BRINGING OPERATIONAL GIS INTO UNIVERSITY CLASSROOMS

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As geospatial technology matures, the demand for well trained GIS professionals is increasing. Universities and colleges are adding new GIS programs to meet this demand. However, many students who enter the job market after taking a few courses in GIS still find themselves challenged by the complexity of the real-world tasks. Data is not clean; analytical procedures are not laid out; visualization requirements are too diverse. GIS projects in the real world are seldom as clear-cut as the course exercises. Students who have a Master's degree in GIS may be well prepared for such challenges, but many more hope to become employable with just two or three GIS courses. How to effectively prepare students for the operational GIS jobs becomes a challenge to instructors.

This study explores an innovative approach in teaching operational GIS to students who have taken only one introductory GIS course. It brings real world cases into university classrooms and exposes students to practical solutions of multiple scenarios. In the course of 15 weeks, students learn the complete project cycle from problem definition, data review, project planning, to step-by-step operations, including data modeling, procedures automation, visualization, presentation and reporting. The class forms teams to solve network logistic routing for an emergency relief operation, design a geodatabase for a municipal GIS department, and perform 3D modeling for a campus solar radiation analysis.

The design of the course allows students to learn the skills needed for solving all three cases in class, while focusing on one of the cases for hands-on work in lab hours and take-home assignments. The combination of lectures, demos, student presentations and class discussions provides an engaging environment for all students. Guest lecturers from the case sponsoring organizations bring real world experience and scenarios into the classroom, enriching students' understanding of the problems and making sure that the classroom solutions are indeed operationally sound. Such a course becomes the students' training ground and the case sponsoring organizations' problem solving test bed.

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Introduction

The Harvard Extension School is Harvard University's primary resource for continuing education for nearly a century [*Harvard University Extension School* 2009]. It offers an open and comprehensive academic curriculum, with over 600 courses in more than 65 fields to meet the interests and needs of a diverse public. Its degrees and certificates programs are designed to enhance students' professional skills, prepare them for a new career, or help them pursue intellectual inquiry for personal enrichment. Classes are open to any student up to the challenge. Students don't have to be in a degree program to enroll. Regardless of the student's goals or experience, the only general requirement is a true commitment to learning. This open-door policy brings students to the Extension School with a diverse background, motivated to learn. It also imposes a challenge on the instructors to deliver courses that satisfy a class with different knowledge and skill levels, and different objectives and expectations.

Few will disagree that the GIS job market has been booming in recent years. Most government agencies at all levels, and an ever increasing number of private sectors, have realized the critical importance of GIS in its enterprise operation. Even with flourishing certificate and degree programs in educational institutions [*ESRI* 2009], the supply of well trained GIS professionals has yet to meet the fast growing demand of the job market [*Directions Magazine* 2004], as predicted by the panelists at the GIS in Action Job Market Forum [*URISA* 2006]. Furthermore, societal GIS tools such as Google Earth and Virtual Earth have brought GIS to the general public. They inspired a vast number of academic researchers and professionals in almost all fields to apply spatial analysis and visualization to their own fields [*Goodchild* 2007].

Figure 1. Number of users at different levels of involvement with GIS.

The Harvard Extension School has been offering an entry level GIS course for a number of years. Students include both those who want to expand their knowledge and skills, and those who are considering a career change. Most of these students are pursuing their Master of Liberal Arts degree in either Environmental Management or Information Technology. They are mature and motivated, but many have time constrains after a full time job and family commitments. They have various levels of skills in computer usage, some are professional programmers, others are challenged by mapping a network drive, but all have little or no previous knowledge in GIS.

After the entry level Introduction to GIS course (4 credits), many of the students want to learn more. One student wrote in the course evaluation: "I am very interested in GIS and I hope to continue on this path. What this course has taught me is that it is a very rich and complex field and that it will be a long road before I am proficient with the software." The demand for an intermediate GIS course is evident, but how to most effectively equip students with operational GIS skills through just one other 4 credit course becomes a challenge to the instructors.

Operational GIS Course Design

GIS is a science and technology that allows different levels of involvement (Figure 1). Most of the intermediate GIS course students are interested in transitioning from GIS users to GIS professionals. At this level, the students are already exposed to the general software tools and data formats, but are lacking a good understanding of how to use them in real-world problem solving. This phase is particularly important for students at the Extension School who are interested in acquiring practical GIS skills quickly. Therefore, the authors believe that hands-on training is critical, and real-world cases are essential at this phase of learning. Instead of offering another course in "Advanced Studies in GIS", "Advanced Spatial Analysis", "GIS Modeling" or the like, the authors decided to introduce an "Operational GIS" course which allows students to solve real-world cases in groups.

