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chapter 6

# Using ICT as Cognitive Tools for Student-centred Learning

Zhang Baohui

## Introduction

The Ministry of Education (MOE) of Singapore has recently promoted the idea of "Teach Less Learn More (TLLM)" (http://www.moe.gov.sg/bluesky/tllm.htm) at K-12 schools. MOE wisely proposed the idea to change student's learning by changing the way teachers teach. In essence, the policy encourages teachers to use more student-centred approach for active and engaged learning. Learning through authentic activities was also one of MOE's recommendations. As many influential documents have suggested, inquiry should be the recommended approach for engaged and meaningful learning. After launching the IT Master Plan I and II, Singapore schools become more advanced with educational technology infrastructure. This makes the goal of TLLM more possible to be realised. We argue that fostering student's critical thinking, problem solving skills and collaboration are keys for fulfilling the education goal. We believe that technology can help the TLLM movement. Given Singapore's unique cultural and technological environment in school, we propose using technologies as cognitive tools for meaningful, purposeful and efficient learning; eventually, we expect effective learning.

Building mental models of the phenomena that students are studying has been recommended for effective learning. The tools used to construct these models are known as cognitive tools or mindtools. They engage different kinds of critical, creative and complex thinking. Cognitive tools include semantic organisation tools (semantic networks), dynamic modelling tools (systems and population dynamics), web-based conversation/CSCL (Computer Supported Collaborative Learning) tools and other computer-based software programmes (Jonassen, 2005). They are effective because learners are designers engaged in constructing personal meaning that makes the learners intellectual partners with the technology. When learners communicate with their classmates and teachers, they can share expertise and achieve more consensus understanding. There has been research that showed a connection between cognitive tool used and cognitive processing (Liu, Bera, Corliss, Svinicki and Beth, 2004). We do not think that only computer-based technologies can be cognitive tools. However, it is not the focus of this chapter.

This chapter starts by introducing the relevant concepts and theories of using technologies as cognitive tools. It then illustrates how the ideas of cognitive tools are substantiated through educational software tools. Since the field of educational technology is young and technologies are changing so rapidly, there have been few software programmes staying long enough to establish themselves as cognitive tools with empirical studies. We will try to cite those references in order to provide evidence for our arguments. Since we believe that successful technology implementation has to meet certain conditions, we have put our emphasis on software features, curriculum development, learning environment design, teacher's professional development, and assessment for using technologies and make them cognitive tools. At the end of this chapter, we expect the readers to be able to use some of the software tools as cognitive tools for their own teaching and research in an informed manner.

## The Concepts and Learning Theories

### Cognitive Tools

ICT, i.e., Information and Communication Technologies have already become an integral part of our daily life. To make ICT as cognitive tools



depends largely on the creative and integrated use of information and communication technologies. Cognitive tools are instruments that can guide learners' cognitive processes; more importantly, they can amplify cognitive functioning and extend human minds (Pea, 1985). Kozma (1987) maintains "cognitive tools are devices that allow and encourage learners to manipulate their thinking and ideas" (p. 21). Jonassen and his colleagues (Jonassen and Reeves, 1996; Lajoie, 2000) elaborated the ideas in their later publications. Further, Jonassen used another term "Mindtools" to substantiate the idea of cognitive tools in a series of his publications (e.g., Jonassen, 2005, 2000, 1996). According to Jonassen, "Mindtools are computer-based tools and learning environments that have been adapted or developed to enable learners to represent what they know. They are knowledge representation tool that function as intellectual partners of learners... the tool will facilitate learning and meaning-making processes" (Jonassen, 2005).

Jonassen (1996) identifies the following criteria for qualifying a software tool to be a mindtool: (a) Computer-based; (b) Available applications; (c) Affordable; and (d) Easily learnable. We consider these criteria as practical ones. These are criteria regarding the accessibility of a software tool to students. The following are other criteria he proposed: (e) The application can be used to represent knowledge, in other words, the application should allow students to construct knowledge; (f) Generalisable to content in different subject areas; (g) Engages learner in critical thinking about subjects; (h) Develops skills transferable to other subjects; and (i) Significantly restructures or amplifies thinking, such as providing alternative, simple and powerful formalism for representing ideas. These criteria reflect the essence of making a software tool as a cognitive tool, which means that a software tool is used in a way to represent and manipulate mental models, thus promote thinking. Using technologies as cognitive tools here reflects the theory of learning to be constructivist. In addition to individual cognition, we expand the framework to social constructivist, which posits a learner in a community of practices (Wenger, 1998).

## Critical Thinking

There have been quite a few definitions of critical thinking. Here, we adopt the ones that can be realised by cognitive tools. According to Ennis, *critical thinking* is reasonable reflective thinking that is focused on deciding what to believe or do (Ennis, 1987). Critical thinking is the intellectually disciplined process of actively and skillfully conceptualising, applying, analysing, synthesising, and/or evaluating information gathered from, or generated by, observation, experience, reflection, reasoning or communication, as a guide to belief and action. It includes the following aspects in terms of thinking and reasoning: (a) Belief; (b) Knowledge; (c) Skills; and (d) Abilities (Moore and Parker, 2001).

*Critical thinking* is the dynamic reorganisation of knowledge in meaningful and usable ways. It involves the following mental processes:

- *Evaluating*: Making judgements, measuring against a standard, assessing reliability and usefulness, determining criteria for judging, prioritising, recognising fallacies or errors, testing hypotheses.
- *Analysing*: Separating whole entity into parts and understanding interrelationships of parts (recognising patterns, categorisation, identifying assumptions, identifying main ideas, sequencing).
- *Connecting:* Linking wholes (comparing, contrasting, logical thinking, inferring deductively, inferring a principle inductively from data, identifying causal relationships, predicting effects) (Jonassen, 2000). We can also consider the following mental processes, such as synthesising, evaluating and predicting as critical thinking.

## Student-centred Learning and Scaffolding

To get students to use technologies as cognitive tools, the learning activities should be more student-centred in order to provide opportunities for students to construct and manipulate their mental models and engage in critical thinking. Learner-centred learning can be facilitated by both software programmes (e.g., Jackson, Stratford, Krajcik and Soloway, 1996) and instructional design of a learning environment. A learner-centred environment should be sensitive enough to the knowledge, skills, attitudes and beliefs that learners bring to the educational setting (Bransford, Brown, Cocking, Donovan and Pellegrino, 2000).



