Evolving Technical Graphics in the High Schools: A New Curriculum in Scientific Visualization

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ABSTRACT

A new curriculum, Scientific Visualization, is being taught by high school technical graphics and science teachers for the first time in the Fall of 1997. This curriculum reflects a broadening application of computer graphics techniques in the workplace and represents a rich area for technical graphics teachers at all levels of education to be involved in. The goal of the two-course sequence at the high school level is to give students expertise in manipulating both geometry and the visual characteristics of geometry, such as color and texture. These visual elements are used to construct 2-D and 3-D graphic images which support the understanding of scientific and technical principles. These courses are meant to complement rather than replace more mainstream technical graphics courses in architectural and mechanical graphics. The proposed student populations taking the scientific visualization courses are not only the traditional vocational track students, but also pre-college students planning on studying in scientific, engineering, and technical fields. Work is underway developing an extensive set of support materials and sample problems for use in the newly developed curriculum. Implications for teaching technical graphics in higher education will be discussed in this paper, as well as the impact this type of curriculum may have on colleges and universities with future students having gone through this type of course and training.

Introduction

For the past year, a group of educators from NC State University, Wake Technical Community College, the State Dept. of Public Instruction of North Carolina, and numerous high school teachers throughout the state have met to develop a new two-course curriculum in Scientific Visualization. The main goal for this curriculum is to expand the teaching of technical graphics to a new audience: science and pre-engineering students. This new curriculum was taught by high school technical graphics and science teachers for the first time in the Fall of 1997. This curriculum reflects a broadening application of computer graphics techniques in the workplace and represents a rich area for technical graphics teachers at all levels of education to be involved in. The curriculum is designed to articulate into scientific visualization and technical graphics curriculums at both 2-year and 4-year colleges and universities. These courses are meant to complement rather than replace more mainstream technical graphics courses in architectural and mechanical graphics. The proposed student populations taking the scientific visualization courses are not only the traditional vocational track students, but also pre-college students planning on studying in scientific, engineering, and technical fields.

A course in scientific visualization has been taught by the first author at North Carolina State University since 1990 (Wiebe, 1992). This course, intended for college students in any year and from any degree path, was developed as an exploratory course to examine alternative methods of developing visualization and technical graphics skills in a wider audience of students than are traditionally taught in engineering graphics courses. What was soon realized was that material could be developed to be taught at a number of different educational levels. At the high end, graduate students could use scientific visualization techniques to explore data analysis techniques in their discipline-specific areas. Of more interest was moving the scientific visualization curriculum down to the secondary school level. Momentum for a high school-level scientific visualization curriculum developed out of a revision of the complete high school technical graphics curriculum developed by the same team now working on the scientific visualization curriculum (Clark, Wiebe & Shown, 1996). It became clear that a scientific visualization track could both address criticisms of the technical graphics curriculum as it was currently structured and attract a new group of students to technical graphics.

The old technical graphics curriculum in the NC high schools suffers from many of the same attacks which have been leveled at college and university technical graphics courses. Criticisms of technical graphics tend to center around one central theme: relevance. A common argument used is the relevance of teaching students manual drafting techniques. Even after the move of many programs to 2-D computer-aided drafting (CAD), there is still the question raised of the relevance of teaching a highly specialized graphics language (whether it be mechanical or architectural) to a broad population of students. Though many in the technical graphics field argue the general benefits of traditional engineering graphics as a means of developing spatial visualization skills (e.g., Bertoline & Miller, 1989; Devon, Engel, Foster, Sathianathan & Turner, 1994; Leach & Matthews, 1992; Miller, 1990; Rodriguez, 1992; Sorby & Baartmans, 1994; Zsombor-Murray, 1990), most look to our field as a source of applicable skills. At the university level, departments such as electrical and computer engineering no longer see the need to require students to take a course largely based on mechanical examples. Similarly, at the high school level, there is pressure to show relevance of drafting and other vocational skills to more mainstream academic tracks. Pre-engineering tracks have seen tremendous growth in North Carolina, but the pressure is on the technical graphics curriculum to show its relevance to a broad array of college bound students planning on majoring in science, engineering, and other technical fields.