Such "case-based", also called "project-based" or "problem-based", teaching is a common approach in GIS higher education [*Drennon* 2005; *Kelley* 2004; *Chen* 1997]. The uniqueness of this course is that the cases are provided by real organizations having a problem and needing a solution.

The course sponsors expect useful products from the class. The students are required to function as GIS consultants in training. With the instructors' guidance, they are aimed at delivering practically useful results to the sponsoring organizations.

Course Objective

The "Operational GIS" course focuses on case studies of real world GIS problems using primarily the ArcGIS software. Three cases are introduced, covering urban and natural environments and requiring geodatabase design, data editing, spatial analysis, modeling, and visualization. The objective is to expose students to the complete life cycle of a real GIS project, including understanding organizational needs, resolving imperfect data issues, strategizing analytical approaches, managing deadlines and schedules, delivering meaningful results, and presenting the process and the outcomes to both the sponsoring agency representatives and their classmates. Teamwork and communication are important components in this learning process too.

Case 1. UN Joint Logistics Center Emergency Response Plan

This case is a network analysis problem based on aid delivery in Ethiopia. The objective is to derive an optimal configuration of warehouse locations relative to aid distribution points in order to reduce overall transport time and/or cost throughout the country. The project includes data preparation starting with raw and typically 'unclean' data, a common scenario in the humanitarian aid relief field. Network modeling parameters will include road traffic capacity, warehousing constraints and delivery requirements in the transport model.

Case 2. City of Cambridge Geodatabase Design

This case uses GIS data layers from the City of Cambridge, MA, and refers to the current operational work flow of this agency. The objective is to organize all the data into a geodatabase structure, designing domains, subtypes, relationships, topology rules, geometric networks, and other necessary geodatabase components. It is aimed at streamlining the GIS operation across many departments in the City.

Case 3. Harvard Campus Solar Roof Analysis

This case works with 3-D buildings and terrain models of the Harvard campus. The objective is to systematically evaluate the suitability for installing solar panels on Harvard buildings' roofs. The project will derive building roof direction, slope, size, shading, and other factors from multi-source, multi-format 3-D models, and calculate solar energy conversion efficiency based on these factors. The final result could help influence the University's renewable energy growth.

Instructional Structure

Students form three to four-person groups and take on one of the three cases as their primary project. There are many risks in group-based project work in GIS learning [*Livingstone and Lynch* 2002]. Myth or real, the outcome largely depends on the detailed implementation of the teams and guidance provided through the course. The authors chose to adopt the group-based teaching format mainly because that team-work is a basic requirement for all GIS professionals in most real work environments. It is a must, not an option, in preparing students for operational GIS jobs.

After being introduced to all three cases, students are asked to rank the cases by their individual preferences, indicating which case each of them would like to work on the most. Everybody's choices are posted out for the class to see. The instructors provided advices on skill requirements, learning opportunities and job perspectives for each of the cases. Some students adjusted their case selection after hearing the advices, and after seeing who else are in favor of which case. Those having a strong preference stayed with their selected cases, others teamed up with whom they like to work with, or joined the smaller teams to make the group size even. Eventually all are happy with their home-case.

Class time is divided equally among the three cases on a rotating basis, combining multimedia lectures, hands-on demonstrations, guest presentations from the case organizations, project status updates from students, and diagnostic discussions.

The project cycle includes the following steps (Table 1):

1. Background, problem statement and conceptual plan of the project;
2. Literature and data review;
3. Detailed project plan;
4. Analysis methods review and testing;
5. Preliminary results review;
6. Visualization and mapping;
7. Final project presentation and evaluation.

All students are required to participate in the complete project cycle of all three cases during the class time, but lab sessions and homework assignments are for their own project only (Table 2).

Table 1. Class time logistics.