Cognitive tools are supposed to engage students in authentic tasks and simulate professional practices including tools that professionals use (Quintana et. al., 2004). However, professional practices are also difficult to access or make sense to young students. Therefore, educational technologists and researchers intend to design software scaffolding to bridge the gap. *Scaffolding* refers to software features that enable students to conduct certain tasks that would otherwise be too complex for students to access (Quintana et. al., 2004). On the other hand, students are learning with their teachers and others. Therefore, scaffolding from other sources, such as teacher scaffolding and peer scaffolding, is also necessary to help a student to proceed (Wood, Bruner and Ross, 1976).

## Meaningful Learning

In short, meaningful learning is achieving deep understanding of complex ideas that are relevant to students' lives. "Meaningful learning is necessarily social, collaborative, intentional, authentic and active" (Jonassen and Strobel, 2005). At another place, Jonassen and his colleagues elaborated what meaningful learning is:

- *Active and manipulative*: Learners interact with the environment and manipulate the objects within it; learners observe the effects of the manipulations.
- *Constructive and reflective*: Involving students in activities is essential but insufficient for meaningful learning. Learners must reflect on the activity and the observations, and interpret them in order to have a meaningful learning experience.
- *Intentional:* Human behaviour is naturally goal directed. Students should have opportunities to articulate their own learning goals and monitor their own progress.
- *Authentic:* This means that the activities and the learning environment should be complex and contextual like real world situations. Thoughts and ideas rely on the contexts in which they occur in order to have meaning. Learning is meaningful and better understood, and thus more likely to transfer to new situations when it occurs by engaging with real life, complex problems.

- *Cooperative:* Students should have opportunities to collaborate and communicate with each other. People live, work and learn in communities, naturally seeking ideas and assistance from each other, and negotiating about problems and how to solve them. It is in this context that we learn that there are numerous ways to view the world and a variety of solutions to most problems. Meaningful learning, therefore, requires conversations and group experiences.

To experience meaningful, authentic learning, students need to do much more than access or seek information – they need to know how to examine, perceive, interpret and experience information, and think critically at all times (Jonassen, 2000).

Susane Lajoie (2000) proposed some similar guidelines to use computers and software programmes as cognitive tools. They should be used: (a) in a problem solving context; (b) to enhance the cognitive ability of students; (c) to help students construct mental models; (d) to represent and capture the knowledge; (e) to reflect and foster self-directed learning; and (f) to provide collaborative settings for students.

In summary, cognitive tools engage students in learning activities that simulate professional practices so that their learning can be meaningful, purposeful and efficient. By promoting critical thinking and collaboration, the ultimate goal is to help students to learn effectively and prepare them for life-long learning.

## Designing Learning Environments that Use Software Programmes as Cognitive Tools

There are very few software programmes that claimed to be designed as cognitive tools. However, usually a software programme fits in some of the criteria for being a cognitive tool one way or the other; more importantly, teachers and researchers need to design learning environments that use software programmes as cognitive tools. Therefore, addressing software features that qualify a software programme as a cognitive tool and describing the learning environment and pedagogy become necessary for using cognitive tools for student-centred learning. Here we use a learner-centred software programme call *Model-It* as an example to illustrate how a computer programme can be used as a cognitive tool.



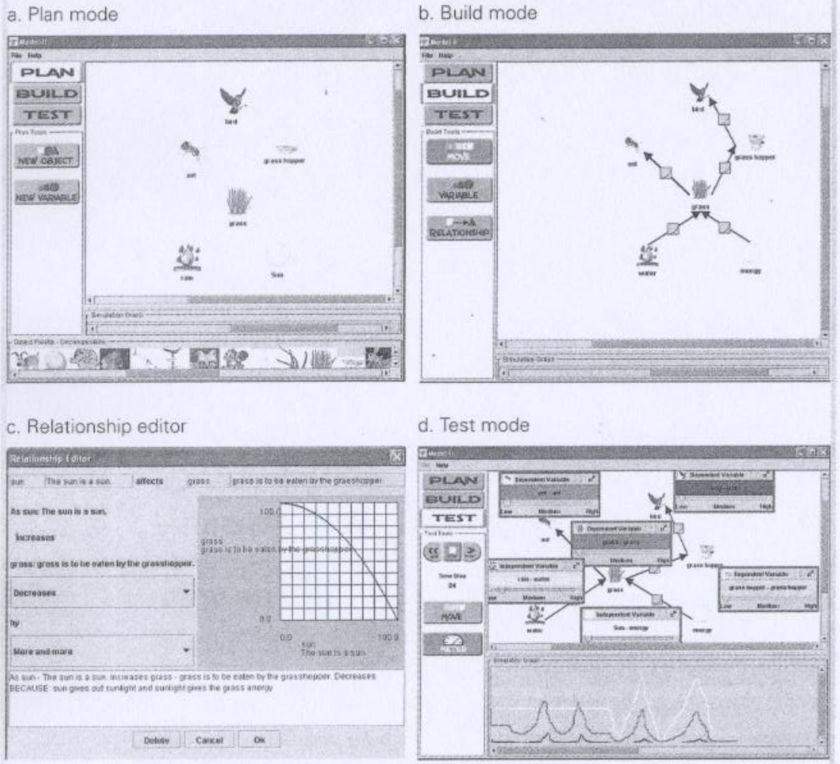
## Computer Software Features and Scaffolds of *Model-It*

There can be different definitions of the term *model*. A model in this chapter means a simplified representation of a system that concentrates attention on specific aspects of that system, such as more complicated ideas, objects, events or processes. The specific aspect of a system in a model can be either complex, or different in scale to that which is normally perceived. Models represent, explain and predict natural phenomena. Modelling is the process of building, testing and revising models.

The modelling tool used in this study, *Model-It*, was developed by the Center for Highly Interactive Computing in Education (http://hi-ce.org) at the University of Michigan (Jackson, Stratford Krajcik, and Soloway, 1999). *Model-It* does not require sophisticated mathematic skills and supports mainly qualitative model building. Figures 6.1a to 6.1d illustrate the three modes (Plan, Build and Test) in *Model-It* that sequence the modelling process. In the Plan mode (Figure 6.1a), a user creates, defines and describes objects (e.g., stream, plants and people) and specifies qualitative or quantitative variables that are associated with specific objects (e.g., the water temperature of the stream and the number of people). Next, in the Build mode (Figures 6.1b and 6.1c), the user builds causal or relational links between the variables that are presented by both verbal description and graphic representations. An example of a typical relationship in verbal representation is as follows: As the BIRD: the number of birds increases, WORMS: the number of worms decreases because more birds will eat more worms. For data visualisation, in the Test mode (Figure 6.1d), *Model-It* provides meters and graphs for the user to view and change variable values. A meter and a coloured graph line correspond to a variable. As students test their models, they can change the values of independent variables and immediately see the effects on dependent variables from both meters and graphs. If the simulation does not run the way the user expected it, *Model-It* allows the user to move back to the Plan or the Build mode to revise objects, variables or relationships.

