Designing a Structured and Interactive Learning Environment Based on GIS for Secondary Geography Education

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ABSTRACT

Geographic information systems (GIS) are computer-based tools for geographic data analysis and spatial visualization. They have become one of the information and communications technologies for education at all levels. This article reviews the current status of GIS in schools, analyzes the requirements of a GIS-based learning environment from constructivist perspectives, and discusses the major issues in the design of a constructivist GIS-based learning environment based on experience from the development of World Explorer, a GIS-based learning environment that provides a theme-oriented data and information base, supports multiple representations and multiple linkages of information, and facilitates interactive learning and knowledge construction.

Key Words: *GIS, geographic data analysis, spatial visualization, constructivism, secondary geography education*

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INTRODUCTION

Geographic information systems (GIS) are one of the most recent information and communications technologies (ICT) for education. A GIS is a computer system designed to collect, store, manage, retrieve, manipulate, analyze, and visualize geographic or spatial data. It provides a new teaching and learning tool for teachers to conduct problem-solving activities in the classroom and for students to explore geographic issues and enhance their spatial cognition and geographic learning. The teaching and learning activities that can be supported by GIS include:

- collecting, storing, exploring, and using geographic data;
- exploring, developing, and presenting geographic concepts;
- making, using, and interpreting maps; and
- investigating geographic issues and solving problems.

Since the early 1990s there has been a considerable amount of effort expended on the development of GIS resources to support these activities. However, these efforts have been largely focused on the development of GIS datasets and lesson plans for specific topics selected from a particular school curriculum. Although the potentials of GIS for education have been widely recognized, the take-up rate is still low. The challenges to the use of GIS arise from the fact that school teachers and students are using the same complex GIS tool that science, business, and industry use. Few studies have been done so far on how to provide an appropriate learning environment based on GIS in which learners have opportunities to interact with geographic information, structure their own learning approach, pursue cross-reference about subject matters, and create and interpret multiple representations of geographic information. This research aims to fill this gap. In this article, we first review the current status of GIS in school geography education, then analyze the requirements of a GIS-based learning environment from the perspectives of constructivism, and finally discuss the major issues in the design of a constructivist GIS-based learning environment based on our experience obtained from the development of World Explorer, a GIS-based learning environment for Singapore secondary geography education.

GIS IN SCHOOL GEOGRAPHY EDUCATION

The first publication on GIS and school education was probably by Robert Tinker (1992). He explored the possibilities of representing data with digital maps in many curricula and noted that a GIS may provide an important link between the personal level of field observation and global effects and concerns. Since then, many studies on GIS and school education have been conducted, and all suggest that GIS can help teachers engage students in studies that promote critical thinking and integrated learning at any grade level (Audet and Abegg 1996; Keiper 1999; Bednarz and Audet 1999).

A lot of efforts have been made so far by instructional designers, educators, and the GIS community at large to develop classroom-ready GIS resource packages including GIS software, data, and instructional materials to meet the teaching and learning needs. However, not many GIS software packages have been specially designed for school education. The earliest one is AEGIS (AUME 1990). It is not a fully functional GIS package, but provides mapping and some database capabilities with sample data files and maps and materials designed to support the UK National Curriculum in Key Stages 2, 3, and 4. The majority of existing GIS resources have been developed through the use of commercialized professional GIS software packages, such as ArcView, IDRISI, and SPANS. Development efforts have been largely placed on providing data and instructional materials that are to be used with a particular GIS software package and support a particular geography syllabus. The National Center for Geographic Information and Analysis (NCGIA) has been engaged in creating GIS resources for K–12 schools in America since the early 1990s (Palladino and Zuyle 1996). Major GIS software vendors, such as ESRI and IDRISI, have also built up strong links with schools by providing schools with GIS resources for teaching. ESRI's efforts to link with schools are very successful. Its ArcView product has become the most popular GIS platform in almost all Singapore schools that are using or plan to use GIS in their teaching and learning activities. The GIS data resources and instructional materials are usually made available on CD-ROM (such as ESRI's GIS for Schools and Libraries and the Ordnance Survey of Northern Ireland's Geographic Information Systems for Schools), or downloadable from the Internet (such as ESRI's GIS for K–12 Education at *http://www.esri.com/industries/k-12/index.html*). There are also several excellent books of GIS lessons (including lesson plans, data, and other resources), such as *Mapping Our World: GIS Lessons for Educators* (Malone *et al.* 2002) and *Community Geography: GIS in Action* (Malone *et al.* 2003).