Week	Date	Project Focus	Presentation	Lecture Topic	Demo Topic
1	1/31/2008	Case 1. UN Joint Logistics Center Emergency Response Plan	Instructor presents brief Case 1 introduction	Introduction to Network Analyst	Course requirements overview
2	2/7/2008	Case 2. City of Cambridge Geodatabase Design	Guest lecturer presents detailed Case 2 introduction	Introduction to Geodatabase	How to write statement of understanding for a project
3	2/14/2008	Case 3. Harvard Campus Solar Roof Analysis	Guest lecturer presents detailed Case 3 introduction	Introduction to 3D Analyst	How to create task list for a project
4	2/21/2008	Case 1. UN Joint Logistics Center Emergency Response Plan	Guest lecturer presents detailed Case 1 introduction	Data Preparation for Network Analyst	Review assignments 1-3 and define project groups
5	2/28/2008	Case 2. City of Cambridge Geodatabase Design	Students present literature review (5-10 min each group)	Planning Geodatabase Solutions	How to review data
6	3/6/2008	Case 3. Harvard Campus Solar Roof Analysis	Students present data review (5-10 min each group)	Working with 3D Analyst Geoprocessing Tools	How to plan a project
7	3/13/2008	Case 1. UN Joint Logistics Center Emergency Response Plan	Students present project plans (5-10 min each group)	ArcGIS Spatial Analyst - Suitability Modeling	How to fix network problems and create a route
8	3/20/2008	Case 2. City of Cambridge Geodatabase Design	Students present project status (5-10 min each group)	Data Model Design Methods	How to define geodatabase elements
	3/27/2008	Spring Break			
9	4/3/2008	Case 3. Harvard Campus Solar Roof Analysis	Students present project status (5-10 min each group)	Introduction to Model Builder	Surface analysis tips and tricks - hillshade w/&w/o shadow; viewshed, raster algebra
10	4/10/2008	Case 1. UN Joint Logistics Center Emergency Response Plan	Students present project status (5-10 min each group)	Model Builder - simulation modeling	Travel cost, service allocation, model builder for watershed analysis
11	4/17/2008	Case 2. City of Cambridge Geodatabase Design	Students present project status (5-10 min each group)	Local Government GIS Template	How to create geodatabase schema
12	4/24/2008	Case 3. Harvard Campus Solar Roof Analysis	Students present project status (5-10 min each group)	3D Analyst - Visualization with ArcGlobe, and introduction to CAD and Sketchup	3D visualization options
13	5/1/2008	Case 1. UN Joint Logistics Center Emergency Response Plan - Final project presentation and evaluation			
14	5/8/2008	Case 2. City of Cambridge Geodatabase Design - Final project presentation and evaluation			
15	5/15/2008	Case 3. Harvard Campus Solar Roof Analysis - Final project presentation and evaluation			

Table 2. Weekly assignments.

Week	Date	Project Focus	Case 1 Assignment	Case 2 Assignment	Case 3 Assignment
1	1/31/2008	Case 1. UN Joint Logistics Center Emergency Response Plan	Statement of understanding for Case 1, list of tasks	Statement of understanding for Case 1, list of tasks	Statement of understanding for Case 1, list of tasks
2	2/7/2008	Case 2. City of Cambridge Geodatabase Design	Statement of understanding for Case 2, list of tasks	Statement of understanding for Case 2, list of tasks	Statement of understanding for Case 2, list of tasks
3	2/14/2008	Case 3. Harvard Campus Solar Roof Analysis	Statement of understanding for Case 3, list of tasks, and your case selection	Statement of understanding for Case 3, list of tasks, and your case selection	Statement of understanding for Case 3, list of tasks, and your case selection
4	2/21/2008	Case 1. UN Joint Logistics Center Emergency Response Plan	Literature Review for Case 1	Literature Review for Case 2	Literature Review for Case 3
5	2/28/2008	Case 2. City of Cambridge Geodatabase Design	Data Review for Case 1	Data Review for Case 2	Data Review for Case 3
6	3/6/2008	Case 3. Harvard Campus Solar Roof Analysis	Project Plan for Case 1	Project Plan for Case 2	Project Plan for Case 3
7	3/13/2008	Case 1. UN Joint Logistics Center Emergency Response Plan	Load data to geodatabase, clean network dataset	Define infrastructure requirements; determine spatial domain for the GDB	Work with LIDAR data, clean up LIDAR data
8	3/20/2008	Case 2. City of Cambridge Geodatabase Design	Complete data cleaning, create network	Determine feature datasets and their justifications, assign feature classes to the feature datasets	Extract building height from CAD, add to DEM
	3/27/2008	Spring Break			
9	4/3/2008	Case 3. Harvard Campus Solar Roof Analysis	Compare current and proposed warehouse sets, evaluate travel time savings	Determine attribute domains and subtypes	Shadow analysis with Modelbuilder
10	4/10/2008	Case 1. UN Joint Logistics Center Emergency Response Plan	Decide which proposed warehouses to keep and which to drop by cost analysis (warehouse maintenance vs. travel time saving)	Determine relationships, topology rules and geometry networks	Shadow analysis with Modelbuilder
11	4/17/2008	Case 2. City of Cambridge Geodatabase Design	Emergency response scenario - flood and landslide, identify high risk network segments	Refine logical design and generate design diagrams	Roof area and slope calculation. Visual analysis
12	4/24/2008	Case 3. Harvard Campus Solar Roof Analysis	Generate alternative route to flood impact locations, avoid high risk roads	Finalize physical design (geodatabase schema) and document design process	Visualization of the final result
13	5/1/2008	Case 1 presentation	Report for Case 1	Review for Case 1	Review for Case 1
14	5/8/2008	Case 2 presentation	Review for Case 2	Report for Case 2	Review for Case 2
15	5/15/2008	Case 3 presentation	Review for Case 3	Review for Case 3	Report for Case 3

