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The interpretation construction design model for teaching science and its applications to Internet-based instruction in Taiwan

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Abstract

This paper uses the Interpretation Construction Design Model proposed by Black and McClintock (1996) [An interpretation construction approach to constructivist design. In: Wilson, B. (Ed.), Constructivist Learning Environments. Educational Technology Publications, Englewood Cliffs, NJ] to illustrate constructivist science teaching. The author discusses eight principles for constructivist-oriented science instruction, including observations in authentic activities, interpretation construction, contextualizing prior knowledge, cognitive conflict, cognitive apprenticeship, collaboration, multiple interpretations, and multiple manifestations. This paper further discusses the possibility of applying these instructional principles to Internet-based science instruction, describing recent attempts in Taiwan. © 2001 Elsevier Science Ltd. All rights reserved.

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1. Introduction

Many cognitive psychologists share a constructivist epistemology in viewing students' learning processes (Brooks and Brooks, 1993; von Glasersfeld, 1989). They suggest that meaningful learning neither stems from direct motivation nor from environmental pressure (i.e., external stimulus); rather, it happens as a result of a reorganization of psychological structures from organism–environment interaction inside the mind (Gilbert and Watts, 1983). Hence, constructivists believe that a learner's prior knowledge plays an essential role in the learning processes in which "the active person reaching out to make sense of events by engaging in the construction and interpretation of individual experiences" (Pope and Gilbert, 1983, p. 194). Learning, in the constructivist frame, is a process of meaning construction and interpretation, and certainly, social interactions from teachers and peers also influence learners' knowledge construction. Teachers are not the course material presenters or controllers; rather, they become the facilitators of students' knowledge construction.

Constructivism has received some consensus among researchers of educational fields in general (Brooks and Brooks, 1993), particularly, in science education (Tobin, 1993; Staver, 1998). This paper first reviews several principles of constructivist

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instructional designs by mainly using the frameworks proposed by Black and McClintock (1996). Black and McClintock proposed an Interpretation Construction Design Model (ICON model), which may be applied to various school subjects in general. The ICON model emphasizes learners' interpretations of information and their processes of knowledge construction. Science learning, clearly, involves a series of information or observation interpretations and knowledge construction. This paper believes that the ICON model provides practical principles for constructivist-oriented science instruction.[1] This paper further discusses the possibility of using these principles in Internet-based science instruction, especially to describe some recent attempts in Taiwan.

2. Principles of the ICON model

2.1. Observations in authentic activities

If there are no authentic observations or tasks involved in the knowledge-to-be-learned, students will learn it through rote memorization and they cannot use it in an appropriate context. For example, if a student learns English merely from dictionary definitions, he or she may speak a sentence like "Mr Brown stimulated the soup" (Brown et al., 1989). Too often, science instruction presents science as a collection of facts, far away from our everyday life. Hence, students can recall important scientific laws in a rote fashion, but they do not know how to use these ideas in solving real-world problems or helping them interpret common natural phenomena. They would be like a group of people who can remember the detailed manual of a machine but they never have the opportunities of seeing or operating it.

The ideas of "situated cognition" (Brown et al., 1989) and "anchored instruction" (Cognition and Technology Group at Vanderbilt, 1990) propose to urge educators to implement some instructional activities for students to make some observations anchored in authentic tasks or situations. Although some scientific ideas cannot easily be observed in typical classrooms (e.g., the existence of atoms), students are encouraged to interpret their observations differently as a result of science instruction (e.g., viewing matter in light of a particle model). This concurs with the learning philosophy suggested by Novak and Gowin (1984) that learning is synonymous with a change of the meaning of experiences.

A series of research works completed by Roth (1995, 1997) explore the "observations in authentic activities" further. He asserted that problems in science instruction need to be defined so loosely that students could construct their own frames. The "authentic" learning environments, which share some features with everyday environments of scientists, can help students experience an adequate level of ambiguity, uncertainty and the social and material aspects in the construction of scientific knowledge. This shapes some implications for current practice in science education, which largely offers highly ideal situations for students to conduct exploration.

2.2. Interpretation construction

The main philosophy of constructivism is the idea that knowledge is not passively received, but it is actively built up by the cognizing subject. Learners cannot simply reproduce transmitted knowledge but have to construct it by themselves. Hence, teachers need to create learning environments where students have opportunities to construct their interpretations of new information. Further, probably with teachers' guidance, they should construct arguments to examine, validate or challenge their interpretations.

