barak and Dori (2005)	To examine the effect of technology-enhanced problem-based learning on students' achievements and their ability of transferring different levels of understanding	Chemistry	215 college students	Mixed-method: experimental; content analysis; interview	Online resources (database) and searching
Conceptual understanding	Bonham et al. (2003)	To compare student performance using web- and paper-based homework in college-level physics	Physics	About 230 college students	Quantitative: experimental	Online resources (database) and searching
Conceptual understanding	ChanLin (2008)	To observe students' use of technology during project-based learning activities in science	Geography and ecology	fifth graders	Qualitative: interview; observation	Online resources (database) and searching
Conceptual understanding	Cole and Todd (2003)	To compare the computer-based online homework assignments, and traditional homework assignments	Chemistry	200 college students	Mixed: experimental; interview	Online resources (database) and animation

Appendix B. (Continued)

Sub-category	Author(s) and year	Purpose of study	Subject/topic	Sample	Research method/design	Internet-related technology utilized
Conceptual understanding	Dantas and Kemm (2008)	To investigate student use of e-learning in a laboratory-based course and to evaluate the learning outcomes	Physiology	31 college students; 47 college students	Mixed-method: experimental; survey; interview	Online resources (database) and searching
Conceptual understanding	Hansen et al. (2004)	To examine student conceptual understanding of astronomical phenomena in relation to two different instructional experiences	Astronomy	33 college students	Mixed-method: experimental; interview	Virtual Reality (VR)
Conceptual understanding	Hoffman et al. (2003)	To explore the depth and accuracy of student content understanding as well as their use of search and assess strategies when they used online resources	Astronomy, ecology, geology, or earth science	16 sixth-grade students	Qualitative: observation; interview	Online resources (database) and searching
Conceptual understanding	Hsu and Thomas (2002)	To investigate the effects of selected characteristics of web-aided instructional simulation on students' conceptual change, problem-solving and transfer	Meteorology	117 college students	Quantitative: experimental	Simulation
Conceptual understanding	Hug et al. (2005)	To examine how the two learning technologies embedded within a project-based science curriculum unit can engage urban students in actively learning key science concepts	Science	33 eighth-grade students	Qualitative: observation, interview	Online resources (database) and searching
Conceptual understanding	Kubasko et al. (2008)	To compare students' investigations with an atomic force microscope and viruses in real-time synchronous and asynchronous learning environments	Biology	85 high school students	Mixed-method: experimental; discourse analysis, content analysis	Asynchronous and synchronous communication

Appendix B. (Continued)

Sub-category	Author(s) and year	Purpose of study	Subject/topic	Sample	Research method/design	Internet-related technology utilized
Conceptual understanding	Lin et al. (2002)	To investigate the effect of an Internet-based project on students' cognitive preferences and on their performance	Biology	77 tenth-grade students	Quantitative: experimental	Online resources (database) and searching
Conceptual understanding	Mistler-Jackson and Songer (2000)	To present case study data on one sixth-grade classroom of 'Kids as Global Scientists' participants during the eight-week program	Atmospheric science	One sixth-grade classroom of participants	Mixed-method: experimental; interview; observation; survey	Integrated/mixed
Conceptual understanding	Penn et al. (2000)	To describe the development and the effectiveness of an online homework and testing system	Organic chemistry	College students	Quantitative: experimental	Online resources (database) and searching
Conceptual understanding; cognitive skills specific to science inquiry	Sancho et al. (2006)	To create a virtual laboratory system in which experimental science students could learn required skills and competencies	Biology	292 college students	Quantitative: experimental	Virtual laboratory
Conceptual understanding	Shim et al. (2003)	To investigate the effectiveness of a three-dimensional virtual reality learning environment	Biology	72 middle school students	Quantitative: experimental; survey	Virtual reality
Conceptual understanding	Sun et al. (2008)	To explore the learning effect related to different learning styles in a web-based virtual science laboratory	Science laboratory	132 fifth-grade students	Quantitative: experimental, survey	Simulation/ animation; Virtual reality
Conceptual understanding	Taraban et al. (2005)	To examine the effect of online homework on in-class test performance	Physics	101 college students	Quantitative; experimental	Online resources (database) and searching

Appendix B. (Continued)

Sub-category	Author(s) and year	Purpose of study	Subject/topic	Sample	Research method/design	Internet-related technology utilized
Conceptual understanding	van der Meij and de Jong (2006)	To examine the effects of different types of support for learning from multiple representations in a simulation-based learning environment	Physics	72 students from middle vocational training	Quantitative: experimental; survey	Simulation/ animation
Conceptual understanding	Wang et al. (2006)	To investigate the effects of different types of assessment and the effects of learning style on students' science achievement	Biology	455 seventh-grade students	Quantitative: experimental	Online testing
Conceptual understanding	Williams and Linn (2002)	To investigate how a knowledge integration learning environment increases students' understanding of plant growth and development	Biology	23 fifth-grade students in Year 1; 23 fifth-grade students in Year 2	Mixed method: experimental, interview	Discussion forum, Online resources (database) and searching, simulation/ animation
Conceptual understanding	Woodrow et al. (2000)	To describe an evaluation program designed to assess the effectiveness of technology-enhanced instruction	Biology	Secondary school (grade 9–12)	Mixed-method: experimental, interview, survey, observation	Online resources (database) and searching
Conceptual understanding	Wu and Huang (2007)	To investigate ninth graders' cognitive, emotional, and behavioral engagement in teacher-centered and student-centered technology-enhanced classrooms	Physics	54 ninth-grade students	Mixed: observation; survey; experimental	Simulation/ animation
Conceptual change	Hsu (2008)	To explore in what ways a technology-enhanced learning environment support learning about the causes of the seasons	Earth sciences	78 second-year senior high school students	Mixed-method: experimental, content analysis	Online resources (database) and searching, simulation/animation