**Figure 6.1**

The Various Modes of *Model-It*




The software features such as variable editor and relationship editor are considered software scaffolds. *Scaffolding* refers to software features that enable students to conduct modelling tasks that would otherwise be too complex. Although modelling is a desirable professional practice that students can involve and thus make sense of science as an enterprise, it is remote from student experience; therefore, we consider those scaffolds to be necessary to make modelling accessible to young students. In Table 6.1, we demonstrated how *Model-It* software features and the way to use it (learning environment) can make it a cognitive tool.



**Table 6.1**

What are the Criteria for Software Programmes to Become Cognitive Tools? (*Model-It*)

| Criteria | Software features (Scaffolds): *Model-It* | Curricula and learning environment: *Model-It* |
|---|---|---|
| 1. Scaffolds intentional learning and metacognition | Curriculum unit selection, e.g., "Water Quality" unit; image panel (Figure 6.1a at the bottom) that is unit-specific. | Students are asked to specify their driving question and focus of a model. |
| 2. Allows students to construct knowledge | Students create models with objects, variables (Figure 6.1a) and relationships (Figures 6.1b and 6.1c) to represent their understanding of a science phenomenon as a system. | Student models should be based on their science inquiry experience and their data. |
| 3. Is generalisable to content in different subject areas | The content of the model is not limited to one subject. Students can create their own unit in *Model-It* by creating a new folder and import images of their choice. | Curricula should help student in sense-making with variables, relationships and science as systems; students can use images as part of their data in their model. |
| 4. Engages learner in critical thinking about subjects | Going through modelling processes allow students to engage in scientific practices such as planning, analysing, synthesising, evaluating and publicising. | Students should learn how to define an object, a variable or a relationship; they should also learn how to fill in descriptions of the objects and variables and provide "because" statements for the relationships they specified. |
| 5. Develops skills transferable to other subjects | The Plan, Build and Test modes will remain the same. However, if students are able to adopt the reasoning skills scaffolded by the software features, transfer can happen. | As long as a phenomenon can be represented with objects, variables and relationships, it can be represented in *Model-It*. |
| 6. Significantly restructures or amplifies thinking | Students can add, delete and modify the model components (i.e., an object, a variable or a relationship), move the icons and run simulation in test mode. | Allow students to manipulate the representations to promote meaningful and deep thinking. |
| 7. Facilitates collaboration and distributed cognition | Students can work in pairs or small groups (No specific features in *Model-It* yet). | Students should be encouraged to work in pairs or small groups and they should be able to search the Internet and other resources for information. |

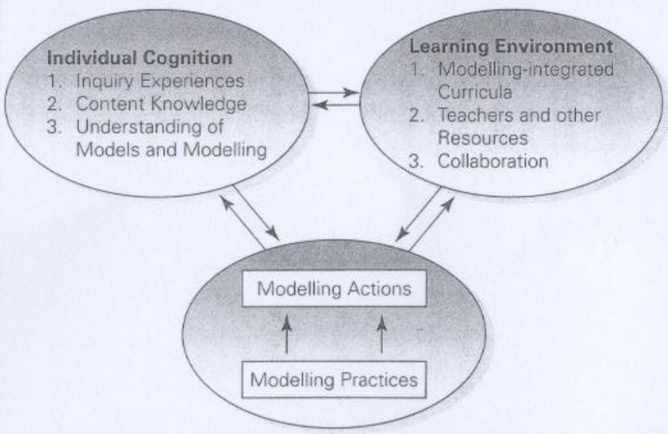
## Learning Environment and Pedagogy

Every software programme has its limitations. We argue that it is not only the software features that make it a cognitive tool, but also HOW the tool is used in a learning environment. There is a need to develop curriculum units to integrate a programme as a cognitive tool; here we are still using *Model-It* as an example to demonstrate how to build the learning environment. In another word, a learning environment decides whether a tool can be used in a manner of being a cognitive tool.

Below is a framework to implement *Model-It* to make it a cognitive tool (Figure 6.2). For **Individual Cognition**, we hope that a student builds his/her understanding of science on his/her prior knowledge on content, models and modelling, and inquiry experiences. *Inquiry experiences* refer to the process of designing, carrying out investigation, analysing data, and making conclusions. For **Learning Environment**, we hope a student will collaborate with his/her partner(s), makes use of resources including their teacher and interacts with cognitive tools. Modelling is considered an integrated part of the *curricula* because modelling allows students to represent and develop their understandings after their investigations of units on water quality and decomposition. *Collaboration* is highlighted as an important dimension of student learning

**Figure 6.2**

Theoretical Framework of Examining Modelling Practices






because student learning occurs in a knowledge building community (Scardamalia and Bereiter, 1993/1994). ***Modelling Actions*** refer to what students do during modelling, i.e., moves on computer screen when constructing models. When constructing and evaluating computer-based models using *Model-It*, modelling actions include specifying what to model, deciding on variables, defining relationships, testing and debugging, and sharing and communicating the products with others. ***Modelling Practices*** are ways of thinking demonstrated by a series of modelling actions and conversations that help modellers to complete modelling tasks, make sense of what they are doing, and communicate their ideas with others including planning, analysing, building or constructing, interpreting, synthesising, evaluating, and critiquing models. In other words, modelling actions are student's physical actions that we can detect through their body movement and conversational actions, while modelling practices are the cognitive processes that underlie those actions.

## Evaluate the Effectiveness of Using *Model-It*

There have been a number of studies that evaluate the software design and implementation in real classroom setting (Jackson, Stratford, Krajcik and Soloway, 1996). The participants were mainly middle (Fretz, Wu, Zhang, Krajcik and Soloway, 2002; Fretz, Wu, Zhang, Davis et. al., 2002) and high school students. From past studies of *Model-It*, Jackson and her colleagues used a learner-centred design approach with built-in scaffolding made computer-based modelling accessible to high school students (Jackson et. al., 1996). Stratford and his colleagues (1998) found that the use of *Model-It* engaged students in a range of cognitive strategies in computer-based modelling, such as analysing, relational reasoning, synthesising, and testing and debugging. Spitulnik, Stratford, Krajcik and Soloway (1998) found that *Model-It* engaged students in discussing and building relationships and explanation of a subject area.

