GIS ENABLED PBL PEDAGOGY: THE EFFECTS ON STUDENTS' LEARNING IN THE CLASSROOM

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ABSTRACT

In efforts aimed at acquainting learners with 'how to learn' skills rather than static content knowledge, more student-centric instructional approaches are being increasingly adopted in informing curriculum design and delivery. Technology-rich problem solving environments offer great promise in scaffolding and facilitating student-centred learning. Geographic information system is one powerful technology that enables learners to become proficient spatial problem solvers, analytical users of geographic information and expert decision makers. This paper investigates the pedagogical benefits of GIS in influencing students' problem solving performances in Singapore. Data was collected by administering a likert-scale based questionnaire constructed specifically for this study and analysed using statistical method. Students participated in this research highlighted many of the instructional strengths of GIS that enabled them to become competent problem solvers and self-directed learners. They also pointed out some of the challenges which educators need to bear in mind in the development and enactment of GIS enabled pedagogy.

Keywords: Geographic Information Systems (GIS), Educational Technology, Problem-Based Learning.

INTRODUCTION

With the increasing emphasis on life-long learning and globalised knowledge economies, there is a need for educators to experiment with and adopt new instructional methods as well as adapt old teaching practices to make them more current. In the context of such an educational climate, learners need to be self-directed in their readiness to want to learn, draw upon their life experiences as valuable sources of knowledge codification and engage in collaborative discourses with their peers and tutors in pursuit of intellectual inquiry. Problem solving is a pedagogical approach associated with effective learning. It encourages students to be independent in their learning and actively seek subject matter content from a various information sources to deconstruct problems that are ambiguous in character and possess multiple solution states. The immense potential of educational information technologies in facilitating the development and implementation of innovative, student-centred curricular approaches has been well documented. Geographic information systems (GIS) are being commonly exploited by educators for their instructional effectiveness in training learners to become proficient spatial thinkers, knowledgeable users of the specifications of geographic information infrastructures and tactical decision makers.

Student-centered Learning in Geography Education

Student-centred pedagogy engenders a learning culture that is based upon narrative conversations between teachers and students (Caulfield 1991). Student-centred learning models create pedagogical structures that are useful and relevant by empowering students to be actively involved in the learning process. Students are encouraged to explore meaningful content knowledge processing and application of learnt expertise in real-world applied contexts. Hands-on collaborative activities are used to scaffold instructional modalities and knowledge sharing (Estes 2004). Problem-based or inquiry-based learning is a frequently relied upon methodology of student-centred learning in geographic education since it promotes spatial awareness and comparative thinking more naturally. By using this method to study a world region, for example, students are stimulated to personalise their learning by identifying their prior knowledge competencies, investigating new data sets, evaluating and applying the new data to make sense of a geographic location that is being analysed. In this way, a deeper conceptual understanding of relevant disciplinary content is obtained to build up schemas of associative understandings rather than the learning of disembodied facts. For example, Hardwick (2001) designed a problem-based learning activity for middle and high school students where they used historic city directories to map and analyse ethnic patterns in Sacramento, California. Fournier (2002) implemented problem-based learning at university-wide level by developing collaborative activities for a world geography class and preparing students for their role as problem solvers in the working world. Halvorson and Wescoat (2002) posed ill-structured and complex problems in a problem-based setting in large enrolment undergraduate class to teach issues surrounding world water resources by modelling real world experiences. Students in the study found that going beyond merely acquiring decontextualised subject matter they developed authentic learning experiences by negotiating and reaching consensus within diverse groups of students and solving multi-faceted problems. They came to the conclusion that problem-based learning is a successful pedagogy that can enhance the quality of instructional transactions in large-enrolment classes. Collaboration, an essential component of student-centred pedagogical orientations has been consistently shown from studies to be an effective learning enhancer. Synergistic partnerships in classrooms foster interactive educational environments where exchange of ideas and opinions are freely and actively encouraged to foster greater opportunities for socially-mediated learning to occur. Rutherford and Lloyd (2001) compared two instructional approaches to teach introductory world geography. Improvements in student achievements were noted due to the positive impact of small-group collaboration when combined with computer-aided instructional strategies.

Use of GIS in Inquiry based Geography Education

Geographic inquiry skills provide the necessary tools and techniques to enable one to think geographically. These skills promote spatial awareness and comparative thinking. The inquiry process when applied to geography requires students to be able to visualise data, propose hypotheses, analyse and interpret spatial phenomenon. Geographic information system (GIS) is a technology that is able to support the cognitive development of essential geographic inquiry skills in the context of problem solving and case analysis. GIS is capable of capturing, storing, analysing, and displaying geographically referenced information identified according to location. The power of a GIS comes from its ability to relate different information in a spatial context and to help learners to reach cogent conclusions predicated on these relationships. Hence analysis with GIS can provide vital information leading to better strategic decision-making.