Recently, philosophers of science have come to believe that science does not represent the truth (Duschl, 1990; McComas 1996, 1998). It is only *a* way (not the way) of interpreting natural phenomena while it is *invented* by human beings, not *discovered* from the physical world. For example, Einstein, though living in the age of logical positivism, once stated that "[s]cience is not just a collection of laws, a catalogue of facts, it is

[1] "Constructivist-oriented science instruction" means instructional resources and activities in science which are informed by the constructivist theory.

the creation of the human mind with its freely invented laws and concepts” (Einstein and Infeld, 1938, p. 310). However, school science, commonly, is portrayed as a body of absolute truths, discovered from the reality, and science students widely believe that scientific models are copies of the physical world (Driver et al., 1997; Ryan and Aikenhead, 1992). This inappropriate image of science may discourage students’ free (or creative) interpretation construction in science classrooms. A proper understanding of the creative nature of scientific knowledge can help students actively engage in the interpretation construction process.

2.3. Contextualizing prior knowledge[2]

Recent research findings reveal that students, before receiving formal science instruction, have firmly established some naive science knowledge, labeled as “misconceptions” or “alternative conceptions” by science educators.[3] Such prior knowledge, which often conflicts with accepted scientific views, influences their observations of demonstrations and experiments, their interpretations of these observations and their comprehension of science texts and teachers’ lectures (Champagne et al., 1983). If their prior knowledge cannot be explicitly explored or challenged, they will return to their alternative conceptions soon after science instruction, or they will study the scientific concepts in isolation without relating what they have already known (Wandersee et al., 1994; Solomon, 1983). As expected, students bring various sorts of prior knowledge about the knowledge-to-be-learned. Science teachers need to create contexts for students to explore or apply their prior knowledge and then teachers can diagnose their alternative conceptions.

2.4. Cognitive conflict[4]

Many educators have stated that cognitive conflict, which may be caused by discrepant or anomalous data, is a necessary, although not sufficient, condition for students to change their alternative conceptions (e.g., Hewson, 1985; Posner et al., 1982). Discrepant events are designed to provide novel evidence to challenge students’ alternative conceptions. However, teachers should choose proper discrepant events that neither cause student confusion nor frustration. Also, it is recognized that the demonstration of discrepant events is only one of the many steps for students to process conceptual change (Tsai, 2000).

2.5. Cognitive apprenticeship

The constructivist teacher is a good model in processing new information and constructing expert performance (Bednar et al., 1992). Collins et al. (1988) suggest the following sequence of the cognitive apprenticeship: modeling, coaching and fading. They also assert that teachers’ responses cannot be scripted and they need to give proper situated guidance when facing students’ various interpretation constructions. In other words, constructivists, on the one hand, view learning as an individual’s knowledge construction, but on the other hand, they emphasize the importance of the cognitive apprenticeship guided by teachers. Hence, the constructivist instructional design is seriously different from the “discovery learning” proposed by educators around the 1970s.

The discovery learning approach assumes that learners acquire meaningful knowledge when they can discover it solely by their own efforts. In other words, the proponents of discovery learning suppose that testing a hypothesis and interpreting an experiment are straightforward and simple enough for children in isolation to discover and vindicate

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[2] This principle is a little different from the “contextualization” proposed by Black and McClintock (1996). The contextualization intends that students access background and contextual materials of various sorts to aid interpretation and argumentation. Hence, background and contextual materials are mainly provided by the instructors. “Contextualizing prior knowledge” in this paper suggests that students are encouraged to use their own relevant prior knowledge to interpret some phenomena in a certain context.

[3] “Alternative conceptions” is recently a more acceptable term among science educators, as pupils’ existing ideas have value rather than being wrong (Wandersee et al., 1994).

[4] This principle is not proposed by Black and McClintock (1996).

the scientific knowledge (Matthews, 1994). However, constructivists cannot ignore the fact that students, in many situations, should serve as apprentices to teachers to master observations, interpretations and knowledge construction. Educators shall also recognize that constructivist teachers are very different from so-called traditional teachers, who are simply the information providers. In the constructivist frame, the role of science teachers would become an adversary in the sense of a Socratic tutor and a model of scientific thinking (Posner et al., 1982).

2.6. Collaboration

Scientific knowledge grows and becomes mature through a series of arguments and negotiations among a large group of scientists. Hence, Nadeau and Desautels (1984) asserted that "[w]hat we have agreed to call science is nothing more or less than the process by which we collectively construct a representation of reality" (p. 24). Similarly, students' science knowledge is viewed as individually constructed but socially mediated. We cannot neglect the social nature of cognition (Cognition and Technology Group at Vanderbilt, 1992), and learning should be viewed as a social activity in which students are engaged in meaning construction through discussion, argumentation and negotiation among teachers, peers and other students. Numerous educators highlight the importance of collaborative learning for students' knowledge construction. As expected, abundant past studies have shown that, in general, collaborative group learning can promote students' achievement, motivation and attitude toward learning (Springer et al., 1999). From a constructivist perspective, educators should encourage students to be collaborative in observation, interpretation and contextualization. In this sense, constructivist science teachers do not only play the roles of questioners (Socratic tutor) and knowledge providers (model of scientific thinking) as described previously. They also need to negotiate experiences and explanations with students and then to arrive at convincing explanations via the co-construction of knowledge. Teachers also need to persuade students of the value of accepted scientific concepts (Newton et al., 1999).