In the recent studies with *Model-It*, students demonstrated the following modelling practices that are aligned with the notion of using a software programme as a cognitive tool: planning, searching, analysing, synthesising, explaining and evaluating (Fretz et. al., 2002). Here are the working definitions of these modelling practices that students have demonstrated when working on *Model-It* in pairs or small groups. *Planning* includes practices of decision making regarding the driving question or scenario to be modelled, objects, variables, and relationships in a model before actually building a model (at brainstorming stage) or before creating a component of a model. *Analysing* involves student statements and actions that decompose a large system or a phenomenon that they are going to model into sub-systems or components in terms of the focus or overarching question. *Synthesising* practices are indicated from statements or actions related to viewing the content, behaviour, or form of a model as a whole, or to making connections between previously unconnected ideas or use their investigation experience for explanations and making arguments. *Evaluating* practices include statements and actions that students talk about the quality of their model; present their model to others to get feedback; or test the model in order to improve their model. *Publicising* in the class context means student pairs' demonstrations of their models to other students, teachers or researchers in class or beyond class for comments and feedback.

Student artefacts, such as models, have also been evaluated. Results showed increased quality of models created by student pairs. Table 6.2 shows some criteria for evaluating the models.

## Other Computer Programmes that can be Used as Cognitive Tools

There are more and more educational software programmes that can be used as cognitive tools. We will select several representative programmes to further illustrate how we can use educational technologies as cognitive tools. The exemplar programmes are also free-of-charge at present. Therefore, a reader can download the software and use it by himself/herself to obtain first-hand experience with the idea of cognitive tool. We are not going to specify how the different software tools should be used in a learning environment because the learning environments have some characteristics in common. They should be: (a) student-centred; (b) with technology-integrated curricula; (c) with student collaboration; and (d) with alternative assessments. In the following sections, we will focus on software features and empirical research results to illustrate how to use the software programmes as cognitive tools. Because these programmes are representative to different types of educational technologies (see Table 6.3), we hope that we can present a variety of options for students at different levels and use technologies for different subject matters.



**Table 6.2**

Model Analysis Criteria in Detail

| | Focus and structure | Completeness | Accuracy | Functionality (coherence) |
|---|---|---|---|---|
| Excellent (5) | Major concepts are presented; more relevant concepts are clustered to show clear patterns. | All details of a model's components (i.e., objects, variables and their descriptions and relationships and its "because" statements) are complete. | Details of a model's components are aligned with commonly accepted science knowledge. | A model coherently represents a science phenomenon. |
| Good (3) | Most major concepts are presented; more relevant concepts are clustered to show some kind of patterns. | Details of a model's components are relatively complete. | Details of a model's components are basically aligned with commonly accepted science knowledge. | A model in generally coherently represents a science phenomenon. |
| Poor (1) | Missing some major concepts and difficult to find patterns and clusters of concepts. | Details of a model's components are incomplete. | There are some misconceptions. | A model does not coherently represents a science phenomenon that exists. |

# Synergeia

## History of the Software

Synergeia is a software system developed within the ITCOLE research project funded by the European Union in 2001–2003. The Synergeia system combines an asynchronous component named BSCL (Basic Support for Cooperative Learning) and a synchronous component named MapTool (http://bscl.fit.fraunhofer.de/). It was designed to support collaborative knowledge building. Synergeia provides a scaffolded web-

**Table 6.3**

**Some Exemplar Programmes that can be Used as Cognitive Tools**

| Categories | Software tools | Other similar programmes |
|---|---|---|
| CSCL* tools | Synergeia http://bscl.fit.fraunhofer.de/ | 1. Knowledge Forum http://www.knowledgeforum.com/ |
| Concept mapping tools | Cmap http://cmap.ihmc.us/ | 1. Semantica http://www.semantica-software.com/en/home.html<br>2. Inspiration http://www.inspiration.com<br>3. Axon http://web.singnet.com.sg/~axon2000 |
| Systems modelling tools | *Model-It* http://goknow.com/AppDownloads/ModelIt/index.html | 1. Starlogo http://education.mit.edu/starlogo/<br>2. Stella http://www.iseesystems.com/softwares/Education/StellaSoftware.aspx<br>3. Netlogo http://ccl.northwestern.edu/netlogo/<br>4. Pedagogica http://pedagogica.concord.org/ |
| Visualisation tools | Virtual labs http://www.chemcollective.org/applets/vlab.php | 1. Mathematica http://www.wolfram.com/products/mathematica/index.html |

** CSCL stands for Computer-Supported Collaborative Learning.*

based work space for: (a) facilitating collaborative learning; (b) sharing documents and ideas; (c) storing discussion posts; and (d) constructing and presenting knowledge artefacts (Stahl, 2002).

## The Software Features that Make it a Cognitive Tool

Synergeia can be categorised as a CSCL (Computer-Supported Collaborative Learning) programme. In Table 6.4, we elaborate how the software features make it a possible cognitive tool.

## Empirical Research Results

One empirical study we could find that used Synergeia was done with 26 tenth grade students who worked in groups of three. Students could