Without GIS, geographic inquiry can be cumbersome for a teacher. For example, if a teacher wants students to understand population trends in Asia and its impact on economic development, without reliance upon an integrated system such as GIS researching on past and current population sizes, energy data sets and creating information rich maps for further student-led analysis becomes onerous tasks. On the other hand, with access to GIS tools and an understanding of resources, teachers can create or co-create with students accurate and standardised representations of data. Students are immersed in a learning environment that takes them through global, regional and advanced investigations using the geographic inquiry process scaffolded by affordances of the GIS system (Peterson 2007).

Benefits of teaching with GIS

There is little contention in research literature on the pedagogical effectiveness of GIS in the classroom. It has been shown comprehensively that adaptive implementation of GIS enhances geographic learning. Keiper (1999) posits four main reasons buttressing the argument for incorporating GIS within curricular design: GIS is becoming more common locally; GIS is a valuable tool for environmental analysis; GIS enhances students' interests in the subject area being taught; and GIS exposure develops in careers in science and engineering. Baker and White (2003) tested the effect of GIS on student learning in middle school science classes and found that GIS can foster contextually rich student learning and aid in-depth analysis. The researchers documented that GIS-enabled geography learning facilitates students' mastery of spatial reasoning, inquiring ability, location awareness and problem solving skills. Going beyond rote memorisation of discrete facts, teaching with GIS improves students' integrated science process skills, especially with data analysis activities (Baker & White 2003). Using GIS has also been noted to have an impact on the affective domains of learning: Students' attitudes toward learning the subject were found to have been improved, naturally increasing their learning achievements. This has been attributed to the immediate feedback students receive by working with GIS. GIS enables teachers to create lessons focusing on geographic issues at local, national and global levels that are of interest to students. In this way, GIS has the ability to enhance intrinsic motivation in students because of the high levels of engagement with the learning process and the ability to study geographic phenomena of a more personal significance (West 2003).

Numerous studies have been done to evaluate the overall effectiveness of incorporating GIS in curricular design. Wanner and Kerski (1998) found that students with low to average geographic achievement prior to GIS lessons can raise their achievement to the same level as higher achieving students when GIS is implemented in geography curriculum. This was due to the positive influence of GIS in strengthening student learning in inquiry-based and standards-based skills. Drennon (2005) developed a problem-based learning environment using GIS to teach geographic skills to an undergraduate class of non-geographers. She reported that students taking the course assimilated strong connectional and technical skills and were able to apply GIS technology to address real world issues. Similarly, Kerski (2003) conducted research on the efficacy of GIS on learning for high school students and concluded that GIS improved geography content and analytical skills for both average and below-average students. Summerby-Murray (2001) used GIS to teach undergraduate students how to analyse historic landscapes as a way to tackle real-world problem solving and reported that the use of GIS has shaped students' ways of thinking of historical geography and educates students in thematically driven and theoretically sound research practices. Keiper (1999) designed GIS-oriented lessons for a fifth-grade class to search for and query data to solve problems through a treasure hunt. Keiper reported that students felt motivated by their learning experiences and were more confident about the problem solving abilities.

Barriers to teaching with GIS

Besides considering the numerous pedagogical strengths of integrating GIS within curricular design, educators also need to be aware of the barriers to implementing GIS supported lessons. One impediment to successful GIS implementation is the availability of appropriate hardware and software for running the GIS program (Patterson, Reeve & Page 2003). Another pedagogical concern centers on the appropriate academic levels for teaching with GIS and which content-related concepts are best taught using GIS. A key difficulty lies in the lack of time for the teacher to master fluency in new technologies such as GIS and exploring avenues for their implementation in classrooms to promote learning ecologies emphasizing critical thinking and knowledge generation activities. The majority of teachers utilizing GIS are probably the only ones in schools using the technology and spend enormous amounts of time in learning GIS and preparing GIS-driven lessons. Due to a lack of external incentives and recognition in rewarding teachers who actively explore the educational possibilities with GIS, a GIS teacher is often referred to as the 'solitary GIS missionary' (Audet & Paris 1997). Finally, there is the need to train teachers and provide on-going professional development support in guiding teachers after formal training in the proficient usage of GIS with educational intent. Bednarz and Audet (1999) observed that if pre-service teachers are taught with and about GIS within the educational technology component of their teacher preparation program there is a higher likelihood of them embedding this technology in their teaching. Bednarz (2007) suggested that experienced teacher need continual support to encourage leveraging upon the affordances of GIS technology in the classrooms. This support takes on two different forms: (i) internal support in establishing networks or communities of practice within individual schools or a cluster of schools in engaging in joint collaborations with experienced GIS teachers to tap their expertise (ii) external support come from external training vendors or agencies in disseminating information on technical updates to the GIS software or in raising GIS-oriented pedagogical proficiencies. Secondary teachers who have gained experience from implementing GIS have recommended that more initiatives to situate GIS as a learning tool need to be mounted through the offering of more workshops to teachers and handholding in the development of GIS-related modules that are well-integrated within existing curriculum (Palladino 1994).