2.7. Multiple interpretations

Science is often regarded as a subject that provides a single correct answer. However, lessons from the history of science tell us that scientists can explain the same phenomena from different, but valid, theoretical perspectives. For example, there are various scientific theories explaining the causes of earthquakes (e.g., changes in barometric pressure, rising gas from the mantle, moving plates of rocks; for details, see Duschl, 1987). As described previously, science does not represent the truth; therefore, it is possible to have multiple interpretations for natural phenomena. Similarly, students should be encouraged to explain or solve scientific problems through different theoretical perspectives. As far as 1972, M. Martin, following Feyerabend's philosophy, stated that:

> [S]tudents of science should be taught a number of different theoretical approaches in a domain of research. If necessary, discarded theories from the history of science should be resurrected and reexamined. Student should not only be exposed to different theoretical approaches, but should also learn to work easily with different theories, now seeing the domain from the point of view of one theory, now seeing it from the point of view of another, switching back and forth to get various theoretical perspectives and insights (Martin, 1972, p. 125).

By being exposed to multiple interpretations and theoretical perspectives, students can acquire flexible knowledge structures of scientific concepts for further applications. For instance, in solving modern physics problems, students can use either a wave or a particle perspective to interpret behaviors of matter. Also, through being exposed to various theoretical perspectives, students can understand the limitations as well as the strengths of each theory, and then shape a more authentic image about science. Further, the collaborative learning approach can be a central strategy for achieving multiple interpretations (Bednar et al., 1992). For instance, students can collectively construct various interpretations for a natural phenomenon, and they can together evaluate these views and further decide which one is most useful and meaningful in explaining this phenomenon in the particular context. Moreover, because multiple interpretations imply the idea that students may have different ways of achieving the same scientifically "correct" answer, it suggests that educators provide multiple modes of assessment to obtain a more complete picture of students' ideas in science.

2.8. Multiple manifestations

Typically, a valid scientific concept can be applied to numerous situations. For example, Newton's law of motion can be used to explain the interplanetary motion as well as the motion of small particles. Educators also suggest that when learning a new scientific conception, showing its "fruitfulness" is a necessary condition for students' conceptual change (Posner et al., 1982). In other words, the new conception should not only solve its predecessors' difficulties, but also have the potential to be extended, and to open up new areas of inquiry. Students acquire transferability by seeing multiple manifestations of the same idea. They are encouraged to use the same idea at different times and in various contexts.

3. The relationships between the ICON model and other frameworks of constructivism

Tsai (1998a) has synthesized three major forms of constructivism: radical constructivism, social constructivism and contextual constructivism. Tsai (1998a) reviewed various studies of student science learning and then proposed eight assertions of constructivism for science learning, listed in Table 1. The first five assertions are oriented to radical constructivism (e.g., von Glasersfeld 1989, 1993), whereas the final three assertions are more oriented to social constructivism and contextual constructivism (Solomon, 1987; Cobern 1993, 1998). Table 1 further shows the relationships between Tsai's (1998a) constructivist assertions and the (modified) ICON model proposed above.

Table 1 shows that the principles of the ICON model can be easily integrated with Tsai's (1998a) constructivist assertions. For example, Tsai's first assertion, emphasizing the importance of existing conceptions (or prior knowledge), clearly, is related to "observations in authentic activities", "interpretation construction" and "contextualizing prior knowledge" of the ICON model. Tsai's sixth assertion, discussing group learning, peers and student–teacher interactions, is related to the ICON model's "cognitive apprenticeship", "interpretation construction" and "collaboration". Especially, "interpretation construction" is the core principle across the assertions. In fact, "interpretation construction" represents the main tenet of the constructivist theory.

4. The relationships between conceptual change and the ICON model

In the last two decades, science educators believe that students need to discard some prior knowledge, that is, alternative conceptions, and then to experience a process of conceptual change when learning science. Although several researchers have proposed theories of conceptual change (Carey, 1985; Chi, 1992; Posner et al., 1982; Strike and Posner, 1985; Vosniadou, 1991; Vosniadou and Brewer, 1987), they share some commonalities in interpreting conceptual change (see a review by Tsai, 1998a). The conceptual change model proposed by Posner et al. (1982) and Strike and Posner (1985) is the often-quoted perspective in the relevant literature.[5] These researchers suggest the following four conditions for students to restructure their alternative conceptions during the process of conceptual change.