**Table 6.4**

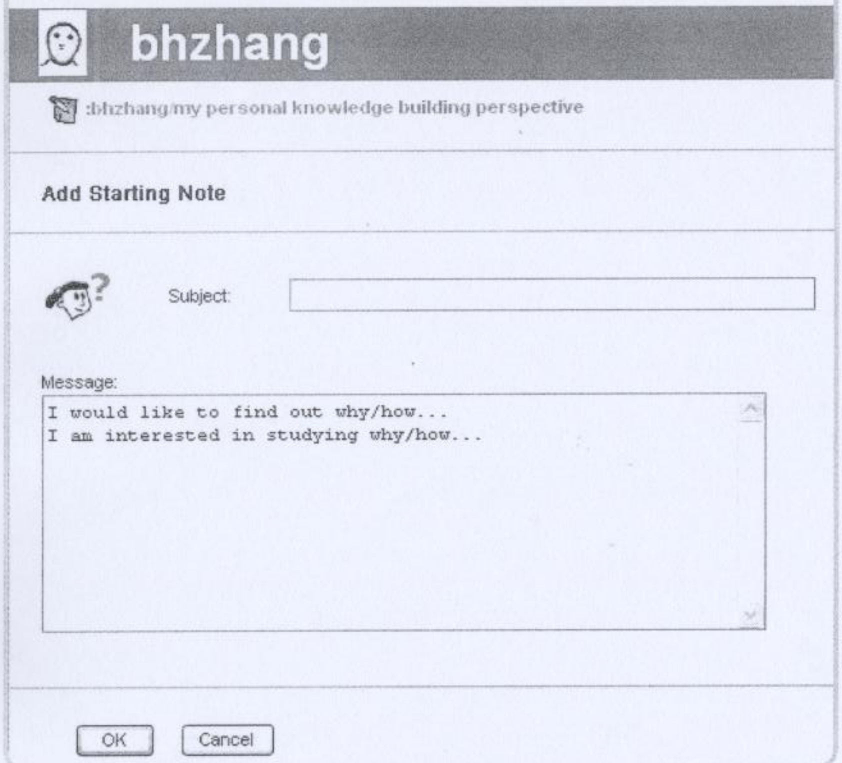
**How is Synergeia Qualified for a Cognitive Tool?**

| Criteria | Software features (Scaffolds) |
|---|---|
| 1. Scaffolds intentional learning and metacognition | A teacher can create a "new course" with a title and description of the course; all posts are organised and can be sorted in several ways to allow students to keep track of their progressive inquiry. |
| 2. Allows students to construct knowledge | Students post their ideas about the answers to problems and share resources that they seem to help solve problems (e.g., Figure 6.3, the incomplete sentences are "sentence starters" as scaffolds). |
| 3. Is generalisable to content in different subject areas | The content can vary from course to course or topic to topic. |
| 4. Engages learner in critical thinking about subjects | Here are the built-in thinking types that scaffold student's critical thinking: Problem, My Explanation, Scientific Explanation, Evaluation of the Process and Summary. |
| 5. Develops skills transferable to other subjects | The critical thinking skills, the understanding of "thinking types" and the way to make arguments will transfer (e.g., Figure 6.4). |
| 6. Significantly restructures or amplifies thinking | Making thinking visible and sorting the posts in different order certainly help students to restructure their knowledge. |
| 7. Facilitates collaboration and distributed cognition | The software programme was developed to foster collaboration; The Virtual Learning Places include personal, group and course spaces; a learner can post, add reply, create personal reflect and use MapTool session with chat option (e.g., Figure 6.4). |

upload and share files and participate in thread-based discussions. The problem presented for inquiry was "coin toss problem". The students were offered different options for the possible direction and magnitude if the total force on the coin (seven possible answers). They were asked which choice was the appropriate one when: (1) The coin was moving upwards after it was released; and (2) The coin was moving downwards. The lessons started from "traditional" didactic lessons and followed by CSCL lessons. During CSCL lessons, the students wrote down their opinions on Questions 1 and 2 in Synergeia, justified them, read and commented on the opinions of other groups and on texts uploaded for consideration by the teacher. They also reported how their opinions changed over time and why. Results showed that at the first Synergeia

Figure 6.3

A Scaffolded Post Composer with Sentence Starters




hour, none of the students gave the scientifically correct answer for both questions. However, by the third Synergeia hour, 70% of the groups were right in both answers. This means that the scaffolded collaborative learning environment did help students to reach more scientifically correct answers.

## Cmap

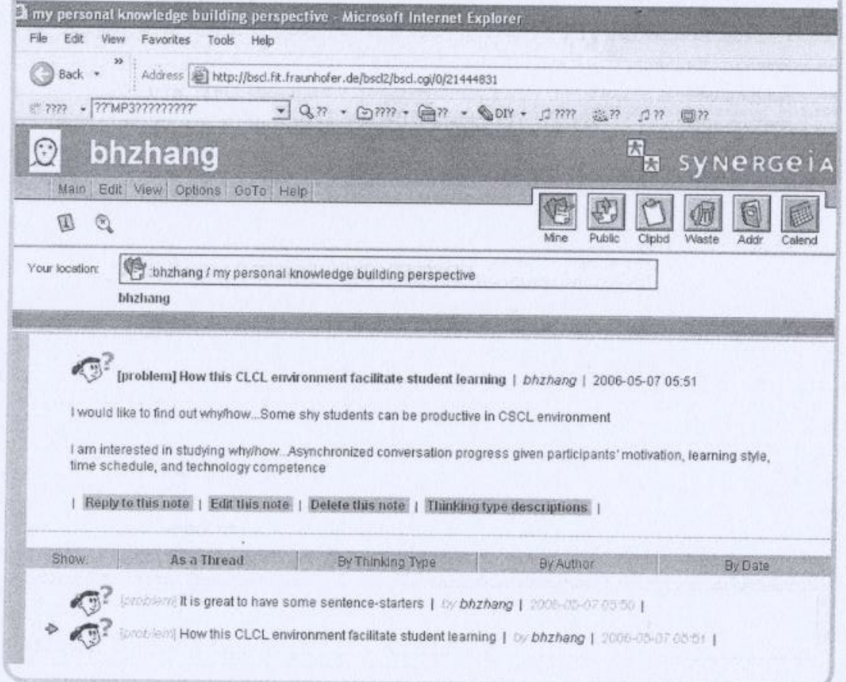
### History of the Software

The CmapTools programme is a client-server based software kit developed at the Institute for Human and Machine Cognition (IHMC). It is designed



Figure 6.4

An Online Post with Options that Facilitate Further Discussion




as a web-based authoring tool. It allows users to construct, navigate, share and criticise knowledge models represented as concept maps (e.g., Table 6.5). Users can construct their Cmaps in their personal computer and they can share them on servers (CmapServers) through the Internet. Furthermore, users can even automatically create web pages of their concept maps on servers, edit their maps synchronously (at the same time) with other users on the Internet, and search the web for information relevant to a concept map (Cañas et. al., 2004).

### The Software Features that Make it a Cognitive Tool

A concept map is a spatial representation of concepts and their interrelationships (Jonassen, 2005). Concept maps, also called *Semantic networks*, are graphical tools for organising and representing knowledge.