In a previous study (Liu *et al.* 2010) which evaluates the efficacy effects of geographic information systems (GIS) in enhancing and augmenting the problem solving performance of secondary school students in Singapore, it was amply demonstrated with evidence that GIS technology indeed offers rich learning opportunities for improving students' geographic problem solving and analytic thinking abilities. This paper is an extension of the previous one and is particularly aimed at investigating the context-dependent pedagogic usefulness of GIS and the specific ways in which it can define and impact problem solving outcomes.

Research Methodology

The strand of research examining the affordances of GIS in promoting higher-order learning as covered in this paper was carried out within the broader context of the research agenda of the problem-based learning using GIS technologies (PBL-GIS) research project that attempted to study the effectiveness of PBL-GIS in secondary school geography education. The overarching PBL-GIS project adopted a quasi-experimental approach to test the PBL-GIS pedagogy with an experimental group of students and compare their learning outcomes with a control group who were exposed to PBL but not GIS technology. Though an experimental research strategy involving random sampling would have been ideal, due to pragmatic constraints a quasi-experimental approach was adopted. Attempts were made to minimise threats to internal validity and approximate an approach that comes close to the rigours of a true experiment. In the PBL-GIS project, three PBL activities were developed and given to students in the control and experimental groups to investigate the mediating effects of the intervention training on GIS in influencing PBL outcomes. The research site was the National University of Singapore High School of Mathematics and Science (NUS High School in short). This school is a specialised independent high school emphasising critical thinking, independent learning, problem solving, writing, research and excellence in science and technology within a broad-based curriculum using innovative teaching methods and technologically rich classrooms. The participant students were Secondary 3 students of 14 years of age from a geography course called 'The Human Population Dynamics'. The control and experimental groups respectively consisted of 25 and 24 students.

The data collection for the study presented in this paper was carried out with the use of a survey instrument which was carefully constructed to explore the different meaningful ways in which GIS could potentially impact problem solving pedagogy. The survey consisted of a combination of 5-point Likert-scale items and open-ended questions (a copy of the survey is found in the appendix). Likert-scale items were chosen since they provide a structured framework to gathering and assessing students' feedback on the situated usefulness of GIS as a problem solving enhancer. Likert scale also is easier to construct and carries a higher degree of reliability than other scales (Tittle & Hill 1967). However, a Likert scale is constrained in that they fail to unearth the underlying reasoning and explanations to support the perceptions triggered in the target audience in responding to the items listed in the Likert scale. They reveal little about the causes for answers and thus might have limited usefulness (Gall, Borg & Gall 1996).

With a view to mitigating the effect of this limitation, open-ended questions were included in the survey to probe deeper students' perceptions of their experiences in using GIS technology and how it shaped their conceptual learning of geographic phenomena. In addition, open-ended descriptive questions provide richer contexts for respondents to post detailed reflections on their feelings, attitudes and understandings on the issues being examined.

The survey was administered to the 24 students in the experimental group in a printed format through the teacher-in-charge at the end of the PBL-GIS project. 22 out of the 24 students participated in the survey thus contributing to a high response rate of 92 per cent. Students' responses to the quantitative and qualitative items in the survey were analysed to draw out salient findings that are discussed in the following sections.

Results and Discussion

The mean score and standard deviation computed for the different items listed in the survey administered to participant students are presented in the following Table 1.

The power of GIS in promoting student-centred learning cultures and knowledge transforming discourses in geography classrooms was analysed in this study. Readers need to take note that though the primary objective of this study was to examine the pedagogical affordances of GIS in modelling and shaping problem solving processes, the technology alone is not the sole determinant of students' success in accomplishing GIS-directed problem solving goals. There is a matrix of other interacting factors that influence engagement with GIS-driven problem solving environments: the effectiveness of the design of problem solving task; the richness of simulation of task domain by task requirements; the types of scaffolding structures and tools embedded in the problem space; and the levels of cognitive interactivities facilitated by task demands between the features of GIS software and learners and technology fluency of learners. Hence, in evaluating the pedagogical significance of the results of this study on GIS integration in geography education, readers need to consider the effects of these variables on problem solving outcomes since they were not totally accounted for or controlled due to unavoidable limitations of time, manpower and access.