Appendix B. (Continued)

Sub-category	Author(s) and year	Purpose of study	Subject/topic	Sample	Research method/design	Internet-related technology utilized
Conceptual change	Hsu et al. (2008)	To understand in what ways a technology-enhanced learning environment supports learning about the causes of the seasons	Earth sciences	76 eleventh-grade students	Mixed-method: experimental; interview	Online resources (database) and searching, Simulation/animation
Conceptual change	Muller, Bewes et al. (2008)	To examine the effects of four online multimedia treatments on student conceptual learning regarding Newton's first and second laws of motion	Physics	364 college students	Quantitative: experimental	Visualization
Conceptual change	Muller, Sharma et al. (2008)	To investigate techniques that can raise the useful cognitive load engendered with linear multimedia	Physics	272 college students	Quantitative: experimental	Visualization
Conceptual change	She and Lee (2008)	To evaluate the effects of an adaptive digital learning project on conceptual change and scientific reasoning	Chemistry	62 sixth-grade students	Quantitative: experimental design	Discussion forum, online resources (database) and searching
General cognitive skills	Ng and Gunstone (2002)	To focus on how students perceive the effectiveness of the World Wide Web for researching information	Biology	22 tenth-grade students	Mixed: experimental, survey, observation	Online resources (database) and animation
General cognitive skills	Oliver and Hannafin (2000)	To investigate whether students use resources at higher levels to solve complex, open-ended problems	Physics (building collapse during earthquakes)	12 eighth-grade students	Qualitative: case study	Discussion forum, online resources (database) and searching, others: evidence organizing tool (Sensemaker tool); note-taking tool (Mildred)

Appendix B. (Continued)

Sub-category	Author(s) and year	Purpose of study	Subject/topic	Sample	Research method/design	Internet-related technology utilized
General cognitive skills	Pedaste and Sarapuu (2006)	To examine how the application of support notes and rearranging the sequence of the problems influence the students' analytical skills gained from a process of inquiry.	Ecology and environmental sciences	65 teams in the first study and 60 teams in the second study; aged 12–19	Quantitative: experimental	Online resources (database) and searching, simulation/animation
General cognitive skills	Piburn et al. (2005)	To create and evaluate a group of computer-based modules for college-level instruction in geology.	Geology	103 college students	Quantitative: experimental	Visualization: multimedia instructional module
Cognitive skills specific to science inquiry	Bell and Linn (2000)	To assess the arguments students constructed and explore the relationship between students' views of the nature of science and argument construction.	Physics	172 middle school students	Quantitative: experimental	Discussion forum, online resources (database) and searching
Cognitive skills specific to science inquiry	Chiu (2002)	To investigate whether a colla-borative team setting benefits secondary science learning in a network supported environment	Earth science	94 tenth-grade students	Quantitative: experimental	Online resources(database) and searching
Cognitive skills specific to science inquiry	Clark and Sampson (2007)	To explore the efficacy of a personally-seeded approach	Physics	84 eighth-grade students	Qualitative: content analysis	Discussion forum, online resources (database) and searching, simulation/animation
Cognitive skills specific to science inquiry	Clark and Sampson (2008)	To assess argumentation in online science learning environments	Physics	84 eighth-grade students	Qualitative: content analysis	Discussion forum, online resources (database) and searching, simulation/animation

Appendix B. (Continued)

Sub-category	Author(s) and year	Purpose of study	Subject/ topic	Sample	Research method/ design	Internet-related technology utilized
Cognitive skills specific to science inquiry	Walker and Zeidler (2007)	To examine what features of argumentation and discourse are utilized by students	Biology	36 vocational school students (ninth to twelfth grades)	Qualitative: interview, content analysis, discourse analysis	Discussion forum, online resources (database) and searching
Interactions	Furberg and Ludvigsen (2008)	To examine how students make meanings of socio-scientific issues in computer-mediated argumentation settings	Biology	Two secondary school students	Qualitative: case study	FLE2-CSCL groupware
Interactions	Saw et al. (2008)	To study what were the interaction patterns of distance learners and their teachers in a video-conference learning environment	Mathematics and physics	college students (six sessions)	Qualitative: content analysis	Visualization/ videoconferencing learning environment
Interactions	Guan et al. (2006)	To find out whether and how the manipulation of discussion conditions would affect the interaction patterns between participants and the quality of discussion	Physics	213 participants (mostly senior high school students)	Qualitative: content analysis	Discussion forum
Interactions	Lipponen et al. (2003)	To study interaction patterns among users in an online discussion collaborative learning environment	Science (human senses)	23 fifth-grade students	Qualitative: content analysis	Discussion forum