**Table 6.5**

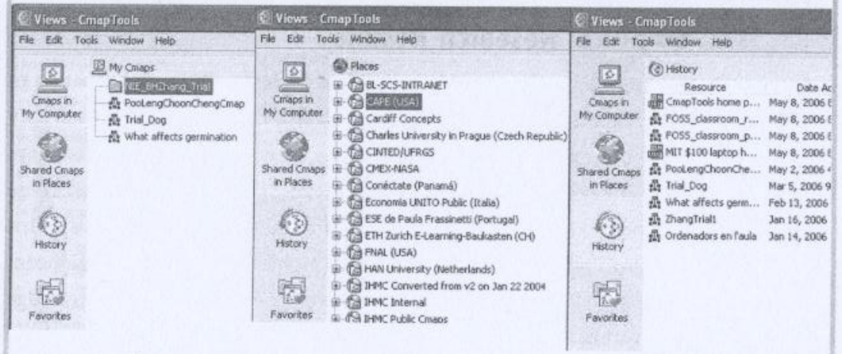
**How is Cmap Qualified as a Cognitive Tool?**

| Criteria | Software features (Scaffolds) |
|---|---|
| 1. Scaffolds intentional learning and metacognition | A focus question and/or root concept as the most important starting point; Views window (Figure 6.5a) allows the user to create a hierarchy of folders in the user's computer or at a server to organise concept maps, images, videos, or URLs, all resources associated with a project. |
| 2. Allows students to construct knowledge | Students create their knowledge models with concepts and propositions. |
| 3. Is generalisable to content in different subject areas | The content of a concept map can be any concepts that are connected. |
| 4. Engages learner in critical thinking about subjects | When constructing "cross-links" and add linking words, there is a need for understanding the words and their relationships between the concepts. Students also need to identify the most prominent and useful cross-links, which involves evaluating and synthesising knowledge. |
| 5. Develops skills transferable to other subjects | The way to construct concept maps and the thinking skills that are involved should be transferred to concept mapping situations for different subjects. |
| 6. Significantly restructures or amplifies thinking | Students can add, delete and modify the model components (i.e., an object, a variable or a relationship), move the icons and run simulation in test mode. |
| 7. Facilitates collaboration and distributed cognition | The shared places (Figure 6.5b) allow students to share and co-construct concept maps through the Internet; "knowledge soup" is a way for students to share their propositions but not see each other's maps. |

A concept map (e.g., Figure 6.6) includes concepts, usually enclosed by circles, boxes or graphical representations. *Relationships* between concepts are indicated by a connecting line linking two concepts. *Linking words or phrases* specify the relationship between the two concepts. A *concept* can be a perceived regularity in events or objects, or records of events or objects, designated by a label. A *proposition* is a statement about some objects or events in the universe, either naturally occurring or constructed. A proposition is a unit of meaning (Novak and Cañas, 2006). An exemplar concept map can be found on the web portal of a concept mapping

**Figure 6.5**

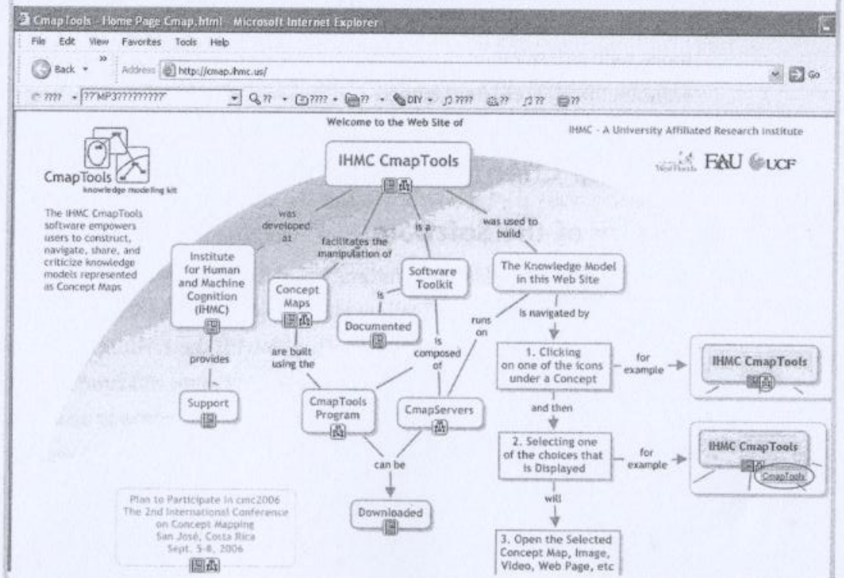
**Interfaces of Cmaps in My Computer, Shared Space and History of Files Opened**



(a) (b) (c)

**Figure 6.6**

**Cmap Web Portal that is Created with the Cmap Tool**



software called Cmap. Table 6.5 illustrates specific software features of the Cmap software that make it a possible cognitive tool.

### Empirical Research Results

Marra and Jonassen (2002) found that students who were preparing to build expert systems demonstrated more rules and rule types when they built the expert systems. This might be an indication that concept mapping helped students to construct more complex knowledge. There has been evidence showing that constructing concept maps helps retention of knowledge and enhance problem solving ability. Concept mapping also seemed to have positive effects on student knowledge acquisition and attitude towards learning . Given the fact that there have been many studies explored using concept mapping to improve teaching and student learning from primary level to adult learning since concept maps were developed in 1972, there will be much more evidence to show the effectiveness of concept mapping. That is also why educational technologists are interested in developing concept mapping software tools. Besides Cmap, there are a number of popular concept mapping tools, such as *Inspiration*, *Semantica* (http://www.semantica-software.com/en/home.html) and *MindManager*.

## Virtual Chemistry Lab

### History of the Software

The chemistry virtual lab programme was developed by Dave Yaron and his colleagues at Carnegie Mellow University (http://ir.chem.cmu.edu/irproject/). The Chemistry Collective began with the IrYdium Project's Virtual Lab in 2000. It started from a flexible simulation and later evolved to create scenario-based learning activities. The software was designed to provide interactive, engaging materials that link chemistry concepts to the real world.