Items	Mean	STD Deviation
I was comfortable using GIS	3.3	0.7
Using GIS is an effective method to improving learning	3.4	0.9
I prefer using GIS in my learning as compared to the Traditional method	3.4	1.1
Investigating different topics of concern	3.3	0.8
Analyzing data patterns, linkages and trends	3.7	1.0
Engaging in problem solving	3.4	1.0
Enhancing my ability to ask my own questions and seek answers to them	3.0	0.9
Enabling inter-disciplinary learning	3.0	0.8
Using maps to process and report geographic information	3.6	1.1
Examining spatial organization of different places	3.6	0.9
Creating my own computerized maps	3.3	1.1
Exploring issues from different angles of analysis	3.2	0.9
Facilitating collaboration with my fellow students	3.5	1.0
Developing in me a thinking mindset	3.2	0.9
Supporting me in pursuing scientific inquiry	3.0	1.0
Examining data evidences and making right interpretations	3.2	1.0
Accessing the most recent information to make decisions	3.5	0.9
Increasing my motivation for learning	3.1	0.8
Challenging me to be a better learner	3.1	0.9

Table 1. Mean Score and Standard Deviation Computed for the Different Items listed in the Survey Administered to Participant Students.

Positive impact of GIS in advancing problem solving pedagogy

Student respondents who participated in this research reported that GIS is a useful and promising technology mediator that offered educational potential in enhancing the learning process of problem solving through multifarious ways. Students were generally comfortable enough with the interface and associated tools of GIS (mean score of 3.3) despite the inherent complicatedness of GIS and the short duration of training provided to them during the intervention phases in familiarising them with the features of GIS. Students viewed GIS as an effective technology that could be leveraged upon by educators in improving and innovating students' learning of core competency-based geographic skills (mean of 3.4). Overall, students expressed a favourable stance towards embedding GIS in curricular practices to foster a paradigmatic shift from didactic geography classrooms to student-centred active learning ecologies.

Inquiry-based Learning

The majority of students (82 per cent of students) reported that using GIS to investigate a range of relevant geographic topics was helpful. Since the computerised GIS system has enormous digital information capacity that allows users to rapidly access, analyse and process vast amounts of spatially referenced data, students could analytically explore a myriad of issues and engage in decision making.

Students felt somewhat neutral about the impact of engagement with GIS in enhancing their abilities to pose their own scaffolding questions and solicit answers to them in formulating solutions for the problem tasks. This conclusion was drawn based upon the high percentage of students (55 per cent of students) who returned a neutral response for this item and the computed mean for this item of 3.0. Though GIS itself as an educational technology platform influences the development of independent inquiry skills in students, it is the combined effect of the structuredness of task design and effectiveness of facilitation skills of GIS teachers that actually influences students' mastery of the skills. The focus of the training interventions being on coaching students to be conversant with the technical features of GIS and providing opportunities for exploring the learning potential of GIS, little time could be devoted towards improving students' inchoate skills on self-directed authoring of a repertoire of subsidiary questions that guide students towards constructing cogent answers to the key requirements described in the given task scenario. For instance, Student M aptly underscored this learning gain from using GIS with a cryptic comment in her feedback: "*GIS encourages us to ask many questions*".

Analytical Reasoning & Information Processing

Not unexpectedly, the item on the usefulness of GIS in analysing data patterns, linkages and trends registered the highest mean rate of 3.7 in students' responses as GIS's analytical capability is one of the chief attribute strengths of GIS. The different map layers representing different geographic themes could be independently accessed or combined to reference many different properties associated with a specific geographical location to facilitate study of functional relationships between data sets and points. Student Q specifically remarked that "*GIS has allowed me to learn how to observe and analyse spatial differences and how to make use of this program to facilitate my learning*". He further added that "*GIS has helped me to develop spatial reasoning, spatial problem solving, spatial thinking and computing skills*".

Students reported high scores (mean of 3.6) in their feedback on the effectiveness of using GIS maps to process and present geographic information. This was due to the 'intellectual' affordances of GIS by adding layers of sophistication to ordinary paper-based mapmaking by giving the user the ability to interactively call out and query maps and their embedded data (Van Demark 1992). Frequent use of GIS-enabled maps and making sense of the data contained in these maps improved students' locational knowledge competencies. The integration of database management functions with the visualisation and statistical analysis benefits offered by GIS situates it as a powerful instructional technology system. Graphic display techniques of GIS turn abstract models of the real world otherwise static on printed paper into dynamic representations allowing students to manipulate the elements of the digital maps and visualise the relationships between these elements to explain phenomena, predict outcomes and plan strategies.

A large proportion (about 60 per cent) of students valued the power of GIS in scaffolding students' efforts in examining the spatial organisation of different places. Linking physical locations to information in a database and then extracting and analysing needed information from multiple spatial perspectives helped students become better decision makers. Scrutinising maps, images and data associated with different places in a highly interactive manner supported the systematic development of spatial thinking, reasoning and problem solving proficiencies in students. The process of searching for, processing, interpreting and synthesising spatial information enhanced learners' engagement and motivation.

Students found the feature of creating their own computerised maps in GIS to be particularly useful in catalysing their learning experiences. This observation is evident from analysing the relatively high mean score of 3.3 registered for this survey item, with 55 per cent of the students finding GIS to be either helpful or very helpful in producing maps. This is due to the flexibility provided by GIS in generating customisable maps of varying degrees of complexity that easily meet the specific needs of users. Performing spatial analysis, creating data models and presenting results in visually rich map representations enables students to better simulate the task domain and formulate viable problem resolution plans. Student E highlighted this strength of GIS by noting that "*using maps to obtain data from different places to look at similarities and differences was helpful*".

