Scientific Visualization for Secondary and Post-Secondary Education

Introduction

North Carolina State University's Department of Math, Science, and Technology Education; along with Wake Technical Community College's Engineering Technology Division; and North Carolina's Department of Public Instruction (Vocational Education Division), sought ways in which to build a strong secondary program in Scientific and Technical Visualization, focusing on the use of sophisticated graphics tools to study mathematics and sciences. Momentum for this high school-level scientific visualization curriculum developed out of a revision of the complete high school technical graphics curriculum used throughout the state (NC Public Schools, 1997). It became clear that a scientific visualization track could both broaden the scope of the current technical graphics curriculum and attract a new group of students to technical graphics.

For the past four years, educators from North Carolina have met to develop and improve a new sequence of courses in Scientific and Technical Visualization. The main goal of these courses is to teach technical graphics to a new audience: science, technology, technical, and pre-engineering students. The courses are designed to reflect a broader application of computer graphics techniques in the workplace and represents a rich area in which technical graphics teachers at all levels of education can be involved. These new courses complement, rather than replace, more mainstream technical graphics courses in architectural and mechanical drafting currently being taught.

While contemporary high school drafting (technical graphics), technology education, and college programs now use sophisticated graphic tools to create two-dimensional (2-D) and three-dimensional (3-D) wire-frame and solid models, their focus has remained narrow. It is now apparent that changes primarily brought about by advances in technology have created new opportunities to use similar tools to promote and enhance the study of the physical, biological, and mathematical sciences.

These new courses are designed to articulate into scientific visualization and technical graphics curriculums at both two-year and four-year colleges and universities through the Tech-Prep initiative. Articulation between schools allows for a broader range of students to have a visual science course count for admission into a college or university. The courses have the potential to replace the fundamental drafting course required for most degrees in engineering and technology.

The proposed student populations taking the scientific visualization courses are traditional vocational track students, and pre-college students who plan on studying in scientific, engineering, and technical fields. The graphic tools used in these courses can help students to understand abstract and numerical concepts and understand how these graphic tools are used in the sciences, business and industry, finance, and virtually all major areas of our economy.

Background

Technical graphics have long been recognized as a powerful communications tool by professional engineers, scientists, mathematicians, statisticians, and other technical professionals. Use of technical graphics to convey scientific and technical data and concepts have a long tradition in print media. William Playfair, working in the 18th century, is often recognized as being one of the earliest practitioners of using graphics to communicate technical data to the public at large (Tufte, 1983). More recently, theorists in the 1970's and 1980's began work on a modern basis for technical communication with graphics (Bertin, 1983; Cleveland, 1985; Tufte, 1983). This work, using graphic design, rhetoric, and psychological theory as its basis, attempted to try and understand the appropriate match of information to be conveyed, graphic technique, and audience to be served.

Through most of this period, scientific and technical data continued to be produced using largely manual methods by professional graphicians. During the 1980's, improved printing and computer technology combined with demands from the public increased the use of technical graphics in textbooks and newspapers. The success of the national newspaper, USA Today is subscribed partly to its revolutionary use of full-color artwork and extensive use of informational charts and graphs (Brock, 1998). Though now being widely viewed by the public, these graphics were still being produced largely by trained professionals.

The 1980's also brought into use by scientific and technical professionals the color graphics workstation. In combination with custom-written programs, graphics workstations were used to produce graphic visualizations of the masses of data being produced by a new generation of supercomputers (Friedhoff & Benzon, 1989; McCormick, Defanti & Brown, 1987). During this period of the late 1980's and early 1990's, individuals began to bring together the technical communication theories of effective graphic communication with the new flexibility and power which computers brought to professionals (Keller & Keller, 1993; Patrikalakis, 1991; Senay & Ignatius, 1990). Still, the audience for these computer-based scientific visualizations was for professional researchers who could hire staff to program and produce these visualizations on high-end computer technology. In parallel with the development of supercomputing graphics, the desktop publishing revolution brought, for the first time, computer graphics tools to the general public. Now the types of tools being used to create graphics for the newspapers could also be purchased by the average computer user. New books became available to help guide scientists, engineers, and technicians in creating their own visualizations without the use of specially trained staff (Kosslyn, 1994; Tufte, 1990). In addition to general purpose graphing tools, off the shelf scientific visualization tools became more generally available, taking the place of custom-programmed tools researchers were using to create more specialized visualizations.

The mid-1990's saw the greatly increased demand for 3D modeling tools meet with affordable desktop computers capable of running this class of software. Now, both 2D and 3D graphics tools were available to a general public. During this time period, professionals in fields related to graphics have also seen an increased demand for technological and computer competencies among both teachers and their students (Technology Assessment Project, 1999). This is coupled with an understanding of the important role that hands-on activities can play in the math, science, and technology classrooms (Luna, 1998).

Transformation to Scientific Visualization

In the 1990's technical and engineering graphics courses in secondary and post-secondary institutions across the country began facing criticism concerning their content. Even after the move to 2-D/3-D computer-aided drafting (CAD), many still questioned whether it is relevant to teach a highly specialized mechanical or architectural graphics language to a broad population of students (Raudebaugh, 1996). In this context, many professionals and researchers in graphics began to explore the role graphics played in a larger instructional and work context.