The revision of the technical graphics curriculum at the high school level integrates both 2-D CAD and 3-D modeling with more traditional drafting techniques. At the same time it leaves in place the more traditional architectural and mechanical course sequences. A separate scientific visualization track creates a well placed complement to these other tracks. Like the other tracks, the scientific visualization track introduces and reinforces a foundation of basic spatial visualization skills and the use of computers for the creation of both 2-D graphics and 3-D models. At the same time, it applies these visualization and computer skills in areas relevant to a broad population of science and technical oriented students. Instead of focusing on the graphical representation of tangible objects — whether they be mechanical or architectural — the emphasis is on graphics to support conceptual and theoretical ideas. In particular, how can graphics be used to help understand the concepts being taught in high school biology, chemistry, physics, and earth science courses. These courses are critical foundation courses for future scientists and engineers alike.

Foundations of Scientific Visualization

First and foremost, scientific visualization is a graphic language. Though text is often used as part of the visualization, it should play a secondary role of elaborating or clarifying graphic elements. As a graphic language, a theoretical foundation needs to be laid as to how and when graphic elements should be used to convey the intended message. In the case of the types of visualizations we are concerned with here, the graphics needs to support theoretical and conceptual problem solving in the scientific and technical fields. In addition, these visualizations can be used as a means of communicating these ideas to both audiences of experts and lay people. Lastly, it should be emphasized that this goal for graphic communication is largely a superset of traditional engineering graphics. Though the audience for the graphics are typically more narrowly defined, engineering graphics uses a system of projections and graphic symbols to precisely convey information that otherwise would have to be represented as numbers or words.

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The design of a scientific visualization is driven by the encoding of scientific and technical information as a graphic. At the highest level, a visualization can be considered a collection of 'marks' (Senay & Ignatius, 1990). A mark is a primitive element of a visualization which can be described through its attributes. The primary attributes a mark can have are:

- Form
- Surface characteristics
- Spatial relationships
- Temporal qualities

Form describes the mark's dimensionality such as whether it is a line, a two dimensional polygon, or a three dimensional solid. Each of these categories can be further broken down further using the same taxonomies employed in traditional technical graphics.

Surface characteristics is a broad term that covers color, texture, pattern, and line thickness and symbol. Some of these characteristics are tied to the dimensionality of the mark; for example, texture only really has meaning in representing the third dimension. Similarly, line thickness is typically associated with one dimensional lines (though, it in fact, it represents the second dimension of the line).

Spatial relationships can refer to both the relative relationship of one mark to another or the absolute relationship of a mark to an accepted reference frame (e.g., the scales of a graph). Though all marks can have location in space, whether orientation can be used is tied to the symmetry of the mark. Again, the dimensionality of the mark and the space in which it is displayed will determine how the spatial relationship is expressed.

Temporal qualities is a special, but important, class of characteristics referring to how a mark is represented in time. For example, a changing mark can be shown serially as a series of frames in an animation, as a series of images in parallel, or as a vector in a single frame.

The definition of a graphic in these terms allows the creator to use perceptual theory to gauge the effectiveness, not typically of one mark, but of a collection of marks which make up the visualization (Cleveland, 1985; Kosslyn, 1989; Wiebe, 1994). Thankfully, the graphician does not have to have an extensive background in experimental psychology to create a successful visualization. In most instances, 'rules of thumb' representing good design practice can be applied to create these graphics (Kosslyn, 1994; Senay & Ignatius, 1990; Tufte, 1983). It is important for students to appreciate, at some level, the psychological basis of these rules. Again, though the language of engineering and technical graphics is rarely expressed in these terms, the principles underlying the creation of these graphics rests on the same foundation; line weight and style represent surface characteristics, arrangement of views and projection of surfaces represents spatial relationships, and form is used code the symbols used in geometric dimensioning and tolerancing. In both scientific visualization and traditional technical graphics, 'common practice' is applied where there is no clear choice of characteristics or where the application of the rules do not lead to the most unambiguous representation.