Yet another pedagogical strength of GIS as highlighted by students was the affordance of GIS in facilitating investigation of issues from different angles of analytical reasoning and argumentation. This item in the survey received a mean score of 3.2. Rather than seeking singular solution pathways or fixed, correct answers, GIS supported ill-structured problem solving by allowing students to examine a wide gamut of alternatives and possibilities in deconstructing a problem task. GIS-led curriculum creates open-ended learning environments where opportunities are provided for students to move away from prescriptive to heuristic approaches of problem solving. Students are able to cognitively explore a problem situation from multiple dialectical perspectives and develop solution artefacts that are theoretically well-grounded to unified frameworks of understanding. Supporting this finding, Student C mentioned in his feedback that using GIS to "*study different perspectives of geography was educational*".

Multidisciplinary Problem Solving and Decision Making

The effectiveness of GIS in accomplishing problem solving was highly rated (mean of 3.4) by participant students in the survey. Nearly 59 per cent of these students indicated that they found GIS to be of great utility in augmenting their problem solving skills. The uniqueness of GIS lies in its ability to integrate geography's spatial perspectives with the data organisation and analysis capabilities of modern information technologies. Hence GIS served as a powerful problem solving tool in creating learning environments that stimulate students' active exploration and solving of problems in an interactive and integrated manner. GIS was especially valuable in fostering open-ended problem solving skills such as conceptualising problem space, drawing linkages between the elements of the problem structure, acquiring needed information, drawing inferences from data pattern observations and formulating solution schemas. Since GIS is widely utilised in workplace settings outside of academic learning environments such as governments, businesses, environment management organisations as a productive problem solving aid, promoting GIS-enabled classrooms is a positive step towards preparing students to meet the challenges of knowledge-based economies of the future. As indicated by Student D in his response, "*using GIS to find out more about Singapore's ageing population and thinking of plausible solutions to combat the problems of an ageing society was a positive learning experience*".

Another item in the survey which solicited from students an overall mean score of 3.0 was the utility of GIS in enabling inter-disciplinary learning. This finding was rather surprising since GIS is inherently interdisciplinary in outlook and facilitates the integration of content matter and expertise from varied core subjects such as mathematics, geography, environmental science, sociology and so on. GIS promotes both short-term and long-term transference of skills spanning across a range of multidisciplinary themes and yet reinforces learning in each individual disciplinary field through data analysis and application. GIS thus has the capability to support cross-disciplinary curricular emphasis. However, the moderate response feedback from students on the item of interdisciplinarity of GIS can be attributed to the fact that the GIS interventionist training held was conducted in the context of a Geography classroom and by a Geography GIS-trained teacher. Naturally, the focus of the practice tasks administered to students in practicing their GIS skills was on Geography subject matter. Hence, students might have entertained the misconception that GIS is a geography-specific learning tool with limited versatility to foster multidisciplinary learning.

Nearly half of the participant students were of the opinion that GIS reliably provides access to comprehensive data sources with the most updated information allowing them to draw the right interpretations and conclusions in making correct task-based decisions. Students highlighted the effectiveness of GIS software in its ability to extract a vast array of data and overlay or combine it so that the data can be manipulated and analysed with enhanced visual acuity. The data output can be achieved in multiple representational modalities such as detailed maps, images or movies to communicate conceptual ideas in relation to a geographic area of interest. The statistical tool in GIS enabling students to use standard database queries to retrieve and examine data to accomplish problem solving was an added feature of GIS that students reported to be of valuable utility. The relative ease with which a rich body of current information can be located in the GIS databases and contextually applied to make strategic problem solving decisions honed students' skills of divergent and analogical thinking. Corroborating this piece of analysis, Student P thus reflected: "*GIS provided good access to lots of data and plotting the data in graphs was made much easier*".

Collaborative Learning

The item on the ability of GIS to foster collaborative learning discourses in classrooms between students registered high scores (mean of 3.5). Half of the participant students found GIS to be either highly helpful or adequately helpful in facilitating technology-mediated communications and discussions. Positive feedback was anticipated since group synergy was encouraged by assigning students to paired teams in tackling the GIS-enabled problem solving tasks. Team-based engagement with GIS promoted an iterative cycle of collaborative learning activities involving peer brainstorming, tutoring and interactions in conceptualising the elements of the problem space, identifying possible problem solving strategies and reaching the intended goal state through implementation of the most effective action plans. In exploring the efficacy of different GIS mapping techniques and applications, students had to engage in discursive dialogues and constructive argumentation to tap the expertise and knowledge of their fellow students to model consensual problem solving approaches. The collaborative space created by working with GIS through teamwork helped students to verbalise aloud their individual thinking, support the defensibility of their ideas through evidence-based reasoning, clarify misconceptions and strengthen their conceptual understanding of geographic principles. GIS-centric peer learning made tacit knowledge concrete through applied practice in real-world contexts and built new knowledge bases seen as the common, collective property of team members. In the process of sharing ideas and learning from one another, students became tolerant of perspectives that might be opposed to their own and appreciate the eclectic diversity of different worldviews on issues of mutual concern. Affirming the power of GIS in fostering the development of collaborative synergy amongst students, Student B expressed that working together as a group to tackle the given problems was a positive learning experience for her.