In Singapore, GIS was first introduced to primary, secondary schools, and junior colleges in 1998 when a teaching package for use with ArcView called EduGIS was developed jointly by the National Institute of Education (NIE) and the Ministry of Education (MOE). EduGIS consists of a series of practical lessons with GIS data sets for geography studies, accompanied by teacher's guides and student activity worksheets. In 1999 some schools started to use EduGIS with relevant data sets for the core geography syllabus at the secondary level. In 2000 EduGIS was revised based on teachers' feedback and two additional volumes were developed. In the same year, an interdisciplinary project work module using ArcView was introduced. EduGIS played an important role in promoting the awareness of GIS education in Singapore schools. In addition to this GIS teaching resource package, NIE and MOE developed a set of satellite images in 2001, entitled "Learning Geography from Space," to be used with ArcView and its relevant extensions, which aimed to encourage junior college teachers to use an exploratory approach to teach selected urban and physical geography topics. In 2002 MOE launched an interdisciplinary fieldwork project on the "Mesocyclops as a Biological Control Agent Project," involving students and both science and geography teachers from twenty schools in using GIS, GPS, and dataloggers. Over the past several years, NIE and MOE have also conducted extensive training courses and workshops to help teachers develop their own lesson activities using GIS. Some school teachers have actively used GIS as a tool for inquiry-based learning and for interdisciplinary project work.

Despite these successes, only a small number of schools have consistent curriculum related programs that integrate GIS into geographic teaching and learning. According to our survey of 323 geography teachers from 106 Singapore secondary schools conducted during the period of April to June 2003, two-thirds of them were aware of GIS or learned its use, but only ten percent actually adopted GIS in their teaching (Yap *et al.* forthcoming). Recent experience in Singapore suggests that, however good the quality, creation of data and instructional materials alone does not guarantee successful uptake and use of such resources by teachers in schools. Many factors may limit the uptake. Our survey in Singapore suggests that among the top reasons why teachers do not use these resources are insufficient curriculum time, the perceived irrelevance of the materials (including data and instructional materials) to meeting learning objectives, and the complexity of GIS software. GIS software like ArcView is a powerful tool for geographic data management, spatial analysis, and visualization. However, such software tools are designed mainly for GIS analysts, scientists, and other professional users. Even a professional requires many hours of training and practice in order to use them effectively. In a focus group discussion on the use of GIS in Singapore schools organized by NIE, one geography teacher commentated that "ArcView's screen interface could be quite intimidating even though there was flexibility for the user to customize and remove unnecessary buttons." A quick analysis of the teachers' comments in the focus group discussion reveals that

1. GIS software lacks flexibility and user-friendliness and is difficult for both teachers and students to use;
2. data in the existing resource packages are limited in scope; and
3. lessons are isolated units without links to other aspects of the topics.

In order to make GIS a practical, useful, and effective tool for school education, there is a need to explore new approaches for transforming a GIS into a learning environment that overcomes the limitations with the current GIS teaching and learning resources discussed above, and that supports interactive learning, knowledge construction, interdisciplinary learning, multiple representations, and multiple linkages of information.