> Condition 1: students must be dissatisfied with existing conceptions (or alternative conceptions).

[5] It is recognized that Ponser et al.'s conceptual change model emphasizes a rational lens of conceptual change, while the possible influences of student views of epistemological, ontological and affective domains on conceptual change cannot be ignored (Hodson, 1999; Pintrich et al., 1993; Tsai, 1998b,c; Tsai, 1999a,b; Tyson et al., 1997).

Table 1
The relationships between Tsai's (1998a) constructivist assertions and (modified) ICON model

The constructivist assertions of student science learning proposed by Tsai (1998a)	Relevant principles by the ICON model
1. Students' existing conceptions play an important role for new knowledge acquisition.	Observations in authentic activities; interpretation construction; contextualizing prior knowledge
2. Students' alternative conceptions are resistant to change by conventional teaching strategies; discrepant events would not always work.	Cognitive conflict; interpretation construction
3. Students should experience a series of conceptual changes when learning science.	Cognitive conflict; interpretation construction
4. Students' ideas and those of teachers may be incommensurable; we should understand students' learning and thinking from their perspectives.	Interpretation construction; contextualizing prior knowledge
5. Students are knowledge producers, not knowledge reproducers; learning is an active process of knowledge construction, not a passive process of knowledge reproduction; learning science requires students' creativity.	Interpretation construction
6. Students learn effectively and meaningfully in a favorable environment where their ideas are explored, compared, criticized and reinforced through talking and listening to others.	Cognitive apprenticeship; collaboration; interpretation construction
7. Students learn by various methods; we should encourage students' multiple ways of researching, questioning and problem-solving; it is suggested to use qualitative assessment to examine students' learning.	Multiple interpretations; multiple manifestations; interpretation construction
8. Students' knowledge acquisition occurs in a complex social, historical, cultural, and psychological context; we should have an integrated view of science education, incorporating philosophy, history, sociology and psychology into curriculum materials.	Interpretation construction; multiple interpretations

Condition 2: a new conception must be intelligible.
Condition 3: a new conception must be initially plausible.
Condition 4: a new conception must be fruitful or open to new areas of inquiry.

Table 2 further shows the relationships between the four conditions of conceptual change and the eight principles of the ICON model.

Science educators usually use discrepant events, challenging students' alternative conceptions, to achieve the first condition of conceptual change, causing the dissatisfaction of students' existing conceptions (Tsai, 2000). The discrepant events may occur through observations in authentic activi-

Table 2
The relationships between conceptual change and the ICON model[a]

Conditions of conceptual change	Dissatisfaction	Intelligibility	Plausibility	Fruitfulness
Observations in authentic activities	✓✓	✓✓	✓	✓✓
Interpretation construction	✓✓	✓✓	✓✓	✓✓
Contextualizing prior knowledge	✓✓		✓✓	
Cognitive conflict	✓✓		✓	
Cognitive apprenticeship	✓	✓✓	✓✓	✓
Collaboration	✓	✓✓	✓	✓
Multiple interpretations	✓✓		✓✓	
Multiple manifestations				✓✓

[a] ✓✓: Highly related; ✓: possibly related.

ties. These events can contextualize students' prior knowledge and cause cognitive conflict. They may also induce multiple interpretations about the events among learners. The discussion of these events relies on teachers' (or higher achievers') cognitive apprenticeship or peers' collaboration. The intelligibility of the scientific conceptions mainly comes from the observations in authentic activities, cognitive apprenticeship from science teachers and collaboration with learning peers. Through these methods, the scientific conceptions can become understandable. The plausibility of scientific conceptions, making scientific conceptions consistent with students' other ideas, is mainly achieved through the ICON model's principles of interpretation construction, contextualizing prior knowledge, cognitive apprenticeship, and multiple interpretations. The fruitfulness of scientific conceptions, clearly, is related to the multiple manifestations in the ICON model, and it can be explored primarily through students' observations in authentic activities and interpretation construction. Therefore, the conditions of conceptual change can be fulfilled by practicing the eight principles of the (modified) ICON model.