Critical Thinking Skills

Students reported that GIS favourably influences the cultivation of critical thinking mindsets in them (mean of

3.2). a Mean of 3.2 indicates neutrality!! Incorporating GIS in curricular design in schools and training students to be proficient in using the tools found in GIS software aids in the development of spatial thinking and analysis skills in students in a process-oriented manner. This is significant in light of the report from the National Research Council (National Research Council 2006), *Learning to Think Spatially: GIS as a Support System in the K-12 Curriculum*, that points to the importance of imbibing spatial thinking skills in learners of all ages and the educational potential of GIS in accomplishing this objective. Our study determined that GIS technology promotes higher order thinking by helping students to understand the complexities of spatial relationships observed in the working world and model spatial analysis activities such as location selection, tracking changes over time and manipulation of variables to study environmental impact.

Other key cognitive competencies learnt included working on scales and units, comparing and evaluating sizes and shapes, identifying associative patterns and integrating new knowledge architectures within mental models. These thinking skills learnt in a GIS-driven learning environment may be transferred and applied in non-GIS contexts of everyday problem solving to holistically examine and solve problems from varied spatial perspectives. Spatial thinking is critical since it entails analytical inquiry that encourages learners to probe phenomena beyond cursory understandings dictated by the 'where' construct in terms of names and locations of places in maps to deeper levels of scrutiny driven by questions such as 'why' and 'how'. The favourable comment by Student N affirmed the positive impact of GIS in informing critical thinking: "*It enabled me to think deeper and to do research more easily, using the variety of resources*".

The item in the survey on pursuing scientific inquiry examines affordances of GIS in furthering students' pursuit of scientific inquiry and is closely linked to the previous item on scaffolding the development of cognitive skills in students. A thinking mindset is naturally underpinned by a profound desire to want to engage in scientific inquiry and contemplation. One who is inclined to rigorously questioning the validity of and reasoning behind scientific assumptions, phenomena and axioms will constantly think about possible areas of scientific investigation that could be undertaken. This is important since scientific research is an emergent process where 'truths' are accepted based upon the legitimacy of empiric proofs currently available but amenable to further modifications when fresh evidences arise. Hence, it is perplexing that though the mean score obtained for the item on development of thinking mindset was rather high (3.2), the mean score for the item on pursuit of scientific inquiry was the lowest (2.95) amongst all the items listed in the survey. Since the relationship was expected to be correlated, we suspect this reversal to be an aberration rather than a validated finding since errors or biases have been known to be associated with surveys as data collection and analysis instruments in research studies. This irregularity could be attributed to students not correctly grasping the actual meanings conveyed by the words 'scientific inquiry'. Students might have misinterpreted this term to denote the pursuit of the formal agenda of scientific investigations and experimentations by scientists towards achieving academic excellence. Thus, students possibly could have wrongly deduced this item to be of little relevance to them and scored poorly in it since they are only school learners and not trained scientists.

Affective Learning

The last two items in the survey solicited students' views on how well GIS served to increase their motivation for learning and challenge them to be more productive learners. Surprisingly, contrary to expectations, students' responses to these two items had low mean ratings (3.1 each for both items). This is inconsistent with previous research findings on the use of GIS in educational settings. For example, Bodzin and Anastasio (2006) and Drennon (2005) reported that students were enthusiastic about learning GIS and educators found integrating GIS in their teaching practices contributed towards achieving enhanced educational outcomes. West (2003) also found that GIS-based curriculum increases students' motivation and interest in wanting to learn geographic concepts. The low scores on motivational levels obtained in our study may not directly per say be reflective of the lack of ability on the part of GIS technology to stimulate and incentivise learning. Rather the lukewarm response could be attributed to the rushed manner in which the GIS training sessions were conducted due to time and scheduling constraints. This might have caused the learning curve to be steep and made students feel less at ease in learning the features of GIS at a comfortable pace. This finding further reinforces the need for educators to systematically plan for and implement the instructional design and sequencing of GIS training programs. There should be adequate time factored in for the training sessions and spaced task-oriented practice interspersed in for better applied understanding of the working mechanisms of GIS.