Adjustments During the Course

About 4 weeks into the semester, students formed teams and started to focus on their selected project. They quickly lost interest on the general lecture topics, even though the lecture contents were closely coupled with the project needs. They wanted the precious class time to be more specific on solving their problems. They preferred to ask questions and see an ad hoc live demo answering their questions in class. In other words, it was less effective to teach them how to do certain things before they tried to do it and realized that they didn't know how. Once they brought up the issue, teaching-learning was much easier. They could pick up the skills quickly and push on with their projects.

Based on the students' requests, the instructors stopped the planned lectures about half way into the semester, and used most of the class time for live demos and diagnostic discussions. The lecture materials were provided to the students to study at their own time. At the end of the course, students admitted that the lectures were mostly useful and relevant to their projects. Some even reviewed the lectures multiple times, and found that they understood the contents much better than the first time when they were lectured in class.

Students' Performance and Achievements

During the first few weeks, all students were asked to do a literature review on the subject they had chosen. The purpose of the literature review was to examine the precedents and find out GIS technologies that are suitable to use. This gave the students a chance to see how GIS technology is actually used in the real world. Many students found some good examples and actually borrowed some ideas from these precedents. Besides that, the literature review also served as a chance for each group to evaluate group members' technical strength so as to reasonably assign workload in the next stage.

After the literature review and subsequent project data review, each group made a project plan upon instructors' request. Two teams carefully followed the instructions and made detailed lists of tasks. The solar panel team seemed to have too many good ideas to put into a coherent plan. When it came to performing the analysis, all three teams showed great enthusiasm in implementing new tools that they didn't learn in their introductory GIS course. At this stage, instructors observed obvious discrepancy of students' GIS skills. Some students with good understanding of GIS can easily understand the new tools, while some others with weaker background seemed to be overwhelmed by new knowledge and could not catch up with their teammates' progress. This was the time when the instructors introduced live demos into the class routine, which helped bringing students to a more even footing.

One phenomenon that was not expected in the course design was that students weren't active in discussing other teams' projects. This was largely because of the distinction of technologies used in these three projects. For the UN logistics project, the main task involves quite a lot of network analyses. The Cambridge Geodatabase is about geodatabase design and management, while the solar panel project requires 3D analysis. Due to the tight schedule and differentiation of the projects, students didn't have time to gain enough knowledge to comment much on other teams' work.

Nevertheless, the final product from each team was quite remarkable. The UN logistics team not only devised a sophisticated model to identify the optimal arrangement of warehouses in Ethiopia to most efficiently distribute food aid under different conditions (Figure 2), but also created a hazard model to help predict areas where natural disasters are likely to occur (Figure 3) so that an emergency response plan could be made (Figure 4).

The Cambridge geodatabase design group aimed at minimizing complexity and maximizing functionality of a citywide geodatabase. Though none of the team members had a strong GIS background, they managed to examine a large amount of existing GIS and non-GIS datasets and came up with a hybrid approach in the feature datasets design. Their geodatabase schema was devised by balancing functional grouping, thematic grouping, and departmental grouping. The final geodatabase includes 7 feature datasets, containing 74 feature classes, plus 9 topology datasets and 2 geometric networks (Figure 5). This could serve more than 20 departments and groups in the city of Cambridge for different purposes. During a relatively short period of time, they had learned not only how to design a geodatabase, but also how to convert different data formats into a geodatabase, as well as how to do topology editing.