GIS and Learning

The use of GIS can change the way students gather and analyze geographic information. However, existing GIS resource packages focus on projects that require learners to follow instructional sequences to learn particular geographic content skills. School education has been progressing gradually towards a model of instruction that emphasizes hands-on and inquiry-based learning experiences in the classroom. As a method of instruction, geographic inquiry draws on a learning theory referred to as constructivism. Constructivism emphasizes problem-solving and inquiry-based learning rather than instructional sequences for learning of certain content skills. In constructivist learning, the responsibility of teachers is to arrange for required resources and act as a guide to students, who are responsible for formulating their own goals and research questions, gathering relevant data and information, analyzing the data and information, and drawing conclusions, thus teaching themselves (Hassard 1992; Roblyer 2004).

The theory of constructivism is one of the major conceptual frameworks that have been used to guide contemporary educational practices (Wilson 1996). It has two main strands: cognitive constructivism and social constructivism. Cognitive constructivism focuses on thinking skills and learning strategies and ascribes the primacy to the role of the individual in learning (Martin and Sugarman 1997). According to the cognitive constructivist's point of view, learners construct their own knowledge of the world through assimilation and accommodation. Assimilation is a process of incorporating new experiences into existing ones, while accommodation is to modify and adapt existing cognitive structures in response to one's personal environment. Social constructivism puts emphasis on the learner's ability to solve real-world problems and construct knowledge through social processes and interaction (Gasper 1999). The constructivist learning environment should provide learners with opportunities to negotiate ideas, conduct inquiry, and reflect their thoughts so that they are engaged in meaningful learning and high-order thinking (Wen *et al.* 2004). Such a learning environment should have the following characteristics (Jonassen *et al.* 1993; Jonassen 1994; Maddux *et al.* 1997):

- present multiple representations of the world;
- offer real-life problem-solving tasks in a social context;
- support context-dependent and content-dependent knowledge construction;
- enable collaborative knowledge construction;
- engage reflective practice; and
- provide open learning environments.

A GIS is a toolkit for geographic data analysis, exploration, and visualization. GIS technology is not developed for educational applications by the constructivist approach, but it provides useful tools for constructing a computer-based constructivist learning environment for geography education. These tools can support geographic inquiry by allowing learners to formulate geographic questions or hypotheses, access and obtain geographic data from multiple sources, present geographic data and information in forms of maps, images, tables, and charts, explore the data through carefully constructed queries, and analyze the data to answer the questions or draw conclusions. A GIS-based learning environment can be developed through careful design to match learners learning processes. In addition to accommodating the basic features of a constructivist learning environment as discussed above, a GIS-based learning environment should allow for multiple dimensional navigation through a body of spatial data and information and support interactive learning. It should also allow learners to be actively involved, have full control over the learning situation, control the interaction between users and computers, and perform problem solving tasks through critical thinking.

According to Bruner (1966), there are three different modes of representation of the real world: enactive, iconic, and symbolic. An enactive representation is the form of representation through action, including enactment and demonstration. Iconic representations include visual and other summarizing images and pictures. Symbolic representations include words and numbers. Any geographic idea or problem or body of geographic knowledge can be presented in a form simple enough so that any particular learner can understand it in recognizable form. Each mode of representation supports different aspects of geographic thinking. However, different representations use different forms of knowledge, each of which has advantages and hidden difficulties. Therefore, multiple representations of the real world are required to support learning and improving understanding. Although GIS tools are complex, they can be customized to create an effective learning environment that combines enactive, iconic, and symbolic representations. Using GIS tools, learners can enactively explore geographic data, manipulate maps, images, graphs, and tables, and perform "what-if" scenario analyses. Maps and graphs in GIS correspond to the iconic mode underpinning the geographic ideas, which enable learners to understand spatial patterns and sense spatial relationships. One map layer of information stacks on top of another in a GIS environment. By changing the map symbols, altering the sequence of map layers, or zooming in to specific parts of the map, patterns and relationships can be revealed. Therefore, when putting a geography curriculum and a relevant data and information base into GIS, a GIS-based learning environment can be created for doing geographic knowledge.