The following cogitations of students on the quality of their experiences in interacting with GIS underline the positive influence of GIS in motivating students' learning behaviours:

"It was fun to learn something new but my learning was slow due to the software not being easy to use." (Student S)

"It was wonderful and stimulating.........." (Student P)

"Working on the Singapore Project, the learning process was enjoyable, especially the research, presentation and report." (Student Q)

Challenges encountered and recommendations

A predominant majority of 85 per cent of students remarked that the interface of GIS system was not user-friendly and they faced difficulties in becoming familiar with the numerous GIS tools. They assessed the GIS environment to be complex and industry-oriented with many of its multitude of features not being applicable or relevant within a high-school learning context. The following sample comments extracted from students' feedback highlight this problem:

"GIS was un-user friendly and had a hard-to-use interface." (Student A)

"It had a complicated user interface." (Student X)

"Learning how to use it was difficult as many functions had to be learnt on how to use them." (Student M)

Two students suggested that a clearly delineated instructional manual be provided to students in scaffolding their efforts at becoming conversant with the technology in a more structured manner. This is indeed a worthwhile suggestion since a step-by-step manual helps to train students to become familiar with GIS mechanisms in a systematic and methodical manner. However, the authors feel that though a written instructional manual would be helpful, it might have the unintentional effect of fostering didactic modes of instruction rather than the heuristic approach to learning that we hope to promote in using GIS within an educational context. In addition, an instructional manual might not necessarily alleviate the problem of students having to deal with the complexity of the system since GIS as it currently is available is sophisticated and targeted largely at professional users in the scientific, business and corporate communities. The complicatedness of GIS and its higher-order cognitive processing demands impeded students' motivation to want to keenly explore and try out its various applications with a learning intent. A few students noted that they found it confusing navigating their way through the cluttered environment of GIS, especially during the initial phase of introduction. The authors recommend that a simpler and customised version of GIS inclusive of a limited number of features and analysis tools specifically catering to the educational needs of students be prototyped and evaluated in schools for later production.

Another important observation the authors as researchers noted in carrying out this study was the need to convince teachers themselves on the utility of GIS as an instructional enabler and ensure that they take active ownership of the GIS project from its onset. Teachers need to be involved in all the different phases of any GIS-directed educational initiative including needs analysis, goal setting, task design, project implementation and evaluation so that they feel themselves to be key stakeholders in this endeavour of empowering students to be independent learners and critical thinkers.

Some students reflected that they were not given adequate time in training to learn and become knowledgeable practitioners of GIS before being assigned tasks to exercise their newly acquired skills. Supporting this line of observation, Student B commented thus: "*It was a new system. Required time to get adjusted but we did not have the time*."

Since GIS is technical in nature, more time and hands-on practice opportunities need to be provided to students in acquainting them with the technology of GIS before focusing on exploring GIS's instructional affordances. Some of the other pedagogical considerations students' feedback surfaced for further contemplation included appropriate educational levels for GIS education, access to suitable hardware and software and which thematic topics and concepts are best taught with GIS.

Conclusion

The pedagogical productivity and promise of a GIS-enabled instructional orientation to curricular improvement has been evidently well-established in this study. Generally, students were satisfied with the scaffolding role of the GIS technology as a problem solving tool and felt motivated in wanting to use it to deepen their applied understanding of theoretical concepts. The results of this study demonstrated that the variegated ways in which GIS has the capability to infuse rigour and effectiveness into problem solving processes and enhance the delivery of disciplinary content knowledge. It was found that a PBL-GIS framework of learning empowers students to become inquiring knowledge seekers, active intellectual collaborators, analytical decision makers and persuasive critical thinkers. However, the development and application of a GIS enabled curricular methodology does come with its share of teething problems. Some of the key problematic issues that surfaced in this study included the difficulties faced by students in familiarising themselves with the GIS software that catered to the needs of the professional rather than educational community, lack of opportunity for more varied practice during the training sessions and the imperative need to co-opt teachers as designers of the GIS enabled curriculum. Appropriately addressing or mitigating these challenges during the planning and execution phases of a PBL-GIS educational project ensures the successful advocacy and implementation of PBL-GIS as a rigorous curricular model.

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Appendix
Student Feedback on GIS usage

Please respond to the questions in this survey to the best of your ability as that will help us better understand the usefulness of GIS for teaching and learning.

Please rate the following statements on how strongly you agree or disagree:	SD- Strongly disagree SA- Strongly agree				
	SD				SA
I was comfortable using GIS	1	2	3	4	5
Using GIS is an effective method to improving learning	1	2	3	4	5
I prefer using GIS in my learning as compared to the traditional method	1	2	3	4	5
Please rate the use of tools and data in GIS in advancing your learning through the following ways:	NH – Not helpful VH – Very helpful				
	NH				VH
Investigating different topics of concern	1	2	3	4	5
Analysing data patterns, linkages and trends	1	2	3	4	5