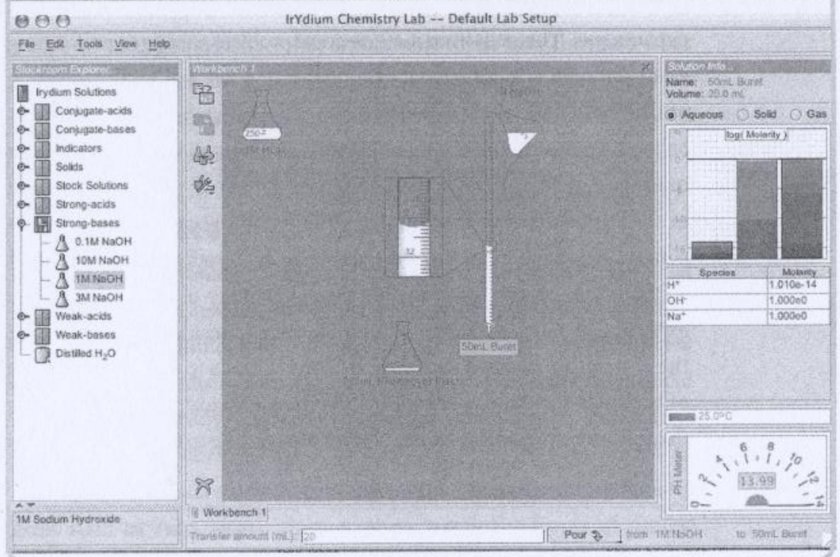
### The Software Features that Make it a Cognitive Tool

The Virtual Lab is a networked laboratory computer simulation in which students can select from hundreds of standard chemical reagents and combine them in any way they see fit (Figure 6.7). The chemical reagents



**Figure 6.7**

Screenshot of the Interface of the Chemistry Virtual Lab Programme




are in the stockroom on the left side. Clicking on a key icon would open a storage cabinet. The workbench is the largest area on the interface. Double clicking or dragging and dropping can bring a chemistry reagent onto the workbench. On the left side of the workbench, the icons can be pop-up windows that allow users to choose glassware and other equipment like a heater. When clicking on a container on the workbench, the solution information would appear on the top of the third column. The colourful chart, the table, and the pH meter below the solution information area show the concentration of the species, temperature and pH value of a selected container and they change when reaction happens. There is a homework depository that can be accessed from the "File" menu and there is a rich depository of homework with descriptions on molarity, stoichiometry, quantitative analysis, chemistry equilibrium, solubility, thermo-chemistry and so on. Instructors may use this environment in a variety of settings including student homework, group projects, computer lab activities and pre- and post-lab exercises to support varied approaches to chemical education.

In general, there are three ways to make use of the online virtual chemistry lab programme as a cognitive tool (see also Table 6.6). First, students can *predict and check* for answers through performing online experiments. This shift from mathematical problem solving to performing an experiment is a non-trivial step requiring reflection on the meaning of the computations. Second, students can *simulate real lab experiments online*. Given certain learning objectives, students can start from asking questions and hypotheses, then design experiments; they can make use of the various chemical solutions, equipment and solution viewers to conduct experiments and collect data. Their exploration is not prescribed so that students can have much greater flexibility in the design of the experiment. Further, students can look directly inside a solution to see the types of species and their concentrations, leads to entirely new types of activities that would not be feasible in a physical laboratory. Third, the software programme can be adaptive according to the student's levels

**Table 6.6**

How is Virtual Chemistry Lab Qualified for a Cognitive Tool?

| Criteria | Software features (Scaffolds) |
|---|---|
| 1. Scaffolds intentional learning and metacognition | Students started from problems that they need to solve. This would lead to the exploration of problem solving paths with clear intention. |
| 2. Allows students to construct knowledge | Students construct new knowledge when designing experiments, obtaining results and providing interpretations to the results. |
| 3. Is generalisable to content in different subject areas | The way the virtual chemistry lab programme works and the way to construct problems can be generalisable. |
| 4. Engages learner in critical thinking about subjects | Students have to do planning, analysing, synthesising, and evaluating to think critically. |
| 5. Develops skills transferable to other subjects | Students need to exercise planning, analysing, synthesising, and evaluating skills that are transferable. |
| 6. Significantly restructures or amplifies thinking | Students can try different ways to combine chemistry species and use different amount of each species; they could see the components in any solution through visualisation. |
| 7. Facilitate chemistry collaboration and distributed cognition | Students can work in pairs or small groups to solve problems together. |



of expertise with *layered activities*. When studying the same chemical system, the problems can model the system with varying levels of complexity and approximation. By scaffolding students to reflect on their problem solving experience, they will be able to see how the removal or addition of an assumption changes both their problem solving approach and the predicted results (Yaron, Cuadros, Leinhardt, Evans and Karabinos, 2004; Zhang et. al., 2004).

### Empirical Research Results

Compared to the rapid adoption of this software programme, empirical research that demonstrates the effectiveness of the software seems to be not enough. It is difficult to have researchers who understand software development, chemistry teaching and learning, and educational research. However, a pilot study followed some college student pairs' collaborative problem solving processes using the Chemistry lab programme and its activities showed that students were able to indicate some critical thinking skills such as: (a) *Domain structure*: Recognising the family of similar problems; (b) *Principled decisions*: Chemical concepts and principles are used to guide decision making; (c) *Flexibility*: Cognitive flexibility in re-routing during problem solving; and (d) *Evaluation*: Checking problem solution paths and critiquing on the decisions made for solving a problem (Zhang et. al., 2004). For the latest progress with the software and activity development and empirical studies of using the programme, refer to http://www.chemcollective.org/papers.php

## Evaluating the Effectiveness of Using ICT as Cognitive Tools

### Data Sources and Data Collection Techniques

#### *Participant self-reporting data*

There are several ways to capture the personal background, motivation, learning style and beliefs of students (participants), such as survey, interview and focus group interactions. These data can be subjective and less reliable. Therefore, they need to be used with other types of data to triangulate the results and conclusions. Survey questionnaires can be delivered by technologies to make data collection and analysis faster, and have larger sample size.

### *Observation data*

Observation data are usually obtained by researchers instead of the participants themselves. Common observation data include field notes, classroom videos and audios, process videos and audios, and log files for computer programmes. Process videos can be computer screen recordings and student conversation in a video format. Some commercial software, such as *Camtatia* and *Morae*, can record this type of videos. These data allow researchers to record participants' behaviours and discourse, and thus track the moment by moment cognitive process of a participant or participants. The complex aspect of having such data is that the collection and analysis is very time-consuming and labour-intensive.

### *Student performance data*

Student performance data are usually used as assessment data, such as pre- and post-tests, student worksheets, notes, and artefacts... these data can be used for distinguishing strong students from weak students (summative assessment) and for diagnosing student's learning difficulties so that teachers can adjust their teaching accordingly (formative assessment).