Design of a GIS-Based Learning Environment

One of the efforts in integrating GIS into school classrooms has been the development of GIS resource packages (such as Singapore's EduGIS). A typical GIS resource package contains isolated lessons of specific topics relating to a particular curriculum. Each lesson contains a sequence of step-by-step instructions on how to explore a set or several sets of geographic data using a particular GIS software system in order to answer a number of questions listed in a student worksheet. Many users of existing GIS resource packages have found that they could not take advantage of these packages if they lacked the required GIS skills. In addition, although these GIS resource packages are interactive, learners have little control over the learning situation and have few opportunities to develop their higher-order thinking skills. In order to support the constructivist approach to geographic learning, we developed a GIS-based learning environment, World Explorer.

World Explorer was designed to provide teachers with abundant resources to develop classroom activities and to provide learners with an interactive computer environment to conduct inquiry-based learning activities in geography education in Singapore secondary schools. It is an open learning environment that provides a theme-oriented data and information base, integrates multiple representations of information from diverse sources, offers opportunities for learners to interact with geographic information, and facilitates interdisciplinary learning and knowledge construction. This learning environment consists of data and information resources of particular themes tailored to Singapore secondary schools and tools for data access, spatial data exploration and visualization, multiple resource linkages, and dynamic navigation through the data and information base. It was built using ESRI's MapObjects and Visual Basic. The data resources currently include statistical data of world population from 1950–2050 from the U.S. Census Bureau and world development indicators from the International Bank for Reconstruction and Development. Four issues in the design of a GIS-based learning environment emerged from the development of the system. They are the support for learning of geographic inquiry skills, data organization, user interface design, and multiple resource linkages.

Support for Learning of Geographic Inquiry Skills

A GIS-based learning environment for schools should be able to not only provide data and information to help develop students' content knowledge, but also help develop students' skills for geographic inquiry. Support for skill development should be one of the major factors that determine the functional design of a GIS-based learning environment. Professional GIS software systems like ArcView aim to support complex spatial analysis and data management tasks in scientific investigation, business, and industry and therefore provide sophisticated functions for advanced cartography, data integration, and spatial analysis. A GIS-based learning environment should enable learners to view, compare, understand, question, interpret, and visualize geographic data and information in ways that develop their geographic understanding and foster their analytical skills.

In terms of geographic inquiry skills, Singapore secondary geography syllabus 2004 requires that students be able to:

- extract and organize relevant information from geographic data;
- use and apply geographic knowledge to interpret geographic data; and
- identify patterns in geographic data and deduce relationships.

More specifically, the students at this level should be equipped with map-reading skills and basic techniques including recognizing and describing geographic phenomena from photographs, extracting and interpreting information from diagrams, graphs, and tables of data, and constructing statistical representations. Based on these requirements, World Explorer was designed to provide functions for making maps, charts, and tables, which allow students to examine, compare, and construct maps, graphs, or charts and tables of geographic data in order to identify and explain patterns in the data and deduce geographic relationships. By using these functions, learners can define problems, create and explore different representations of data and information, judge information, solve problems, and draw appropriate conclusions, thus developing their higher-order critical thinking skills.

Data Organization

Data are one of the central elements of geographic inquiry and one of the key components of a GIS-based learning environment. A GIS-based learning environment should allow students to access data and to receive and create information. Therefore, it should contain a database, storing and managing data that

- connect to themes in the syllabus content;
- are broad enough to allow teachers to design learning activities and allow students to pursue questions that arise through the activities; and
- are sufficient for students to try and apply different geographic inquiry skills.

The current version of World Explorer supports two of eleven themes in Singapore secondary geography syllabus 2004: population and development. Its database contains statistical data describing demographic variables and statistical data describing development indicators of every country in the world. The demographic variables include total population, birth rate, death rate, dependency ratio, age-sex structures, internal and international migration, etc. The development indicators include social indicators, such as life expectancy, infant mortality, and adult illiteracy rates; economic indicators, such as GDP per capita, employment structure, and economic structure; and infrastructure indicators, such as total road network and level of urbanization. An effective organization of data in the database of a GIS-based learning environment is a key factor in providing learners with the ability to access data and arrange information in an effective way and to locate data that are of most interest for a particular activity. In the database of World Explorer, all the data are organized based on themes rather than activities.