5. Applications to Internet-based science instruction

Internet-based instruction has recently received much attention in the education field. Especially, the Internet and the World Wide Web (www) have brought science educators into a new paradigm in science education (Brooks, 1997; Cohen, 1997). Internet-based instruction can illuminate new approaches of science teaching, providing distant, interactive, broad, individualized and inquiry-oriented perspectives of science instruction. For example, the dissemination mechanism of the Internet provides a much broader context for the opportunities of students' collaborative learning than that achieved by traditional teaching. In particular, science learning involves making real-time observations (e.g., the immediate weather information) and reaching conclusions, and the mechanism is very helpful in accomplishing these tasks. The following discussion will address the applications of the ICON model or of constructivist principles to Internet-based instruction. The discussion, where applicable, will mainly cite some recent research projects conducted at the National Chiao Tung University (NCTU), Taiwan, to illustrate the constructivist-oriented Internet-based science instruction.

5.1. Observations in authentic activities

It is important that Internet-based instruction should try to offer more authentic contexts for students to practice scientific knowledge. Recent technology development in animation and the sound effects on the Internet (e.g., JAVA) provides rich information displays for students to navigate in more authentic contexts of exploring scientific knowledge. Moreover, virtual reality provides highly authentic contexts for students to travel in some invisible (e.g., microscopic views of matter, internal organs) or unreachable space (e.g., outer space or deep sea). Certainly, the use of virtual reality (VR) for education is also consistent with the merits of the constructivist theory. First, VR provides relatively more authentic representations for the instructed concepts (compared to other instructional media such as textbook pictures). Moreover, students need to actively interact with VR instructional materials to maintain the learning process. Finally, students can freely travel in VR environments and acquire information of interest, which creates student-centered learning modes. Recent developments in VRML (virtual reality modeling language) can deliver VR on the Internet. Chou et al. (2000) have developed a networked VRML-based system for students to navigate a person's digestive system. Learners can travel with the food to acquire relevant concepts of health science through the Internet.

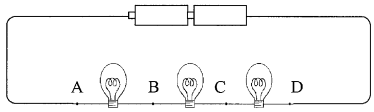
One may argue a conflict between "authentic" experiences and the "virtual" world provided by the Internet. In most circumstances, learning science involves observations of certain phenomena. To have authentic experiences is quite important for science instruction. However, due to some limitations, for example, the high cost of scientific instruments or natural constraints (e.g., observing organs inside the body or tiny particles), students may not easily obtain authentic experiences. In these situations, "virtually authentic" learning environments provided by Internet-based instruction are viewed as the best alternative for teaching science. Through exposure to virtually authentic information, science students can somehow acquire relevant experiences and observations. Post-Zwicker et al.'s (1999) recent work shares a similar rationale. Through the Internet, the high-school students in their study were given access to real-time data and virtual experiments of plasma physics and fusion energy conducted by professional scientists.

5.2. Interpretation construction

Interpretation construction is the core principle of constructivist-oriented science instruction. The content of Internet-based instruction should provide opportunities for students to freely interpret some phenomena, and moreover, encourage students to navigate through instructional nodes and construct their own learning paths (Sun and Chou, 1996). Internet environments should also provide relevant functions for students to review their learning paths and for teachers to monitor students' navigation processes.

5.3. Contextualizing prior knowledge

Internet-based instruction needs to encourage students to interpret new situations on the basis of their prior knowledge and experiences (Sun and Chou, 1996). As described previously, students' prior knowledge may contain various alternative conceptions that influence subsequent learning. Teachers as well as students themselves are encouraged to explore some possible alternative conceptions during the process of science instruction. Two-tier tests have recently been used in science education research to investigate students' alternative conceptions (Odom and Barrow, 1995; Christianson and Fisher, 1999). Fig. 1 shows an example of a two-tier test. The first tier assesses students' descriptive knowledge about a phenomenon, that is, a comparison of the current of different points in an in-series circuit. The second tier explores students' reasons for their choice made in the first tier. Hence, the second tier investigates students' explanatory knowledge or their so-called "mental models" (Genter and Stevens, 1983).



(a). A>B>C>D, (b). A=B=C=D, (c). A<B<C<D.

The reason for your choice above is:

(i) The light bulbs will use up current but not electric potential (energy).

(ii) The light bulbs will not use up current but use up electric potential (energy).

(iii) The light bulbs will use up both current and electric potential (energy).

(iv) The number of free electrons decreases in the circuit.

Fig. 1. An example of a two-tier test about student conceptions of an electric circuit. The scientifically correct answer for this item is (b)(ii).

