The Use of Simulations and Visual Feedback in Learning Spatial Design and Analysis Concepts

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Key words: teaching and learning, spatial geometry, design, simulation, web delivery.

ABSTRACT

This paper describes the process and results of the transformation of the curriculum delivery of four different areas of the syllabus of the geomatics programs at the University of Melbourne. In each case the transformation addresses the teaching and learning problems associated with spatial relationships in two or three dimensions by providing a rich resource of theory material, animations of spatial concepts and, most importantly, visualisations or simulations of real world survey problems that provide immediate feedback. The visualisations and simulations allow students to investigate the design and analysis of spatial geometry and spatial relationships at their own pace, using immediate feedback to reinforce their learning. The online material affords an enhancement of the learning experience for undergraduate students, both complementing and providing an alternative to the conventional teaching methods of lectures, tutorials and practice classes.

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1. INTRODUCTION

Measurement science has always been a major component of surveying, spatial information and geomatics courses, and is typically taught across all years of the courses. At the University of Melbourne entry level measurement science contains curriculum material that is a generic introduction to all aspects of geomatics, whilst material presented in later years becomes increasingly specialised in sub-disciplines such as advanced plane surveying, geodesy, the cadastre, GIS and mapping. The majority of subjects are taught as conventional three or six hour per week units, with lectures on principles and mathematical processes, tutorials on calculation practice, and field work on measurement acquisition with surveying instruments.

In common with many geomatics programs at tertiary level, the proportion of the course devoted to measurement science has been shrinking in response to a number of factors. The first of these is pressure on the number of contact hours in engineering and science courses due to the wide perception of “over-teaching”, which leaves little time for students to engage in elective studies and a more general education at university level. The second factor is the proliferation of combined degree courses, that allow students to graduate after five or six years with two degrees that, when taken separately, would require three to five years each. Although there is commonly some overlap of material between closely aligned disciplines, inevitably some geomatics material is removed from the combined degree program due to the pressure of time. The third primary factor is the change in emphasis in geomatics courses, such as the course at University of Melbourne, moving away from the more technical skills associated with measurement science toward higher level design and planning expertise associated with GPS, GIS and land management.

1.1 The Learning Problem

In concert with the contraction of the time available for measurement science material in courses, it is widely accepted that there is a learning problem associated with the spatial relationships embodied in measurement science. Unlike many of areas of tertiary education, measurement science is a relatively sudden acquisition of new knowledge and new practical skills due to unfamiliarity with the basic concepts of surveying and positioning. Whilst students entering classic disciplines such as medicine, law or economics have some understanding of the fundamentals, this is frequently not true of students entering geomatics, surveying or spatial information courses.

At entry level, students need to understand the geometry of and error propagation associated with, for example, surveys for large-scale mapping. At the advanced plane surveying level, students move on to the more demanding learning task of understanding survey network design, computations and analysis in three dimensional space. Typically students then progress to higher concepts of geodesy and GPS based on the ellipsoidal shape of the earth. The required synthesis of new knowledge and new skills, combined with the management and operation of complex survey equipment in the field and the design and operation of field surveys, is often overwhelming for inexperienced students. In this environment the educational objectives can become completely obscured by the overload and the student does not learn the essential concepts of measurement science.

Further, a continuing difficulty with teaching measurement science in tertiary education is maintaining a clear connection between the mathematical processes, the surveying equipment and the field work techniques, whilst accommodating a variety of practical skill abilities and differing cultural backgrounds of students. At the University of Melbourne, the variety of student cohorts, and the associated different levels of mathematical skills, is a significant issue as measurement science is taught as core material to students in the geomatics programs, and as service courses to students in engineering, science and humanities courses. Students with relatively poor preparation in basic mathematics are clearly disadvantaged, and inevitably have much greater difficulty understanding design concepts that are based on principles derived from geometry and statistical theory. Similarly, cultural differences often result in differing aptitudes for field survey work, and students can also be disadvantaged by the intimidation of taking responsibility for and handling expensive equipment such as total stations and GPS receivers.