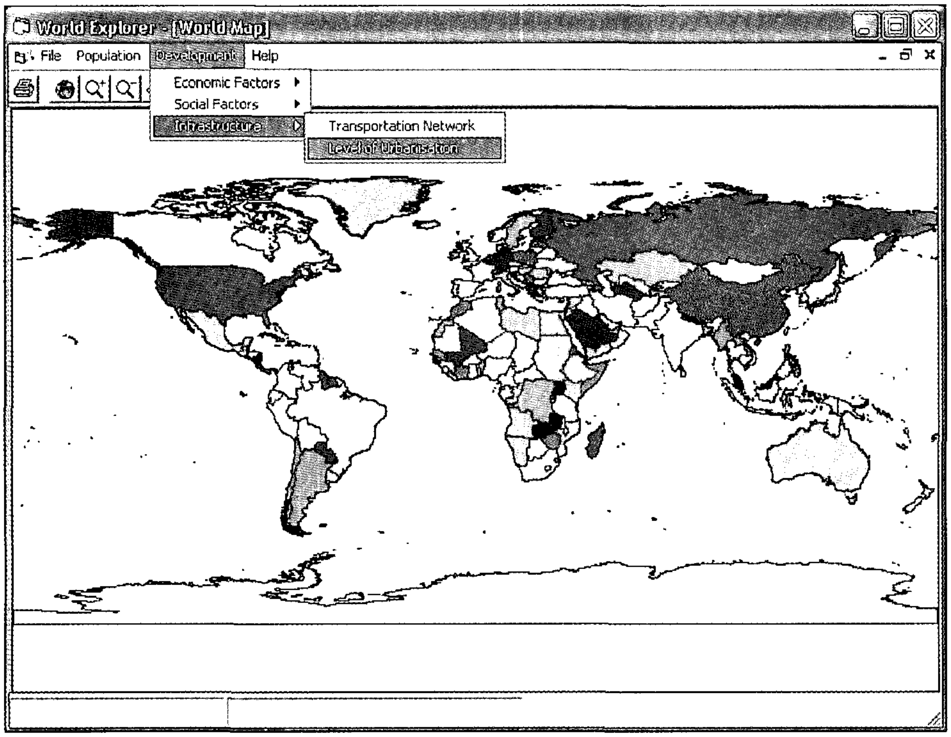

Figure 1. The user interface of World Explorer.