The third group, Harvard solar panel allocation, was in a totally different situation. They didn't have much raw data to start with, but were asked to figure out a creative way to find the best roof for solar panels. Because of the unique situation, they showed great interests at the beginning of the course in trying out different tools and applications. As time passed by, they gradually realized that they needed to find a practical approach first. The key of this project was to construct a 3D surface with ground elevation and building roof heights to support solar radiation analysis. Once the key issue was solved, the rest became easy for the team. They even incorporated Google Sketchup to enhance the presentation of their project (Figure 6, 7).

Overall, most of the students have accomplished what they intended to do in their project plans. There were some common pitfalls they observed or experienced during the course. The first

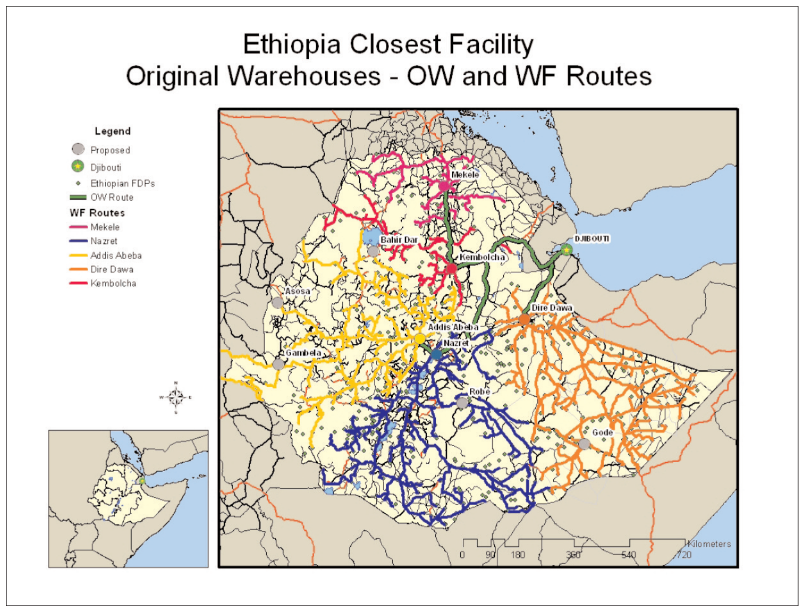

Figure 2. Map of Closest Facility routes analysis, by Rachel Boyce.

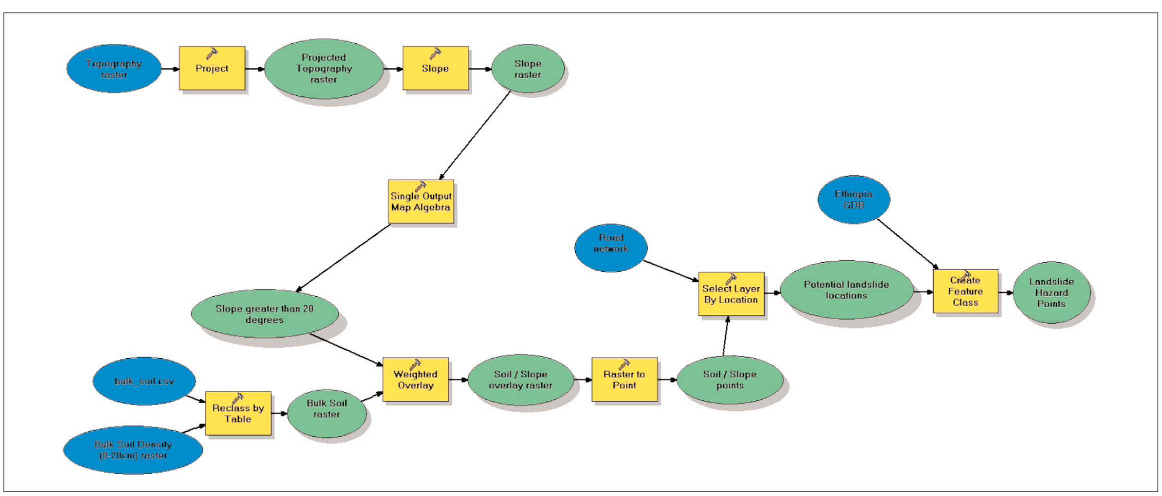

Figure 3. Landslide prediction model created using Model Builder, by Karla Sartor.