Application of Scientific Visualization

In the creation of a visualization, the initial design is typically driven by classification of the graphic along two factors. First, is the visualization going to be concept-driven or data-driven. A concept-driven visualization is typically generated from the development of a concept or theory devoid of any empirical data. It does not mean that there doesn't exist any data that either supports or refutes the theory, but this particular exploration does not require one. For example, if the goal is to represent the development of a volcano over time or the affects of harmonics on a suspension system on a car, it may be more effective to use diagrammatic techniques to represent the phenomena than to graph data values. For this type of visualization, the marks often have symbolic (semantic) meaning which is either assumed to be generally understood or are explained through text. A data-driven visualization uses empirically or mathematically derived data values to formulate the visualization. In this case, a specific relationship between data values and the characteristics of the marks is defined so that a characteristic varies in some predetermined fashion. In both types of visualizations, additional graphic elements can be used to support the interpretation of the primary marks.

The second factor initially considered is typically whether the visualization is going to be represented in two or three dimensions. Evaluation of both the information to be presented and the capabilities of the computer hardware and software being employed become factors in deciding on the dimensionality of the visualization. If the visualization is going to represent time as one of its variables, then a decision also has to be made as to whether time is going to be represented as a geometric dimension (e.g., an axis on a graph) or through another means such as animation. Since both concept-driven and data-driven visualizations can be represented in either two or three dimensions, a matrix of four possible visualization types is derived. Though it is somewhat arbitrary, the four visualization types: 2-D concept-driven, 3-D concept-driven, 2-D data-driven, and 3-D data-driven can be used to as means of classifying assignments and examples in the scientific visualization course.

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Concept-driven visualizations use diagrammatic techniques which are somewhat problematic to classify. When describing the classification or flow of information, traditional charting techniques such as hierarchical charts or flow charts can be used. When representing complex biological or ecological processes, graphic elements can represent simplified or symbolic versions of components of the original system. For example, a virus invading a healthy cell might be represented by a collection of geometric primitives whose shape and color represented the major components of the cell and virus. Often a decision has to be made concerning the realism of the representation; weighing direct visual connection with the real object and the clarity and simplicity of a more abstract representation.

Data driven visualizations, by their very nature, are more easily classified. The type of visualization and the mark characteristics used to map to the data can be chosen using a taxonomy of data characteristics (Bertoline, Wiebe, Miller & Nasman, 1995). First, since data is derived from empirical work or mathematical expressions, independent and dependent variables can be identified. However the data is being derived, the experiment or formula can be thought of as a 'system' which has both inputs and outputs. The independent variable(s) is/are manipulated by the researcher/engineer/technician and 'input' into the system while the dependent variable(s) is/are the observed 'output' results. The variables — both independent and dependent — can, in turn, be further described as being either qualitative or quantitative, with quantitative data being further classified as being either absolute, ratio, or relative values.

The new scientific visualization curriculum brings a new type of student to the classroom...

Typically, the number of independent and dependent variables will determine the types of visualizations appropriate for use and the number of spatial dimensions needed to represent it. The quality of variables (i.e., qualitative, quantitative, etc.) will then further refine the choices. For example, with one independent and one dependent variable, a scatter plot, a line graph, or a bar graph might all be suitable. If, however, the independent variable is qualitative, the bar graph is probably most suitable, while the line graph is best suited for quantitative data which represents a continuous function, and the scatter plot for discrete quantitative data.

What has been outlined in this section and in the previous one represents only a coarse outline of the theoretical underpinnings of the scientific visualization curriculum. It is important to outline at least this much to make the following points: 1) It is possible to guide the use of graphic techniques through the coherent application of scientific principles, 2) it is possible to have a theoretically sound application of graphics which still functions very well in an operational setting, and 3) it represents a wonderful example of the application of graphics which serves the scientific and technical communities while at the same time is built upon concepts developed by both scientists and graphicians. Bertoline (1993), Bertoline & Miller (1989), and others have advocated the development of a graphic science. This scientific visualization curriculum demonstrates one example of how graphic science can be the foundation of a curriculum. It also adds to the foundation of other technical graphics courses taught at both the high school and college level.