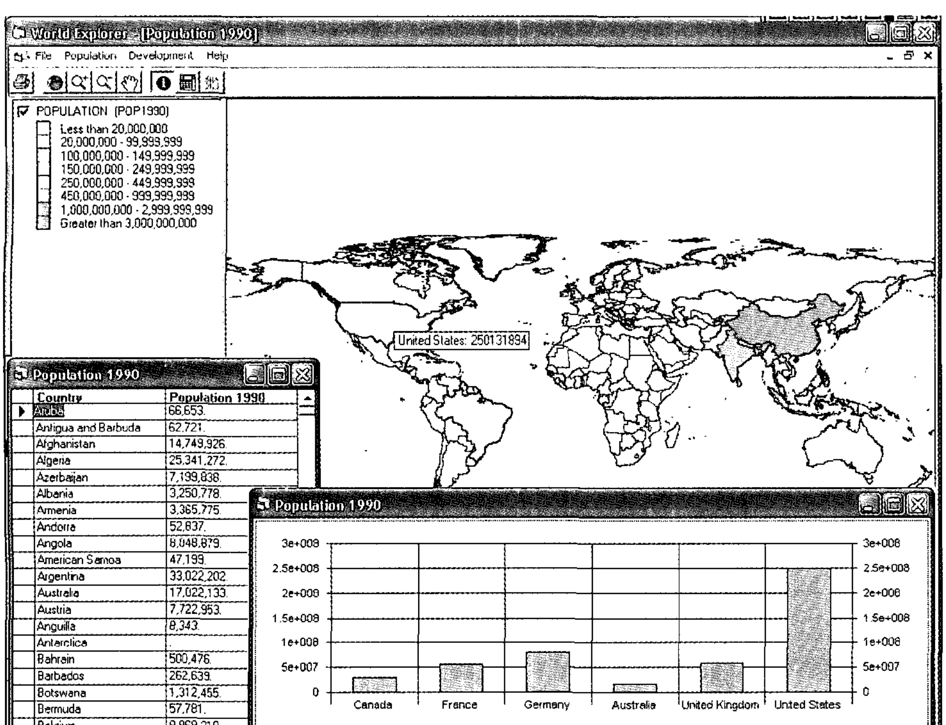

Figure 2. Multiple representations in World Explorer.

In other words, the data in the learning environment are theme based, not activity based. It provides freedom for teachers to select the data from the themes and design activities according to lesson requirements. It also allows students to select data and interact with the content and to select and interpret data and information into their own knowledge. Such a theme-oriented structure represents a philosophy of integrated subject matters. It encourages learners to explore related data and information, and facilitates integrated and interdisciplinary learning activities. In World Explorer, all statistical data are linked with the spatial data describing the locations of the countries in the world so they can be presented in maps. They can also be presented in tables and charts, such as column charts, pie charts, line graphs, and age-sex pyramids. Therefore, World Explorer supports multiple representations of data and information.

User Interface Design

User interface design is crucial for creating a motivating and active learning environment. A GIS-based learning environment should be interactive and learner-oriented. Therefore, the user interface of a GIS-based learning environment should be appropriate to the level at which students can understand, avoid GIS jargons and unnecessary operations, and follow the principle of what-you-see-is-what-you-get (WYSIWYG).

World Explorer's user interface has two main components: the interface for data access and the interface for data display and exploration. The interface for data access is structured in terms of themes (Fig. 1). The user accesses the data of a particular theme by selecting the menu item representing the theme. Therefore, the data access in World Explorer is intuitive and straightforward. It also allows users to add other geographic features (such as world cities and major rivers) to be displayed with the selected thematic data.