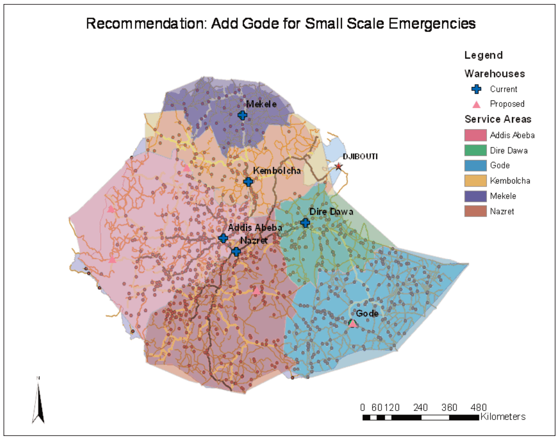

Figure 4. A Emergency Plan, by Tami Buhr, Rachel Boyce, Karla Sartor and Milan Vit.

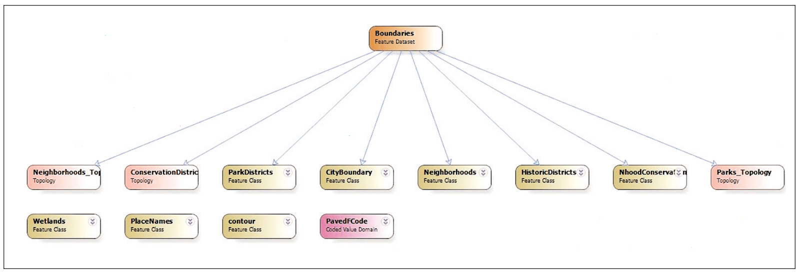

Figure 5. Partial diagram of the geodatabase schema for Cambridge, by Cornelia Herzfeld, Boswell Killebrew and Joseph Roman.

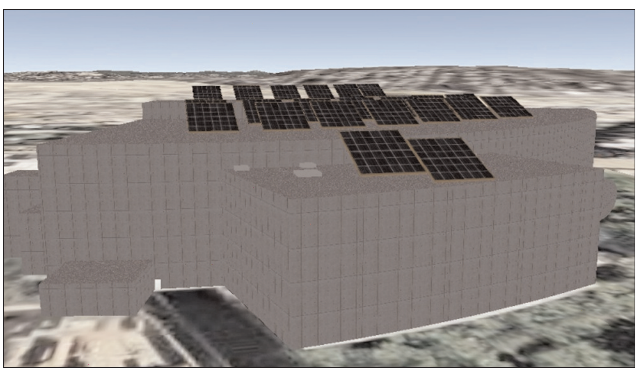

Figure 6: 3D model of the selected building with solar panels in Google Earth, by William Joe Haveman II, Daniel Englander and Lesley Lam.

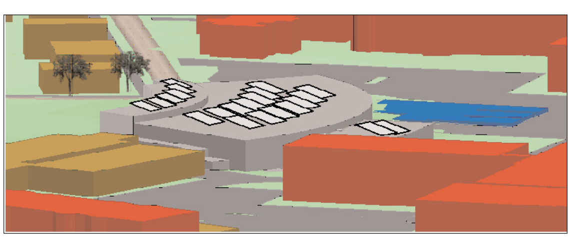

Figure 7. 3D model of the selected building and its vicinity in ArcScene - by William Joe Haveman II, Daniel Englander and Lesley Lam.

tough issue they dealt with was data insufficiency and poor quality. For example, the UN logistics team had planned to adjust the travel speed and route according to road condition and carrying capacity. Soon they realized that they had to make a compromise due to data availability. Each team had spent significant time to find data and fix the errors in the raw data. However, for the Cambridge Geodatabase group, this data problem helped illustrate the importance of topological rules in validating data integrity. Another common problem was that the students seemed to have difficulties in finding proper tools to accomplish tasks they had planned. When they made up the project plan for their projects, they were not sure whether or not certain analyses could be performed with GIS. It took quite a few rounds of trials and errors before they could decide on which tool to use, or how to revise their plan to accomplish the project objective with available tools.

Merits and Areas for Improvements

Excerpts from Students' Feedbacks

"The biggest strength of the course was that real data was used, which encouraged me to work hard on the project, since it wasn't 'just a project'. The start to finish nature of doing a project like this was also a valuable learning experience for real-world GIS consulting work. The biggest weakness of the course was that there was potentially more material covered than was possible to absorb."