1.2 A New Pedagogy

A potential solution to the combined problems of providing quality teaching over shorter time frames, and overcoming learning problems associated with poor synthesis of concepts and skills, is a dramatic change to the pedagogy of teaching measurement science. Rather than teach the basic skills (the bottom-up approach) which must be integrated to provide optimal learning outcomes, the teaching method can be changed to the challenge of problem solving (the top-down approach) with the emphasis on deep learning of design and analysis. This new approach has to be supported by a rich resource of online educational material that provides the details of field procedures and theoretical concepts. A problem based approach concentrates on design and analysis in lectures, de-emphasising issues such as the fine detail of instrument handling and field procedures.

This type of problem based approach has proven to be effective in many disciplines, such as medicine (Finucane *et al*, 1998) and economics (Johnston *et al*, 2000. The use of visualisations and simulations for teaching and learning is widespread, and simulated site visits often have a spatial nature, such as uses in architecture (Newton, 1999), mining (Russ and Wetherelt, 1999) and geography (University of Leicester, 2001). Shortis and Cartwright (2000) gives further examples of multimedia education resources with an emphasis on the spatial sciences.

The outcome of this revised approach to the teaching of measurement science should be a change in the students knowledge acquisition from a rote learning attitude to a problem solving approach, based on a more thorough understanding of the concepts of algorithms, techniques and field procedures. This change in pedagogy requires a change in the culture of learning by the students, and delivery by academic staff, and is facilitated through an integrated approach provided by multimedia material that continually emphasises the links between geometry, measurement and instrument handling. The provision of a rich resource of educational material on the basic concepts of measurement science also allows academic staff the possibility of using more of the available teaching time to address individual learning needs of students on the higher level processes of measurement problems.

A vital component of the new pedagogy is demonstration of the spatial relationships and field procedures through simulations and animations, in order to minimise the intimidating effects of complex survey designs and complicated field procedures. When presented with a field measurement problem, the outcome will be that the students will focus on the solution to the problem in terms of techniques, rather than being absorbed by acquiring the physiological skills of measurement processes with surveying instruments. Multimedia delivery of the curriculum material should also facilitate and encourage independent learning by students, which is often discouraged by “stand and deliver” methods. The availability of and encouragement to use online interactive material gives students feedback on their knowledge acquisition outside of formal contact with lecturing and tutorial staff during class times.

A disadvantage of this approach is that students have less time cultivating practical skills and therefore have less general experience with field surveys and handling of instruments. There are a number of arguments to counter this perceived deficiency in the skills of new graduates. Perhaps the most compelling is that no matter how much field practice is included as a component of a geomatics course, new graduates who become field surveyors learn or re-learn many of their skills on the job. The second response is that many graduates of tertiary programs will never practice as field surveyors and typically will move into information systems or project management, so their need for the skills associated with measurement science is at a management level rather than practical level in any case.

2. FOUR MULTIMEDIA DEVELOPMENT PROJECTS

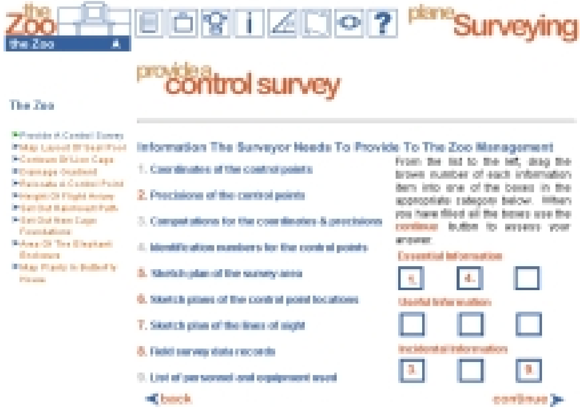
Each of the four projects described in the next sections are based around web sites that have been created to provide simulations or visualisations of spatial problems as a primary function. The spatial concepts are presented either as simulations of real world survey problems or visualisations of spatial relationships. In addition, some of the projects also include an equipment database, detailed simulations of survey equipment and animations of essential field procedures. All projects provide access to theory and practice material, such as lecture notes, tutorial guides and example data sets.