Impact on Future Graphics Curriculums

A curriculum of this type will directly influence the type of student taking a graphics class at the secondary level, as well as the background of students going into a college program requiring visualization skills. With a scientific visualization curriculum, secondary education graphics teachers will have students wanting to understand visual science theories and apply these visual techniques to more than just mechanical or architectural areas. In North Carolina high schools, technical graphics has mainly been offered to students wishing to study a vocational drafting curriculum that emphasizes either mechanical or architectural areas. The new scientific visualization curriculum brings a new type of student to the classroom; students wanting to apply visual techniques to areas of interest beyond these traditional areas and into academic areas that include math, science, chemistry, physics, and biology. This new curriculum allows these nontraditional vocational students to see how visual science can be applied to other career focus areas. Although the basics of visualization are the same no matter what career focus a student may have, students going through the scientific visualization curriculum have a broader experience using their visual skills in nontraditional ways.

As the curriculum is implemented in secondary school systems, educators at the post-secondary level will be influenced by this new curriculum. The backgrounds of students that have had a engineering graphics course at the secondary level will most likely stay the same, but more students will have had a scientific visualization course where students have developed their visualization skills using scientific data. These students will not have studied conventional standards and practices used in engineering areas, but will have more diverse skills in using graphics to illustrate information that is both technical and nontechnical. Although these students do not have a traditional engineering graphics background, the training they received in the scientific visualization curriculum will allow them to easily understand the application of using graphics to engineering related professions. It is the hope of the writers of this curriculum that more students will become involved in the understanding and use of graphics for all professions, as well as provide better trained students for further studies at the post-secondary level.

Scientific Visualization Curriculum Outline

The curriculum team for this project consisted of teachers and administrators from both secondary and post-secondary education. These professionals came from the disciplines of technical graphics, biology, physics, science, technology, community college instructors of scientific visualization, State Department of Public Instruction, and representatives from the university system.

... students going through the scientific visualization curriculum have a broader experience using their visual skills in nontraditional ways.

Each member contributed to the curriculum representing their expertise in a major field of study directly related to the scientific visualization curriculum. Although this project was an integrated approach to curriculum development, over half of the participants were teaching or had taught technical graphics.

After one year of development, a first year course in scientific visualization was produced and distributed to graphic teachers across the state (North Carolina, 1997). The curriculum team decided to have five major competencies for this new curriculum. The first competency, mandated by the North Carolina State Department of Public Instruction, centers around leadership development. This competency is designed to give students basic leadership skills, as well as develop a career plan that includes the information taught within this curriculum. The second major competency developed for the curriculum is designed to teach students the basics of problem solving using design concepts through the process of involving visual science theory. Total Quality Management tools are included within this competency to aid the students in finding solutions to problems and develop consensus building measures. While students are working on problem solving and critical thinking skills, competency three

1. Leadership Development:
    - Basic techniques for parliamentary procedure
    - Steps for processing a motion/vote
    - Establish goals
    - Identification of career goals
2. Apply Problem Solving and Design Concepts:
    - Explain the concepts and principles of problem solving and design
    - Apply problem solving and design methodology
3. Basic Computer Knowledge and Concepts:
    - Identify and explain basic computer terms and concepts
    - Advantages and disadvantages for using computers in scientific visualization
    - Apply concepts and principles of computer file management
4. Visualization Principles:
    - Identify and explain the application of description systems for space and time
    - Explain the fundamental concepts of shape description
    - Identify and explain visual properties of objects
    - Describe visual methods for representing data-driven visualizations
    - Describe visual methods for representing concept-driven visualizations
5. Apply 2-D and 3-D Visualization Techniques:
    - Design and evaluate a simple visualization
    - Produce computer-based concept visualization projects

Table 1 *- Scientific and Technical Visualization I curriculum outline.*

teaches the students how to use the computer as a tool for visualizing scientific data and information. The fourth and fifth competencies are the most demanding from the student. These competencies require students to learn different visualization principles needed for analyzing information and apply this knowledge towards a scientific problem using a computer. Eighty percent of the course is conducted around these two competencies. Major focus areas for competencies four and five include the following: coordinate systems, spatial relationships, time representation, geometric shapes, terminology, orthographic projection, pictorial projection, shape properties, color, qualitative and quantitative data, dependent and independent variables, scales, and technical presentation skills. Listed in *Table 1* are the major components and concepts for this curriculum.