A new research project about two-tier tests is currently being undertaken at NCTU, Taiwan. The project is intended to develop an on-line, two-tier test system for high-school science students. Through the technology of the common gateway interface (CGI), this Internet-based instructional system will further provide some corresponding feedback or clues for students with an incorrect answer combination. For instance, if a student chooses (a)(i) in the two-tier test illustrated in Fig. 1, he or she clearly has a common alternative conception that the bulbs would use up the current. The on-line instructional system will then suggest the student to conduct a simple experiment to prove that the current at points A, B, C and D is the same value. Or, the system will ask the students to use water-circuit analogy to interpret the electric circuit. By this feedback and suggestive guidance, the on-line, two-tier test system is intended to help students correct their alternative conceptions and then achieve an interactive and individualized approach to instruction.

5.4. Cognitive conflict

From the perspective of students' alternative conceptions and conceptual change learning, cognitive conflict is important for knowledge acquisition in science. Tsai (1999c, 2000) analyzed the sources of cognitive conflicts for science learning, including student intuition, daily experiences, common language, previous science instruction, meth-

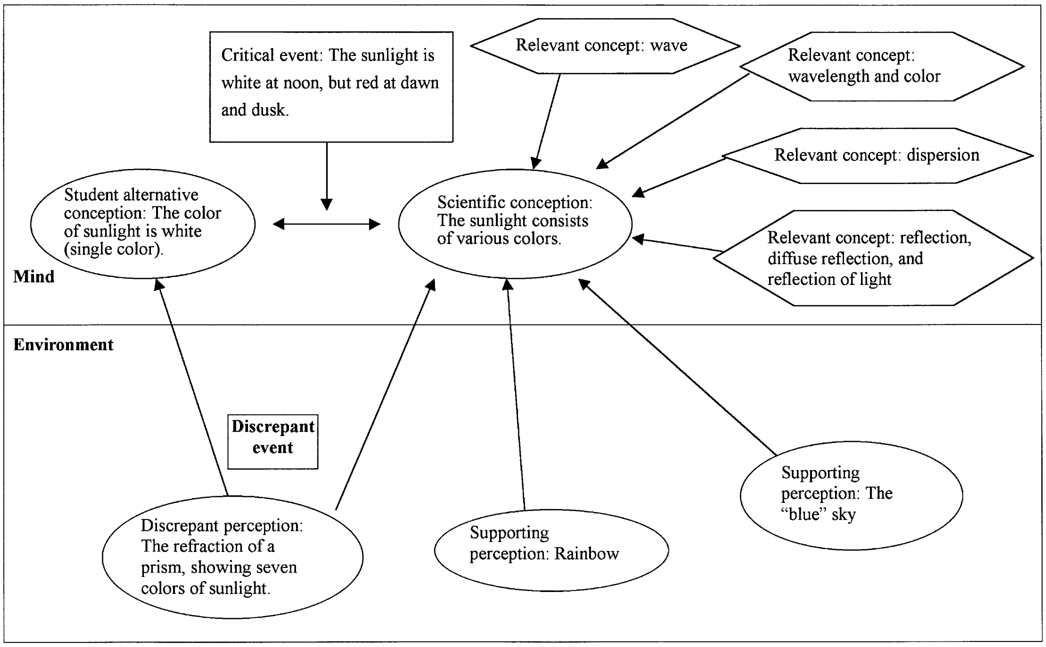


Fig. 2. A conflict map about color and sunlight.

odology and ontology. Teachers may carefully explore these sources and then design proper instructional activities to challenge students' alternative conceptions. Tsai (2000) further proposes a series of conflict maps, which include discrepant events and demonstrations of various student alternative conceptions for science teachers and students.[6] Fig. 2 shows an example of a conflict map.

The conflict map in Fig. 2 addresses students' alternative conception that sunlight includes only white color of light. The conflict map displays a discrepant event and a critical event and relevant concepts and supporting perceptions for the alternative conception. Tsai (2000) further suggests the following teaching sequence of the conflict map to promote students' conceptual change: the discrepant event, the scientific conception, the critical event, relevant scientific concepts and finally supporting perceptions (for details, see Tsai, 2000). The conflict map presents a clear framework for science teachers to design a series of instructional activities that challenge students' alternative conceptions. Based on such a framework, Tsai (2000) also encourages practicing teachers to submit their ideas to remotely and collaboratively design some cognitive conflict activities or conflict maps through the Internet.

5.5. Cognitive apprenticeship

Constructivist-oriented science instruction cannot ignore the role played by science teachers. The cognitive apprenticeships provided by science teachers will become more available through the use of the Internet. Students would be free of the space and time constraints to receive teachers' guidance. The distant communication provided by the Internet also makes it possible for students to receive a cognitive apprenticeship from practicing scientists. Cohen (1997) has presented a series of cases of student–scientist partnerships through Internet links for science education. As described previously, a constructivist teacher should, at least,

[6] Again, the perspective of conflict maps focuses on a rational lens of conceptual change, while the possible effects of students' views of epistemological, ontological and affective domains on conceptual change cannot be ignored.

play the role of a Socratic tutor or a model of scientific thinking. Practicing scientists may well model these roles. Some professors at the College of Science at NCTU, Taiwan, have connections with gifted high-school students through the Internet to guide them in some scientific research. Similar attempts will continue in the near future.