In all cases the theory material and equipment databases are straightforward web pages coded in HTML. The animations have been created by Macromedia Director and stored within the web pages as Shockwave applets. Visualisations are presented as VRML models (Web3D, 2002) or rotating images, viewed using browser plug-ins such as CosmoPlayer (Cosmo Software, 2002) or LivePicture (MGI, 2002). Some of the visualisations and animations of field survey procedures required the use of CAD software to create the models and then generate image sequences that were exported to Director, or converted directly to VRML models. The problem simulations are coded in Java as separate modules and are linked to the web pages, or coded in C++ and loaded as a browser plug-in. The problem simulations are supported by a survey analysis tool that processes simulated or actual field surveys and produces feedback in the form of location results and the precisions of computed locations. The survey analysis tool is based on a survey network adjustment program (Shortis and Seager, 1994) that is provided with correctly formatted data by the problem simulations. The advantage of the survey network adjustment program is that it can process virtually any data set and individually tailored solutions are not required.

In all four cases the multimedia material is or will be tightly integrated into the relevant courses. The web sites are used within lectures and tutorials to illustrate problems and theoretical material. Further, all subjects make use of tutorial and practical assignments, and many assignment tasks are oriented around the problems and visualisations included in the multimedia material. In some cases the students' solutions to the problem simulations are submitted as part of the assignment report.

2.1 Plane Surveying Concepts and Field Procedures

This project aimed to transform the entire conventional delivery of common material on plane surveying into a multimedia based, online curriculum for self paced learning and assessment. Plane surveying is taught to approximately 300 undergraduate students in entry level geomatics courses and service courses. There are eight units with full or part curriculum devoted to plane surveying, taught across five discipline areas, namely geomatics, civil engineering, building, forestry and archaeology. Through a problem-based approach, the principal aim of this project was to allow students to familiarise themselves with plane surveying equipment and field procedures before they attempted surveys in the field.



Information The Surveyor Needs To Provide To The Zoo Management

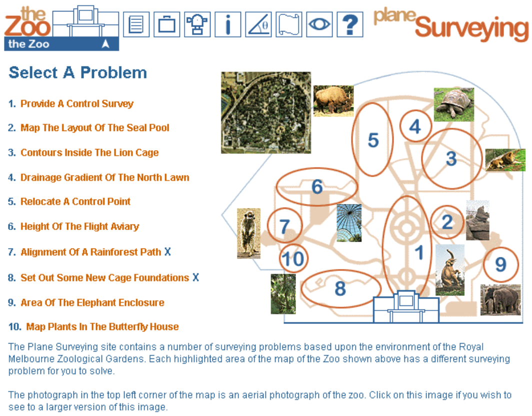
1. Coordinates of the control points
2. Precisions of the control points
3. Computations for the coordinates & precisions
4. Identification numbers for the control points
5. Sketch plan of the survey area
6. Sketch plans of the control point locations
7. Sketch plan of the lines of sight
8. Field survey data records
9. List of personnel and equipment used

From the list to the left, drag the brown number of each information item into one of the boxes in the appropriate category below. When you have filled all the boxes use the continue button to assess your answer.

Essential Information

Useful Information

Incidental Information



Select A Problem

1. Provide A Control Survey
2. Map The Layout Of The Seal Pool
3. Contours Inside The Lion Cage
4. Drainage Gradient Of The North Lawn
5. Relocate A Control Point
6. Height Of The Flight Aviary
7. Alignment Of A Rainforest Path X
8. Set Out Some New Cage Foundations X
9. Area Of The Elephant Enclosure
10. Map Plants In The Butterfly House

The Plane Surveying site contains a number of surveying problems based upon the environment of the Royal Melbourne Zoological Gardens. Each highlighted area of the map of the Zoo shown above has a different surveying problem for you to solve.

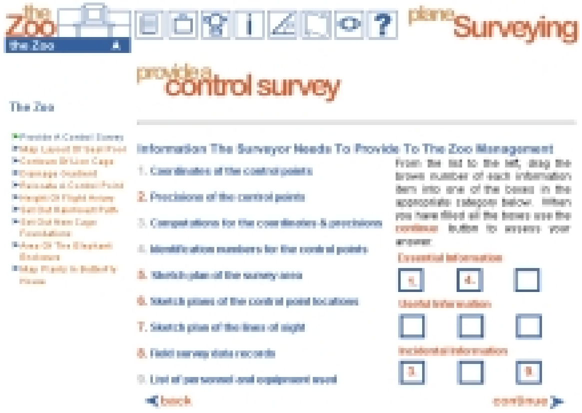
The photograph in the top left corner of the map is an aerial photograph of the zoo. Click on this image if you wish to see to a larger version of this image.

Figure 1. Problem based presentation of material by the web site.

Figure 2. Example explanatory page from a problem brief.