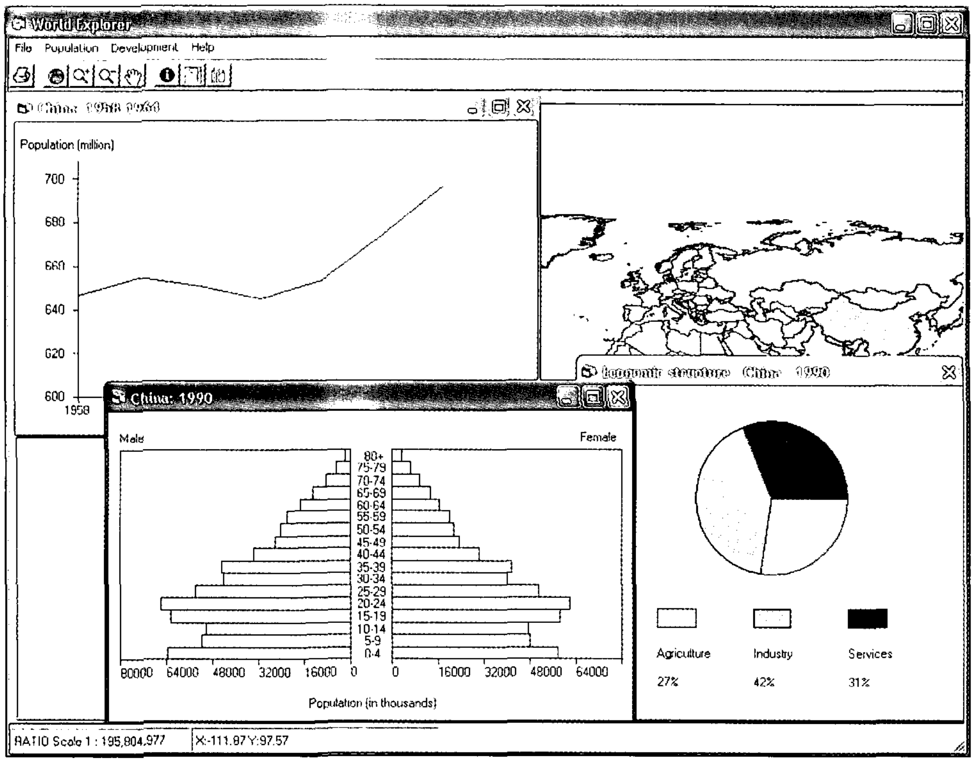

Figure 3. Charts in World Explorer.

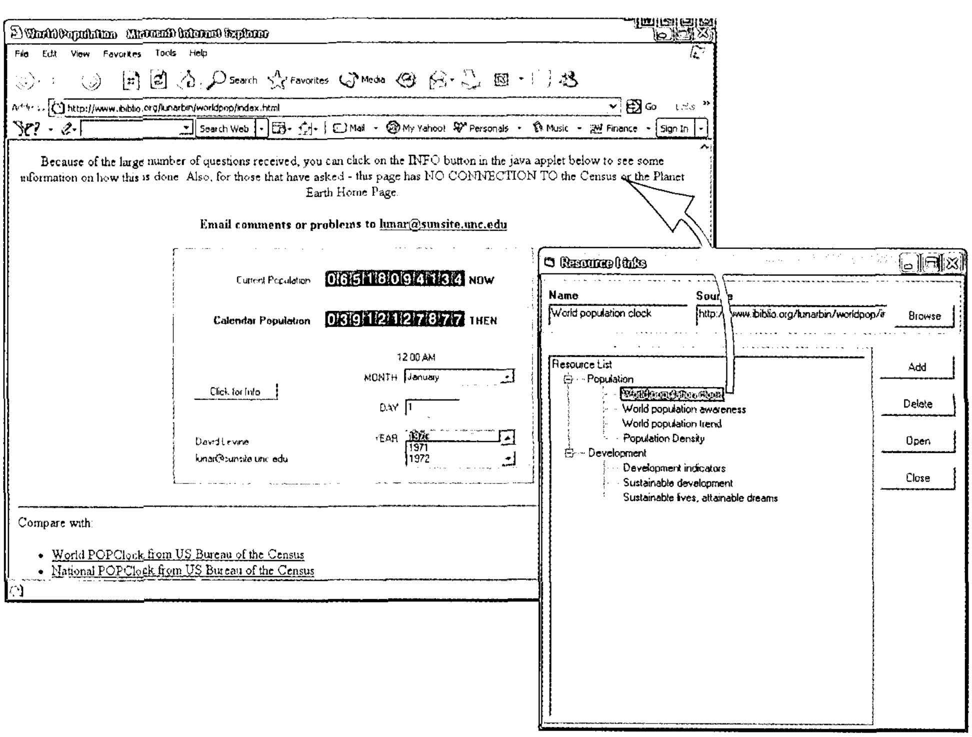

Figure 4. Multiple resource linkages in World Explorer.

The interface for data display and exploration is for visualizing and manipulating the thematic data in forms of maps, charts, and tables. When a theme (except population change, age-sex structure, economic structure, and employment structure) is selected, the data will be displayed in a map and a table. Using the table, the student can select several countries to make a column chart or pie chart (Fig. 2). The theme *population change* is displayed as a line graph according to the student's choice of the country and time period; *age-sex structure* is viewed as an age-sex pyramid for a country in a specified year; *economic structure* and *employment structure* are all shown as a pie chart for a country in a specified year (Fig. 3).