5.6. Collaboration

Internet-based instruction should encourage students to discuss and work cooperatively. In fact, the cooperative or collaborative nature is a key feature of some Internet-based instructional systems. The CORAL (cooperative remotely accessible learning) system developed at NCTU, Taiwan, is an example of this (Chou and Sun, 1996; Sun and Chou, 1996). The CORAL system provides a BBS-like shared notebook, chatroom, electronic whiteboard, audio conference (Internet phone) and video conference to encourage peers (a team of two or more) and student–teacher interactions. The CORAL system can also keep track of each student's progress through recording the number of nodes visited, the number of projects done and test scores. The system, then, can assign advanced students to help slower students and those students who help others could get extra credits in the system.

Peer assessment is another approach of practicing student "collaboration".[7] Computer-assisted peer assessment is an emerging growth area in education, although little data in the literature are yet available (Topping, 1998). Internet-based peer assessment can allow students to review other students' work regardless of the limitation of time and location. Students are also able to read comments through the Internet and then modify their original work. A recently completed project about Internet-based peer assessment at NCTU, Taiwan, was conducted with about 30 college students. The project system was performed by retrieving and storing DBMS's (data base management system) information through the CGI program. These students were asked to submit their science assignments to the Internet system, and their peers read their work and then gave grades and wrote comments, also through the Internet. Students needed to modify their original assignments according to their peers' evaluations. After three rounds of such Internet-based peer assessment, the quality of students' science assignments was statistically improved, both from peers' or teachers' grading. Students' views of using such an Internet-based peer assessment system, in general, were positive (Tsai et al., 2000b). Hence, the Internet environments provide an effective means for teachers to process peer assessment.

5.7. Multiple interpretations

Internet-based instruction needs to encourage students to provide various solutions to given problems (Sun and Chou, 1996). Or, they should learn to view scientific knowledge through different perspectives. The on-line role-playing activities may well function to achieve this. Due to the "decontextualised" nature of Internet environments, everyone on the Internet is supposed to be treated equally, regardless of his or her professions, gender or academic levels. Hence, everyone can freely express his or her views through the Internet. Some science-related issues, for example, the development of nuclear weapons or genetic engineering, may welcome people of various roles and positions to contribute their ideas. Internet environments, clearly, can provide ideal conditions to achieve this. One may argue that there may be a conflict, as the Internet allows decontextualised interactions in which social status is of lesser importance than in the "real world", but at the same time, educators and developers are being encouraged to provide "real world" problems — to present learning activities in a context. In this paper, it is asserted that the experiences and activities in Internet-based instruction are expected to be as close to the real world as possible, but the participants (including students, teachers and even others), in some situations, can be virtual or decontextualized.

Also, multiple interpretations imply the use of multiple modes of assessment in constructivist-oriented instruction. The two-tier test described above

[7] Certainly, the process of peer assessment can also be viewed as a form of providing "cognitive apprenticeship".

could be viewed as one example of an assessment method. Furthermore, concept maps have been used to assist science instruction in the last 15 years (Novak and Gowin, 1984; Novak, 1998). Concept maps can also be used as an assessment tool. A project at NCTU, Taiwan, has developed a www-based concept map testing system for high-school students. The concept map testing system could be viewed as a series of fill-in questions presented in a concept map format. Fig. 3 shows two sample items.

Students are asked to fill in the blanks on-line. The blanks may be a concept or a relation keyword between two concepts. In many cases, the testing system includes typical concept maps, showing hierarchical levels of concepts, and leaves more than one blank for students to fill in (similar to the second item). The system shows one concept map (but often more than one fill-in blank) per screen. The testing system is completed by using ASP (active server page) technology. After one student finishes all the test items, he or she submits his or her answers through the Internet and then he or she can view the reference answers provided by the system on-line. This system has already been implemented in some of Taiwan's high schools. Available empirical data (Tsai et al., 2000a,c) show that students' performance on this system may provide an alternative indicator to explore students' understanding of physics, which may differ from traditional standard tests. Students with higher test anxiety tended to prefer to be tested through such on-line systems. Educators may include this way of testing as one of the multiple assessment modes, especially to provide this system to students with high test anxiety when it comes to taking traditional standard examinations. Students' views of using this system, in general, were positive. They did not think on-line tests would cause problems through cheating. Many high-school students in this study showed a high willingness to use the system in the future.