The design of the web site is oriented around the metaphor of survey problems within the Melbourne Zoological Gardens (see Figure 1). The use of the zoo environment was adopted for a number of reasons, but principally because the site was previously being used for field survey work as part of the teaching program for the geomatics courses. In terms of the presentation of the online resource material, a zoo is a familiar environment for the vast majority of students and has the potential to create or adapt a variety of realistic plane surveying problems.

The presentation of problems is in accord with the problem based, top-down approach that encourages students to be aware of the context in which plane surveying work is carried out. Once selected, a particular field survey measurement task is introduced by a problem brief that outlines the environment, circumstance and the problem to be resolved (see Figure 2). The selection of the appropriate survey technique is reinforced by feedback from the students, required as part of the sequence of web pages presenting the problem (see Figure 3). Questions range from simple selections from multiple choices, selections that can have correct, neutral or incorrect returns, and entry of key words that are linked to major and minor issues. All responses to questions are illustrated by text explanations of the correctness or otherwise of the choices. Students are also required to select appropriate survey instruments to use in the field to solve the problem at hand. Again, feedback through text explanations is used to illustrate the correct and incorrect choices.



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8. Field survey data records
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From the list to the left, drag the brown number of each information item into one of the boxes in the appropriate category below. When you have filled all the boxes use the continue button to assess your answer.

Essential Information

| 1. | 4. | ☐ |

Useful Information

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Incidental Information

| 3. | ☐ | 9. |

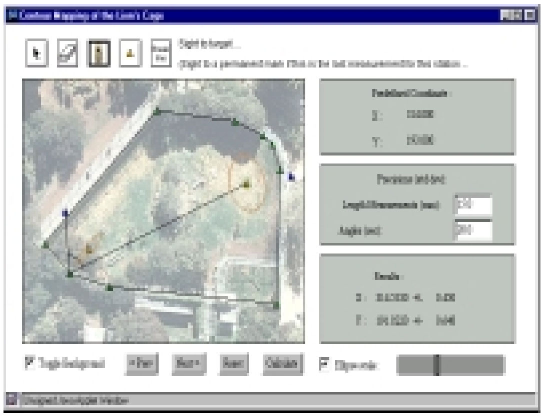


Figure 3. Example feedback page using drag and drop in a problem brief.

Figure 4. Example problem simulation showing feedback from error ellipses.

Once reached, the 2D problem simulation is launched (see Figure 4) and a help page can be opened as a separate browser window to allow a clear explanation of the operation of the simulation. The student is then required to place survey stations and measured positions to solve the problem. Actions by the user are governed by tool selections, which may be survey instruments, survey station placement, measurement deletion or auxiliary information such as break lines in a contour and detail survey. Immediate feedback is provided by the error ellipses, to optimise the design of the survey, and the numerical data, to determine whether the survey is meeting required specifications. The plane surveying site has been used in the geomatics courses and service units since 1999. More detail on this project, including some information on evaluation of the web site, is given in Shortis *et al* (2000).

2.2 Learning Design of Survey Networks

One of the fundamentals of the execution of field surveys is the effective and efficient design of survey networks. This combination of knowledge and design skill underlies much survey work, and is a strategic area of teaching for tertiary courses in surveying and geomatics. An effective method of learning design skills is to expose students to a series of case studies and problems within a realistic environment that provides interactive guidance on the efficiency and effectiveness of the survey network design. Networks can be designed by identifying station locations and measurements within a 3D virtual landscape, and real-time feedback on design outcomes is generated by survey network analysis software. Guidance on the design effectiveness is provided using error ellipsoids that can be used to identify weak areas in the survey network, and reliability and precision data that can be compared to appropriate design specifications. Assessment of efficiency, in terms of time in the field to complete the survey, is currently a manual inspection process that may be automated in the future.