Training Needs for Secondary Teachers

One part of the grant received for developing the scientific visualization curriculum included funding for training educators to teach this new curriculum area. The Graphic Communications program at North Carolina State University was awarded this funding to provide a one week workshop each summer for two years beginning in 1997. The workshops were designed for teachers that have been involved with the project the previous year, as well as for new schools to become involved with the project. Each school was asked to send two representatives, one from a vocational drafting program and the other from a science related area.

Each workshop was 20 hours in length, with the advanced workshop emphasizing problems to be used with students for the curriculum, and the introductory workshop to begin the basic development of what the new curriculum entails. Both workshops used the Internet as its primary resource of information and the teachers were taught how to access this information and use it during the new school year. Each participating teacher received 1.5 continuing education credits in technology which could be used for teaching certificate renewal. Teachers in the introductory workshop received a small grant to begin their implementation of the new scientific visualization curriculum into their school's course offerings. Teachers in the advanced course received funding and training during the past academic year and began piloting the new course the fall of 1997. Both the advanced and beginning teachers also received software training during the 1997-1998 school year.

Example Problems

During the summer workshops for teachers involved with this project, scientific problems were developed for the teachers to use in the classroom. These problems were in areas related to design, technology, biology, physics, chemistry, and earth science. These scientific visualization problems with example solutions were placed on a website that was accessed during the workshop and by the teachers during the school year with their students (Wiebe & Clark, 1997). Each problem begins with an introductory statement explaining the background information needed for starting the problem and the data or information needed to find solutions to the problem. References were indicated for each problem, as well as a comprehensive listing of websites that students can use to find the needed information or background to begin work towards the solution. Downloadable files were included in some problems for additional aid in working the problem. These files included .jpg still images, .avi animation files, and .gif screen captures that demonstrate what the problems entails or can be used in working the problem to completion. Each problem required the students to use research, visualization, and computer graphic skills. Some problems required the use of a graphing software package, others needed a modeling package. Most problems can be enhanced through the use of advanced modeling strategies and incorporating animation into the final visual solution. Listed below are some example problems used during the workshop:

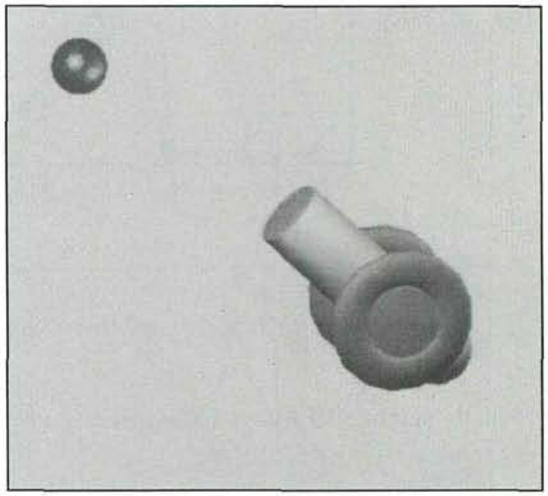

***Figure 1** - Physics problem example.*

Physics Problem Example

(*Figure 1*):(Wiebe, 1997b)

Though many areas of physics lend themselves to visualization, Newtonian physics stands out as an excellent example of how 3-D and 2-D visualizations can help support learning about physical principles. Formulas representing the principles of Newtonian mechanics often use coordinate space values both as independent and dependent variables. These values can not only be represented in traditional graphs, but also as symbolic models. In this problem, we will take the example of a cannonball being shot from a cannon and model it in a 3-D modeling package, TrueSpace™.