The maps created in the system are mainly choropleth maps, which are the most popular statistical maps for representing statistical data within enumeration zones (here, countries). A choropleth map classifies the thematic data into a number of ranges (classes) and uses different colors to show different ranges of value over space. When the cursor is placed on a country, the actual thematic value of that country will be shown on the screen (as shown in Figure 2). When the user double-clicks the legend of a map, a legend editor will pop up. The editor shows the basic statistics of the thematic data, including mean, maximum, minimum, range, and standard deviation and allows the student to change the classification schemes (e.g., the number of classes, the lower and upper limits of a class) and color series to remake the map, which may improve the map presentation and help recognize the patterns in the data. This function can also be used for mapping exercises.

Multiple Resource Linkages

A GIS-based learning environment provides an interactive environment for students to conduct geographic inquiry. In addition to spatial data about the selected themes, it should provide students with access to other relevant content resources or materials to develop their understanding. These resources may provide the context for exploring a theme, explanations of relevant concepts, theories or technologies, multiple perspectives on geographic issues, and more detailed facts about geographic phenomena.

World Explorer provides functions to link different types of content resources to a particular theme. The resources can be text documents, Web pages, videos, photos, and images. However, it is recognized that it is impossible to incorporate the content materials to meet all the learning needs of students. Therefore, the current system does not involve the development of the content materials, but it allows teachers to add links directly to various types of materials, structure them in terms of themes, and allow students to view these materials by selecting relevant links. Once a link is selected, it will launch appropriate programs available in the users' computer operating system (such as Internet Explorer for viewing the Web pages and Microsoft Word for reading word documents) to open the linked materials. Figure 4 shows the interface for adding, deleting, and opening resource links. By providing the function for multiple resource linkages, teachers can add additional non-GIS resources into the learning environment and students are able to use the linked resources to support their exploration of particular themes. In this way, the GIS-based learning environment offers multiple linkages, has multiple perspectives, and provides a means to create more engaging and dynamic instructional settings supporting multiple perspectives and multiple modes of learning. This environment takes advantage of a nonlinear media form typically in a Web system and allows learners to explore rich and diverse bits of information in their own ways. From a constructivist point of view, these multiple perspectives can lead learners to reflect more on their own knowledge construction. In addition, the linked resources and the database discussed in the previous section (Data Organization) together form a theme-oriented data and information base, which allows for both individual and group problem-solving activities for generating and testing new ideas and offers opportunities for learners to develop complex cognitive skills, such as breaking a topic down into subtopics, organizing diverse information, and formulating a point of view.

Summary

As GIS software and supporting hardware become more readily available at affordable prices, all levels of GIS applications for education continue to expand. In the last decade, many efforts have been dedicated to the development of GIS teaching and learning resources. However, the adoption of the GIS resources in school education has been restricted by the complexity of GIS software, inadequate curriculum time, isolation of individual lessons, irrelevance of the materials, and other factors. As an attempt to address some of the difficulties and limitations with the use of GIS resources in school teaching and learning, we developed a GIS-based learning environment, World Explorer, which supports the constructivist learning approach in Singapore secondary geography education. Four design issues arose from the development of the learning environment. These include the support for learning of geographic inquiry skills, data organization, user interface design, and multiple resource linkages. These issues and their solutions in World Explorer can be applied to the design of a constructivist GIS-based learning environment to support school education in other subjects (such as science and social studies) and other curricular contexts. At the moment, World Explorer supports two themes stipulated in Singapore secondary geography syllabus 2004, that is, population and development. It is being used in selected schools in Singapore. Feedback from the schools will be used to refine its functionality and interface and to design the modules supporting teaching and learning of other themes contained in Singapore secondary geography syllabus. World Explorer will be further developed to become a structured and interactive GIS-based learning environment for geographic inquiry, which supports the learning objectives and requirements of Singapore secondary geography syllabus.

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