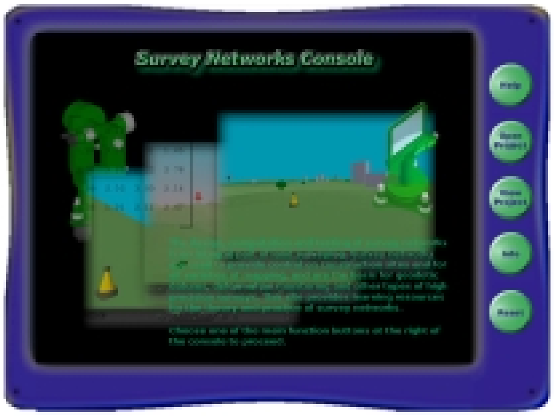


Figure 5. Survey networks console

Figure 6. Intersection tutorial

The web site uses the metaphor of a survey instrument console to provide a familiar "look and feel" and a very consistent and straightforward approach to using the site, based on two levels of navigation buttons (Figure 5). The site includes many interactive animations illustrating theoretical concepts and field survey procedures. Other animations demonstrate the relationship between typical survey measurement geometries and the resultant station location precisions (Figure 6). In all cases the relationships are presented in the context of a real world problem, and the precision information is shown as error ellipsoids. The relative sizes and the shapes of error ellipsoids are a universal mechanism used to evaluate the global uniformity and local strength of survey networks.

The problem oriented approach to the design of survey networks is encapsulated in the concept of survey projects. Again, this is in accord with the nature of survey instrumentation, such as GPS navigators, that tend to categorise data storage in terms of projects. The design of the web site incorporates a survey network simulator and a separate model viewer, indicated by "Open Project" and "View Project" respectively in terms of the console. The latter was included (see Figure 7) to allow students to browse VRML models of survey network case studies using any plug-in viewer so that they could explore the virtual models in "read only" mode from any computer with a network connection.

The OpenProject mode of operation (see Figure 8) is the most important component of the web site and is based on a plug-in developed to allow interaction between the user and the VRML model of the terrain and survey. The TerrainVis plug-in allows the user to:

- Navigate around the VRML model.
- Import and export files of survey station and measurement data.
- Occupy and sight to specific survey stations in the network.
- Add new survey stations and add or delete survey measurements.
- Compute the survey network solution in measurement or simulation modes.
- Display feedback from the survey analysis tool including error messages and error ellipsoids.

Figure 7. Dam surveillance model viewed using CosmoPlayer.

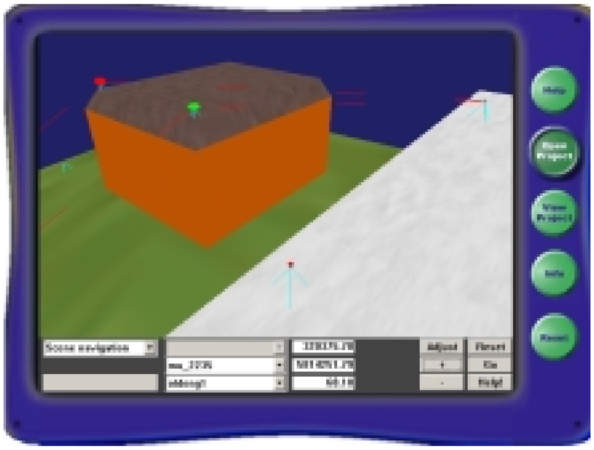


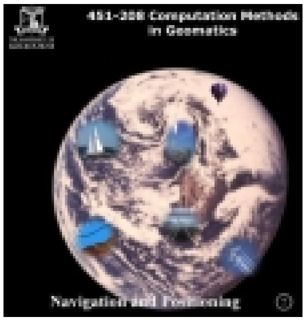
Figure 8. Building model viewed using the TerrainVis plug-in.

As part of the tutorial exercises associated with the course work, students are required to use the simulator to design a building monitoring survey (see Figure 8) and carry out a analysis of a dam deformation survey (see Figure 7). Although the use of the simulator can not and was not intended to replace actual field surveys, it does allow students to practice their design and analysis skills. The survey networks site has been used in the geomatics courses since 2000. More detail on this project, including some information on student use and evaluation of the web site, is given in Shortis and Woodhouse (2001).

2.3 Visualisation of Navigation and Positioning Problems

Students in the geomatics degree programs are required to have a fundamental understanding of navigation and positioning, both on and beneath the Earth's surface. The concepts associated with spatial relationships within a 3D world, and the ability to describe these relationships, are a common thread in the sub-disciplines of surveying, geodesy and mapping. A problem that is frequently encountered when discussing navigation and positioning is the inability of students to visualise the 3D spatial relationships. Conventional diagrams and figures represent these 3D relationships as a series of 2D views which often require a great deal of elaboration in order to explain the representation. The 2D views can often be very complex if the mathematical abstraction and the real world problem are to be shown in context with one another.