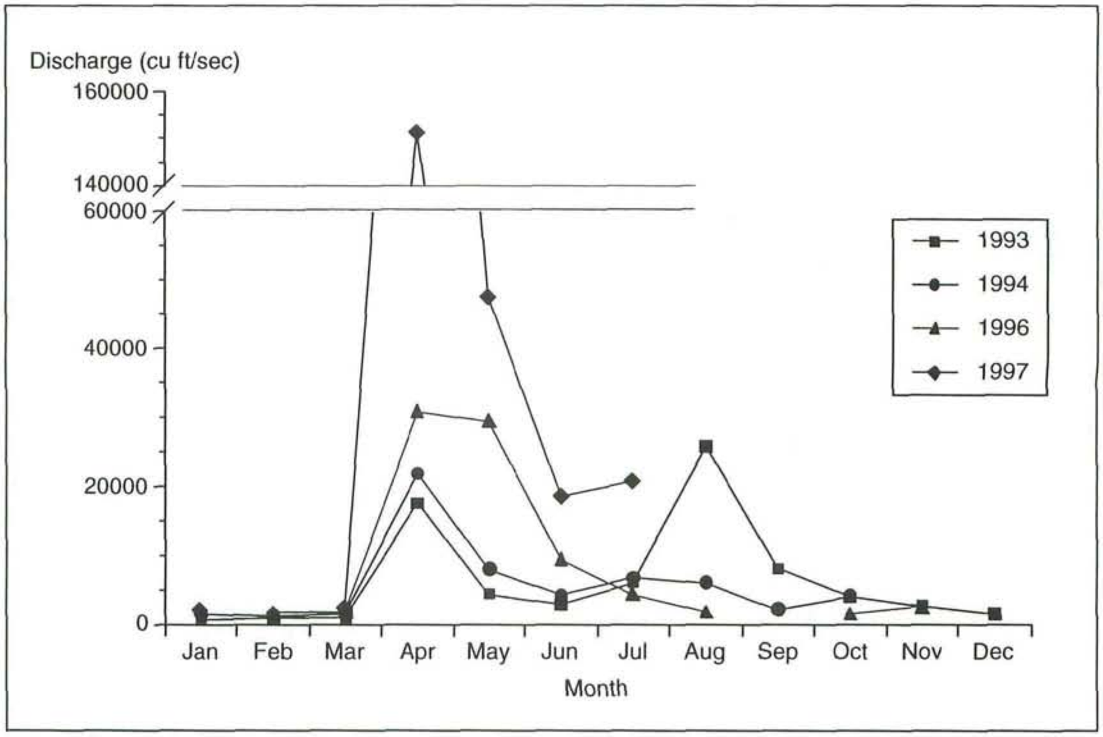

***Figure 2** - Earth science problem example.*

Earth Science Problem Example
(*Figure 2*): (Wiebe, 1997a)

Numerous elements of weather systems can interact to cause catastrophic events. One example of this is the flooding in the Red River Valley this past spring. What were the factors that converged which help cause this particular event? Allen Voelker, a meteorologist with the National Weather Service, put together a short essay entitled, Anatomy of a Red River Spring Flood. In explaining why the Red River flooded this spring, but not in 1994, Voelker points to temperatures in the early spring as a key factor. In this exercise, we will graph data on: temperature, precipitation, river height, and river volume (discharge). The raw data was collected from web sites listed on the resource page, imported into an Excel™ spreadsheet, cleaned up, and then imported into DeltaGraph™.

Biology Problem Example
(*Figure 3*): (Clark, 1997)

In 1892, a Russian biologist by the name of Dimitri Ivanowsky made a revolutionary discovery. After years of research and experiments on tobacco plants infected with the tobacco mosaic disease, he transmitted the disease to healthy plants by rubbing them with juice extracted from the infected plants. In 1935, a scientist by the name of W. M. Stanley found that viruses are very different than bacteria, in that viruses have a noncellular organization. As research continued, information about the structure of viruses became known and that parts of any virus included a chromosome-like part, surrounded by a protein coat, and all viruses have a capsid, DNA or RNA (inside the head of the virus), and a tail (or tail fiber). Each virus type has a different known shape or structure that allows it to be recognized, as well as a life cycle for which it can reproduce (Mader, 1993).