5.8. Multiple manifestations

To achieve "multiple manifestations", Internet-based instruction should provide rich resources for knowledge-to-be-taught. Usually, an Internet-based instructional system will provide a resource center to display rich relevant information about knowledge-to-be-taught. Especially, the hyperlinks in the www can connect all the relevant sites and then provide plentiful information for students. In this way, students may connect to a space laboratory to navigate outer space, or to read the most updated weather information from some national weather web sites. A large www resource center for science and mathematics is currently being constructed by the College of Science, NCTU, through funding from the Ministry of Education, Taiwan.

6. How are these Internet-based instructional activities considered as "constructivist"?

One may agree that a lot of the existing educational resources on the Internet or www are far from constructivist and are based on very simplis-

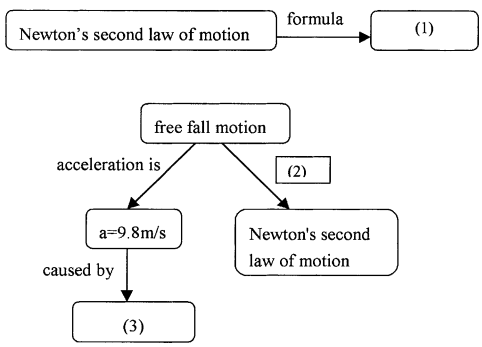


Fig. 3. Sample items used in a www-based concept map testing system. The answers are: (1) F=ma, or (2) follows, and (3) gravity.

tic transmission models. Therefore, it is important to examine how the Internet-based instructional activities described above are considered as "constructivist". That is, in essence, what makes these activities constructivist — the dissemination mechanism, the interface (or gateway design), and/or the activity itself? Table 3 presents an analysis of this.

Table 3 reveals that all of the Internet-based instructional activities per se are considered as constructivist. For example, the goal of the networked VRML health science system is to help students acquire relatively more authentic experiences than those provided by traditional instruction. The two-tier test, the concept map testing system and peer assessment activities offer alternative ways of evaluating students' performance and these may provide better indicators about the processes of knowledge acquisition in science.[8] In particular, the two-tier test system is adaptive, trying to create a student-centered and individualized approach to science instruction. The conflict map is based on some theoretical perspectives of constructivism, for instance, students' alternative conceptions and conceptual change. The projects relating to student–scientist partnerships, CORAL and peer assessment emphasize the collaborative and social facets of constructivist theory. However, the dissemination mechanism and the interface or gateway design of the Internet help these activities to be implemented in a more efficient and potential way. For example, in CORAL and peer assessment systems, the dissemination mechanism of the Internet can facilitate students' social interactions without the constraints of time and location. The same feature of the Internet allows practising teachers in the conflict map project to remotely and collaboratively design science instructional activities that challenge students' alternative conceptions. The interface of the VRML system allows students to navigate a person's digestive system in any way they prefer and to view the organs in detail. Moreover, the adaptive nature of the two-tier test system is possible by the gateway design of the Internet. The same feature of the Internet can help students in the concept map testing system view the correct answers for the test. In sum, these instructional activities themselves are regarded as constructivist, but the Internet is regarded as a powerful medium of implementing these activities. The dissemination mechanism and the gateway design of the Internet are far superior to other media before it, changing these instructional activities from inefficient to efficient, and even from impossible to possible.

7. Conclusions

This paper discusses the use of constructivist-oriented instructional principles to assist Internet-based science instruction. Both constructivist-oriented learning theory and Internet-based instruction are relatively new approaches in teaching science. The integration of these two approaches is expected to produce better learning outcomes for

Table 3
What makes the Internet-based activities "constructivist"?

	Dissemination mechanism of the Internet	Interface or gateway design of the Internet	The activity itself
VRML learning system	✓	✓	✓
Two-tier test		✓	✓
Conflict map	✓		✓
Student–scientist partnerships	✓		✓
CORAL	✓		✓
Peer assessment	✓		✓
Concept map testing system		✓	✓

[8] Hence, the automated testing systems are viewed as "non-constructivist" activities, as the test content and items are simply presented in traditional ways such as multiple-choice items with a single correct answer.

students. Some recent projects in Taiwan have also been presented in this paper. These attempts illuminate possible approaches or applications of implementing constructivist Internet-based science instruction for other countries, especially developing countries. Several projects in Taiwan are currently being conducted to investigate the effectiveness of these modes of Internet-based science instruction. These projects use solid research methods with large samples of students. Through such attempts, the educators and researchers involved wish to accomplish the goal of "science for all" for Taiwanese students.

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