Engaging in problem solving	1	2	3	4	5
Enhancing my ability to ask my own questions and seek answers to them	1	2	3	4	5
Enabling inter-disciplinary learning	1	2	3	4	5
Using maps to process and report geographic information	1	2	3	4	5
Examining spatial organisation of different places	1	2	3	4	5
Creating my own computerised maps	1	2	3	4	5
Exploring issues from different angles of analysis	1	2	3	4	5
Facilitating collaboration with my fellow students	1	2	3	4	5
Developing in me a thinking mindset	1	2	3	4	5
Supporting me in pursuing scientific inquiry	1	2	3	4	5
Examining data evidences and making right interpretations	1	2	3	4	5
Accessing the most recent information to make decisions	1	2	3	4	5
Increasing my motivation for learning	1	2	3	4	5
Challenging me to be a better learner	1	2	3	4	5
What are the ways other than those listed above in which using GIS has promoted your learning?					
What problems did you face in using GIS for your learning?					
What type of skills (computing, mapping, spatial thinking, spatial reasoning, spatial problem solving, etc.) Do you think GIS has helped you to develop?					
Describe your learning experiences (both positive and negative) while working on your Singapore project.					
Can you identify some other areas in your study where you can apply your GIS knowledge and skills? Please give examples and elaborate if you can.					

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References

[1]. Audet, R. H. & Paris, J. (1997). GIS implementation model for schools: Assessing the critical concerns. *Journal of Geography, 96*(6), 293-300.

[2]. Baker, T. & White, S. (2003). The effects of GIS on students' attitudes, self-efficacy and achievement in middle school science classrooms. *Journal of Geography, 102*, 243-254.

[3]. Bednarz, S. W. (2007). Impact and success: Evaluating a GIS training institute. Paper presented at the *19th Annual ESRI User Conference.*

[4]. Bednarz, S. W. & Audet, R. H. (1999). The status of GIS technology in teacher preparation programs. *Journal of Geography, 98*(2), 60-77.

[5]. Bodzin, A. M. & Anastasio, D. (2006). Using web-based GIS for earth and environmental systems education. *Journal of Geoscience Education, 54(3),* 297-300.

[6]. Caulfield, P. (1991). From Brazil to Buncombe County: Freire and posing problems. *The Educational Forum,* *55*(4), 307-318.

[7]. Drennon, C. (2005). Teaching geographic information systems in a problem-based learning environment, *Journal of Geography in Higher Education, 29*(3), 385-402.

[8]. Estes, C. (2004). Promoting student-centered learning in experiential education. *The Journal of Experiential Education, 27*(2), 141-161.

[9]. Fournier, E. (2002). Geography and problem-based learning. *The Journal of General Education, 51*(4), 293-305.

[10]. Gall, M., Borg, W. & Gall, J. (1996) *Educational Research, An Introduction* (6th Edition). USA: Longman

[11]. Halvorson, S. & Westcoat, J. (2002). Problem-based inquiry of world water problems in large undergraduate classes. *Journal of Geography, 101*, 91-102.

[12]. Hardwick, S. W. (2001). The status of geography in higher education in the United States. Paper presented at the *International Network for Learning and Teaching (INLT) Plymouth Conference*.

[13]. Keiper, T. (1999). GIS for elementary students: An inquiry into a new approach to learning geography. *Journal of Geography, 98*(2), 47-59.

[14]. Kerski, J. (2003). *The implementation and effectiveness of geographic information systems technology and methods in secondary education*. PhD dissertation. The University of Colorado.

[15]. Liu, Y., Bui, E. N., Chang, C-H. & Lossman, H. G. (2010). PBL-GIS in Secondary Geography Education: Does it Result in Higher-order Learning Outcomes? *Journal of Geography* (forthcoming).

[16]. National Research Council. 2006. *Learning to Think Spatially: GIS as a Support System in the K-12 Curriculum*. National Academy Press, Washington, D.C.

[17]. Palladino, S. (1994). *A role for geographic information system in the secondary schools: An assessment of the current status and future possibilities.* University of California, Santa Barbara.

[18]. Patterson, M. W., Reeve, K. & Page, D. (2003). Integrating geographic information systems into the secondary curricula. *Journal of Geography, 102*(6), 275-281.

[19]. Peterson, P. A. (2007). *Geographic information systems: Instruction in South Dakota's secondary classrooms.* South Dakota State University.

[20]. Rutherford, D. & Lloyd, W. (2001). Assessing a computer-aided instructional strategy in a world geography course. *Journal of Geography in Higher Education, 25*(3), 341-355.

[21]. Summerby-Murray, R. (2001). Analyzing heritage landscapes with historical GIS: Contributions from problem-based inquiry and constructivist pedagogy. *Journal of Geography in Higher Education, 25*(1), 37-52.

[22]. Tittle, C. R. & Hill, J. R. (1967) Attitude Measurement and Prediction of Behaviour: An Evaluation of Conditions and Measurement Techniques. *Sociometry, 30*(2), 199-213.

[23]. Van Demark, P. 1992. Where is desktop GIS headed? *Urban and Regional Information System Association (URISA) Proceedings*. V3 (2), pp.54-61.

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