One solution to this learning difficulty is to present 3D navigation and positioning problems as 3D simulations that are realistic, layered and animated. Realistic VRML models can present 3D spatial relationships very clearly and the ability to rotate the models is critical, as interpreting the 3D geometry from apparent motion around the object is very often pivotal to students' ability to analyse the spatial relationships between vectors and surfaces. Scenarios can be created for many fundamental spatial relationship problems in surveying, geodesy and mapping. The impact of the visualisation and animation is much more critical for subtle and complex problems, such as the various definitions of 3D vector intersections and the shape characteristics of geodesics on the ellipsoidal Earth.



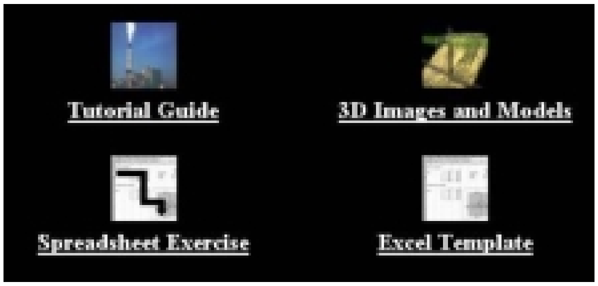


Figure 9. Navigation and positioning site. Figure 10. Components of each scenario.

The web site created for the navigation and positioning project again presents the visualisations in the context of real world scenarios (Figure 9). The six examples included or under development cover vectors in 3D space, vectors and lines, vectors and planes, vector intersections, spherical trigonometry and line intersections on the ellipsoidal Earth. Each scenario contains a tutorial that steps the student through the spatial relationships, a number of 3D models and images that can be viewed using plug-ins, a linked spreadsheet exercise and a spreadsheet template for the exercise (see Figure 10).

Each scenario includes a LivePicture display (Figure 11) for "constrained" investigation of the spatial relationships and a VRML model (Figure 12) for "free" investigation of the spatial relationships. The LivePicture model allows students to rotate the object about one axis to allow an important view aspect to be presented. The VRML of the 3D object allows complete freedom of movement around and within the model. It is easy to get spatially or intellectually "lost" within the 3D model, so in each case pre-defined views are provided to illustrate the most important aspects of the geometry.

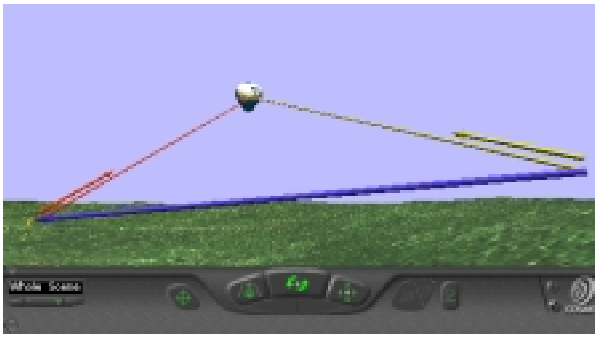


Figure 11. LiveImage model of spherical trigonometry.

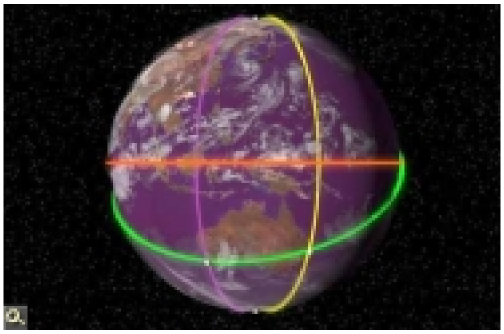


Figure 12. VRML model of vector intersection.

The scenarios are once more strongly integrated into the course work for the undergraduate students, as the tutorial exercises are an assessed component of the course. The web site was used for the first time in 2001 and initial feedback from the students was very positive. In particular the students found that the flexible access to the tutorials and models very useful in understanding the spatial relationships.

2.4 Integrated Systems in Geomatics

The newest multimedia project, under development in 2001/2002, is focussed on preparation of students to use GPS technology in the field and to provide students with virtual experience of the measurement processes and technology of integrated systems. Students will be able to visualise the limitations and capabilities of different data acquisition techniques and the different methodologies that can be combined into feasible solutions for contemporary measurement problems. Integration will be demonstrated using case studies and will be pivotal to the understanding of design and analysis of positioning and navigation systems.