Since viruses can only be seen by powerful microscopes, this scientific visualization modeling problem is to acquaint students in recognizing the various shapes and life cycles of viruses through the process of making both a simple physical model and a virtual model of a virus type on the computer. The physical model will be used to demonstrate the major parts of a virus and the computer model will be used to actually model all components of the virus. Animation can later be used to show movement of the virus through its life cycle. Scientists often make these types of models to study possible viral structures, and model ways viruses may bind to host cells. Modeling materials and Truespace will be the primary resources needed for completing this problem.

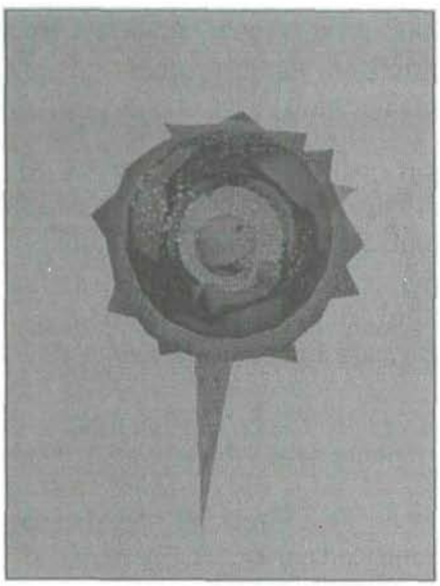

***Figure 3** - Biology problem example.*

Software and hardware requirements

The original scientific visualization course (Wiebe, 1992) was taught on what was then (circa 1990) a typical desktop configuration: a Macintosh II (equivalent to a 16Mhz 386), 4-8Mb of RAM, and a 50Mb hard disk. The latest workshop for high school teachers (circa 1997) used a comparable computer configuration: a 200Mhz Pentium-based PC, 32Mb of RAM, and a 2Gb hard drive. In fact, this was more than enough computer power and disk space for everything except rendering three dimensional models (for which there is never enough computational power).

Both the original and current scientific visualization courses used the same general categories of software tools:

- Spreadsheet
- General 2-D object-oriented graphics software
- Charting software
- 3-D modeling/rendering/animation software
- Web browser
- Presentation software

As taught in the most recent workshop, Microsoft Office was used to provide the spreadsheet (Excel) and the presentation software (Powerpoint). A general 2-D object-oriented graphics package was not used in the most recent workshop, but it was recommended for a year-long course to have on hand a package such as CorelDraw or ClarisDraw. The charting software used DeltaGraph while the 3-D modeling package was TrueSpace. There are a number of alternatives to both of these software packages where cost and a steeper learning curve is balanced against functionality. DeltaGraph represents the high end of graphing software but provides a wealth of standard graph types and tremendous control over the representation of visual elements in the graph. TrueSpace sacrifices some capabilities compared to say, 3DStudio, in exchange for a more affordable price and ease of use. Finally, a web browser is very useful if the computers are connected to a network. The World Wide Web (WWW) is a tremendous resource for both background information and raw data in every major area of science. In addition, a web browser along with a web publishing package/utility can be used for presentations instead of another presentation software package.

Ideally, the course should be taught in a lab networked to both a file server and to the Internet and equipped with peripherals such as a scanner, video capture card, VCR, digital camera, and computer projector. These additions provide sources for the import of raw data and graphic elements for use in the visualizations, distribution of the information, and presentation of the results. In addition, to these peripherals, a typical workstation within the lab would cost about $2500 with approximately $1000 of software (1997 dollars). Though this represents a well equipped and somewhat costly lab, a lab used for teaching CAD or other technical graphics is likely to already have the necessary computer hardware and some of the peripherals.

The Next Stage: Scientific and Technical Visualization II

During the 1997-1998 academic school year, teachers that developed the introductory curriculum over the past year began piloting classes in their schools. These teachers continued coming together during this year to talk about and perfect this introductory curriculum, as well as write a second year course titled Scientific and Technical Visualization II.

This second year course will mainly center on 3-D graphics and image processing. Since it is a second level vocational course, the curriculum will deal with more applications than cognitive knowledge-based learning. The end result for the project is to have a curriculum were students understand and apply their visualization skills in scientific related fields. It is the goal of the curriculum that upon completion of both classes, students may want to pursue a career using these skills in a science related profession, or relate these visual skills to other professions while enhancing their capabilities at using graphics as a career related function.

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