## Data Analysis and Evaluation Criteria

When using educational software programmes as cognitive tools, paper-and-pencil examinations may not be sufficient to capture all the learning gains that students have; furthermore, because students had to spend time learning the educational technologies, time for covering regular class schedule will be less. Therefore, the number of student that scores with traditional examinations might even drop. As such, we need alternative assessment and formative assessment to track student's progress. Besides some tests, using process videos and student artefacts will help evaluate the effectiveness of using cognitive tools. In the following sections, we provide some general guidelines for evaluating the use of some of the cognitive tools.



### *Synergeia*

Traditional evaluation is very difficult to apply to CSCL context because student's learning is collaborative in nature. For different subjects and learning objectives, the criteria of evaluating the effectiveness of a CSCL learning environment might be different. For example, some researchers looked at the emergence of progressive-inquiry culture in Computer-Supported Collaborative Learning. One of the most influential CSCL environments is called CSILE (Computer-Supported Intentional Learning Environment), currently it is called Knowledge Forum. In a three-year study, the epistemological nature of the students' research questions and their answers to the questions were analysed. Researchers found that by using CSILE, students had more opportunities to process explanatory knowledge than factual knowledge (Hakkarainen, 2003). For student's online posts, the unit of analysis is in the ideas of students in the form of "notes" submitted. According to the content of the posts, student's ideas were coded as being one of the following levels: Level 1: *Separated, Simple Low-Level Facts;* Level 2: *Partially-Organised Facts;* Level 3: *Well-Organised Facts;* Level 4: *Partial Explanation;* or Level 5: *Explanation*. The frequency of occurrence of various levels can be quantified to show the changes from the factual knowledge to explanatory knowledge over time. This is one way to assess student online communication in a CSCL environment.

The distinction between CSCW (Computer Supported Cooperative Work) environment and CSCL environment is that CSCW environment is to increase the productivity of work while CSCL environment is to improve the effectiveness of learning. On the other hand, some criteria for CSCW might apply to CSCL environment. Here we introduce a five-dimension approach that can be used for assessing student learning in a learning environment like Synergeia (Henri, 1991). It is expected that student involvement in CSCL environment to fit in some or all the dimensions to show more effective learning:

(1) *Participative* is a starting point for online learning. Counting frequency of online posts and time for posts can be one way to decide student participation.
(2) *Social* dimension can show people's motivation to make use of a system. From the topic and the way a participant addresses a topic, we can infer his/her motivation for participating.

(3) *Interactive* can be measured by who started posting, who responded, how particular events or statements led to particular responses and so on.
(4) *Cognitive* can be measured through the demonstration of reasoning and critical thinking skills. The search for solution should be a process of reaching consensus instead of one right answer.
(5) *Metacognitive* dimension addresses participants' self-awareness of their thinking and learning processes. For example, what are the strategies to get desired responses from other participants can be one way to reveal students' metacognition.

### *Cmap*

We can have a long list for the kind of student learning that we can measure through concept maps and/or concept mapping. One good list of criteria can be found in Jonassen's book published in 2005: Modelling with Technology: Mindtools for Conceptual Change on page 111. There are certainly many papers that illustrated how to evaluate concept maps created using different conventions and software programmes. Here we provide some representative categories for readers to get started:

- Accuracy of Content
  This category addresses whether links, concepts and linking words demonstrate precise and meticulous understanding of subject and whether information presented is accurate.
- Breadth and Depth
  A concept map that represents a phenomenon or answers a question should have clear structure that reflects the relationships between conceptions vertically and horizontally with major concepts.
- Validity and Efficiency of Links
  All links should connect in correct direction; links are distinct from each other; and conventions for constructing the concept map are used consistently.
- Organisation and Embedded
  Main concepts should be easily identified; subconcepts branch appropriately from main ideas; and concepts are interlinked with other concepts.



### *Virtual chemistry lab programme*

The adoption and usage of the virtual chemistry lab and its chemistry problem collection have increased significantly recently (Yaron et. al., 2004). Using recordings of computer screen and student pair's discussion during their problem solving process, we were able to see the following critical thinking practices in chemistry problem solving:

(a) *Domain structure*: Students need to recognise the family of similar problems. This is a must if students wanted to apply the correct formula to solve a chemistry problem;
(b) *Principled decisions:* Students need to apply chemical concepts and principles to guide decision making;
(c) *Flexibility*: Cognitive flexibility are required for re-routing when students could not solve a problem through a path so that they have to find other ways; and
(d) *Evaluation*: Students need to check problem solution paths and critique on the decisions made for solving a problem (Yaron et. al., 2004).

## Conclusion

Growing literature has applauded the ideas of using technologies as cognitive tools. There are increasing cases that can demonstrate how to identify and use technologies as cognitive tools. However, some empirical studies also showed that technologies are oversold and underused (e.g., Cuban, 2001). It is even less common to see that technologies are used as cognitive tools. According to two well-known researchers in the field of educational technology who have rich experience in technology development and implementation, there are six conditions for successful implementation of technologies: 1) Access to technologies; 2) Adequate teacher preparation; 3) Effective curricula; 4) Relevant assessment; 5) Supportive school/district administration; and 6) Supportive community/ family (Norris and Soloway, 2003). Teachers have been identified as the determining factor for the success of any educational reform. However, there have been mounting evidence showing that teachers do not have enough training to be able to use computers, let alone to use them as cognitive tool. For example, in a study of beginning teachers' experience with their reported competence of computer use, the results showed that: (a) they had issues with being able to access computer resources; (b) there had been great differences for supporting technology from school to school; (c) they did not have sufficient preparation to teach with the use of technology compared to their preparation for other instructional strategies; and (d) student teaching experience had little impact on technology use (Strudler et. al., 1999).

We propose the following strategies to prepare teachers to use computers and technologies as cognitive tools. First, for innovative teaching and the use of technologies, pre-service teachers can be the students to use them. If student teachers experience how cognitive tools work for them, they will certainly have better ideas about the benefits and how to use learning technologies as cognitive tools. However, this does not guarantee that they will be able to understand school environment and apply the kind of teaching. Therefore, when students are doing their practice teaching or practicum, they might try to teach using technologies as cognitive tools and find out issues and what they need to prepare for technology adoption and implementation. Since pre-service teachers in Singapore (National Institute of Education) now have the opportunity to go to school every year using teaching assistantship opportunities, this suggestion is more likely to be realised. Teachers will have to take the risk of teaching in an innovative way in order to use technologies as cognitive tools. They have to get support from district and school administration. Lastly, curriculum materials that integrated technology use and alternative assessment have to be implemented in order for the teachers to be able to use the learning technology the way we recommended.

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