A further rationale for this project is the unavoidable limitations on access by students to state of the art equipment. Tertiary education institutions inevitably have restrictions on the resources that can be made available to teaching programs, and the provision of a broad range of current field survey equipment is simply not feasible. It is often the case that a small number of geodetic class GPS receivers, for example, must be shared amongst a large number of students. Virtual access to equipment is not a replacement for actual experience, however virtual access is better than no access, and a simulated GPS receiver does allow students to have some preparation and familiarity with field equipment and therefore make efficient use of the equipment when it is available. Use of virtual equipment becomes an essential enhancement of the student learning process to facilitate very effective access to state of the art equipment.

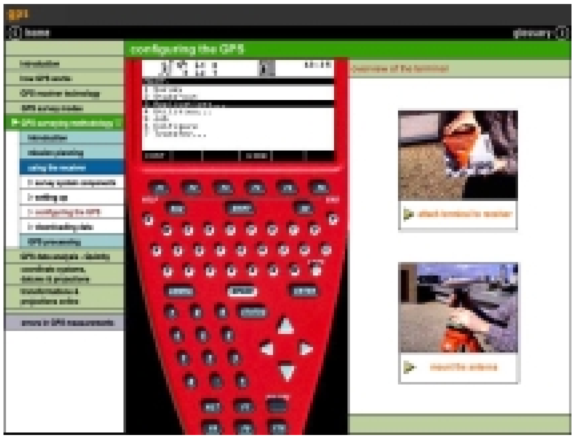


Figure 13. Presentation of case studies.

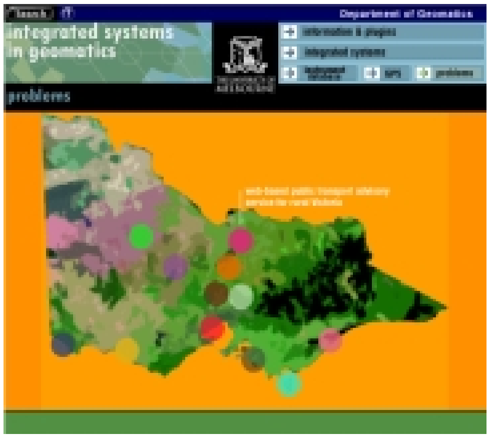


Figure 14. Simulated GPS receiver.

The main components of the web site are:

- A series of local case studies that illustrate the range of measurement solutions provided by integration of technologies such as GPS, GIS, remote sensing and conventional surveying (see Figure 13).
- A comprehensive and detailed tutorial on GPS technology, including animations of GPS survey methodologies and a simulated geodetic GPS receiver (Figure 14).
- A Java utility for the conversion and transformation of geodetic coordinates and datums.
- Links to other resources such as GPS mission planning, reduction and analysis software.

The case studies are used as an assessed component of coursework and are presented as a tender situation in which student teams present a proposed solution to the client. The student response to the tender indicates the team skills and integrated systems approach to accomplishing the task, including project management and costings. Whilst components of the web site were used in 2001, the first comprehensive use of the web site will occur in semester 2, 2002.

3. CONCLUSIONS

In summary, the multimedia projects described in this paper provide rich resources of information and visualisation or simulation of spatial concepts, measurement fundamentals, survey instruments and field processes. The presentation of comprehensive simulations of the field work processes, including instrument handling, prior to the students taking equipment into the field, leads to more efficient use of equipment. Efficient operation in the field enables students to concentrate on the correct implementation of measurement processes, rather than contending with the lack of essential skills in equipment use. The multimedia material reiterates and augments the spatial concepts presented in formal lectures, utilising the dual mechanisms of presenting simulations in lectures and self-paced review by students.

Feedback and evaluation from students has in general been positive and encourages expansion of the current projects and further development in other areas of measurement science. However, as stated at the outset, the online material is an enhancement of the learning experience for undergraduate students, both complementing and providing an alternative to the conventional teaching methods of lectures, tutorials and practice classes. There is no doubt that the experiential learning and regular contact with staff and other students embodied in a campus-based tertiary education is an essential component of the development of students toward their careers in geomatics, surveying and spatial information.

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BIOGRAPHICAL NOTES

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