"This course offered valuable real-work experience using ArcGIS. However, it tended to seem more like a second job than an educational course at times. There was value in seeing a project from start to finish, but perhaps more guidance and structure could have been given."

"This course does a great job of presenting some of the difficulties and hurdles a person might encounter working on a GIS project in the field. I took a lot of price in the fact that the results of my project were a palpable, influencing product that someone might actually put to use. I liked working in a group but there were certain drawbacks to this. If you were unable to communicate nearly continuously with your group members, you could end up wasting a lot of time working on the same task."

"Although I thought it was a great model to have the class divide into teams and each team focus on one project while still following the other teams on their projects, I felt that sometimes I focused too much on my team and didn't find the time to fully understand the concepts involved in the other teams' projects."

"Geodatabase design could be a course in and of itself." "If I were to cut material from the course, I would cut the geodatabase project and depth to which that was discussed. While it is certainly a valuable part of GIS work, and one that there are not enough people with the skills to accomplish, I feel like we would need many more skills than can be learned in a portion of one course to be effective geodatabase designers."

Revised Design

It was obvious from the students' feedbacks that this first-time course needs some revision in its design, and some improvement in its delivery. The instructors are planning to revise the course before it is offered again in the spring of 2009. Major changes include the following:

1. Eliminate the video lectures and focus on demos. The video lectures will be reference materials for the students to study at their own time. The class lecture will be short (20-30 minutes) and focused on addressing project related issues only. It will be followed by hands-on live demo of the tools and procedures needed to carry out the projects. Students may request specific demo topics before each class.
2. At the beginning of the course, the instructors will explain the project objectives more specifically, so that the students can have a clearer goal to guide their work later on. The original design was to let the students learn to scope out their project based on the guest lectures by the project sponsors. It is an essential skill for a GIS consultant type of job, but the students require more clear instructions on what to do and what to achieve. There is a delicate balance to strike between too little vs. too much hand-holding in this type of practical skill courses.
3. Change the scope of the geodatabase project from geodatabase design to geodatabase improvement, including data quality inspection, domain definition, topology rules implementation, geodatabase relationship class creation, and other aspects of geodatabase enhancements, but reduce the responsibility in designing an entire geodatabase from scratch.
4. Reduce the grading weight for the final project paper and redistribute the weight to the weekly project status summary. This will force the students to progress step-by-step on their projects and not to waste too much time on one issue. A weekly written summary on other teams' project presentation, though very lightly weighted, will encourage students to pay more attention to the other projects, thus retaining more knowledge from the other cases. It will also help them complete the final project reviews on the other teams at the end.
5. Specify clearly at the beginning that the weekly project status summaries are to report on their learning process as a student/trainee, and the final project presentation and paper is to deliver their project work as a professional consultant/employee. This separation will allow them to focus on one role at a time, making their papers more concise, shorter, and hopefully easier to write.

Summary

This course provides a chance for students to learn GIS in a totally different way from conventional courses. First of all, the course uses real cases in the classroom. The three case providers were actually expecting students to provide viable solutions. As a result, students had direct interaction with them (as clients) to find out what they needed. During the course, students were exposed to some problems that are common in GIS practice but seldom seen in a classroom, for instance, insufficient and poor quality data. After going through the entire procedure of project planning, GIS analysis and presentation, students are better equipped with skills to solve the real world problems with a set of commonly available GIS tools.

Secondly, the students worked with teammates on each project. This is a brand new experience for those who just finished their introductory GIS course and only used to work on assignments on their own. Teamwork encouraged coordination and communication among team members as well as good project planning. To achieve the best results, students have to find everybody's strength and assign tasks accordingly.

Finally, this course provided students with valuable skills for the job market. Three guest speakers served as mock employers or clients in the classroom. One guest speaker even mentioned that his institution was indeed looking for new staff. The students were asked to provide GIS analysis service in a professional fashion. The GIS tools and applications that they learned from this course are used and proven to be useful in actual problem solving. Some students have planed to publish their project report in professional journals.

Overall, this course proved that bringing operational GIS cases into university classrooms is challenging but doable, and is worth doing. This course filled in a gap between the more theoretical geographic information science courses and the more tool specific "how to do this with this software package" training courses. All three types of education are needed to build a professional workforce, but the operational case-based courses like this one tie the theories and the tools together to equip students with real-world problem solving skills.

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