During the 1980's and 1990's, engineering classes at the post-secondary level began a resurgence of interest in the importance visualization plays in success both in the classroom and in professional life. It has come to be recognized that the creation and manipulation of both traditional and computer-generated graphics can improve visual communications in engineering related professions (e.g., Bertoline & Miller, 1989; Rodriguez, 1992; Sorby & Baartmans, 1994; Zsombor-Murray, 1990). Though many in the technical graphics field who teach at secondary and post-secondary educational institutions have discussed the benefits of traditional technical graphics as a means of developing spatial visualization skills, this was still envisioned by most as happening in the context of mechanical or architectural design graphics. During this time period, however, science educators have also recognized the importance enhancing the visualization abilities of students and professionals (Baker & Pilburn, 1997). Science educators were, as it can be imagined, using very different examples to show the use of graphics than would typically be seen in a mechanical engineering graphics classroom.

In the early 1990's the authors began work on how the some of the same hands-on activities used in engineering graphics classes with engineering students could be used with a broader population of science and technical majors (Wiebe, 1992). In this scientific visualization course, rather than using the documentation of mechanical objects as the vehicle for the creation of graphics, the communication of more conceptual scientific and technical ideas and empirical results were used as a basis for creating graphics. The authors felt that graphic communication principles formalized by theorists in the 1970's and 1980's and applied in professional science and technical professions could also be applied in technical graphics courses at the secondary and post-secondary level (Bertoline, Wiebe, Miller & Mohler, 1997). This goal, facilitated by the increasing affordability of 2D and 3D computer graphic tools and the recognized need to address the graphic/visualization literacy issue at earlier grades, led to the expansion of this effort to secondary schools (NC Public Schools, 1997; Clark, Wiebe & Shown, 1996; Wiebe & Clark, 1998). Though many look to our field as a source of applied skills for professionals in the science, technology, and engineering fields, there was the realization that many of the traditional concepts of technical graphics communication could be applied in a different context to a broader field of scientific visualization.

Scientific and Technical Visualization Curriculum

Unlike the architectural and mechanical tracks, the scientific visualization courses are unlikely to prepare students for a vocation directly out of high school. Instead, these courses will prepare students for a community college program related to scientific visualization or for enrichment in a scientific or technical career in engineering, technology, education, or the physical sciences. Therefore, potential students are likely to be those on an academic track who have never taken a vocational course before.

The scientific visualization courses expose students to all of the major conceptual areas associated with scientific visualization and give them experience in a broad range of graphic techniques (See Figure 1). Unlike many of the graphic techniques covered in the architectural and mechanical areas, scientific visualization techniques are more broadly applicable. Also, because the track is more academic, students focus on theory and operations so they understand why particular graphic techniques are used.

Table 1. Primary areas covered in scientific visualization courses.

* Basic design principles
* Graphing/Plotting
* Image Processing
* 2-D/3-D Modeling
* Animation and Simulation
* Presentation and Publication

The curriculum team, consisting of teachers and administrators from both secondary and post-secondary education, decided to have five major competencies for the first year curriculum (See Table 1). The first competency centers on leadership development. This competency is designed to give students basic leadership skills, and develop a career plan that will include the information taught within this curriculum. The second major competency teaches students problem solving using design concepts involving visual science theory. Total Quality Management (TQM) tools are included to aid the students in finding solutions to problems and develop consensus building measures for working in groups. While students are working on problem solving and critical thinking skills, the third competency teaches students how to use computers as tools for visualizing scientific data and information. The fourth and fifth competencies are the most demanding. These competencies require students to use a computer to learn different visualization principles needed to analyze information and apply knowledge toward a scientific problem. 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.

Table 2 Scientific and Technical Visualization I Curriculum Outline

1. Leadership Development:
   - Basic techniques for parliamentary procedure
   - Steps for processing a motion/vote
   - Establish goals
   - Identify 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
   - Provide 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

In the second year, the curriculum centers on 3-D graphics and image processing (See Table 2). With a focus on applications rather than cognitive knowledge-based learning, students incorporate advanced visualization techniques that are used to enhance existing models. These techniques include the use of advanced color and lighting. Also, students have a greater emphasis in conducting both quantitative and qualitative research. The main focus for this second year curriculum is to develop and present a project in a portfolio format for assessment by the teacher and classmates. The end result is that students understand and apply their visualization skills in scientific related fields. Thus, 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 (See Table 2).

<u>Table 3</u> Scientific and Technical Visualization II Curriculum Outline

1. Advanced 2-D and 3-D Visualization Techniques:
   -Use color, texture, lighting, and rendering
   -Research based graphing for both quantitative and qualitative data
   -Image processing, simulation, and animation

2. Presentation techniques
   -Use software to present scientific and technical data
   -Develop interactive presentations with storyboards
   -Present research data and develop a portfolio

Impact on Future Curriculum Development

A curriculum of this type will influence the types of student that take a graphics class at the secondary level, as well as the visualization skills of students. With a scientific visualization curriculum, secondary and post-secondary education technical graphics teachers will have students who want to understand visual science theories and apply these visual techniques to more than just mechanical or architectural areas. Thus, the new scientific visualization curriculum will bring a new type of student to the classroom: those that want to apply visual techniques into academic areas such as mathematics, science, technology, chemistry, physics, and biology. This new curriculum will allow these "nontraditional" students to see how visual science can be applied to other careers.

Scientific visualization allows students to create the graphics they would normally see in television science specials or in their textbooks. In addition, students have the opportunity to delve into science and technology topics at a depth not allowed in a traditional science class. They do this within the framework of a formal graphics communication discipline (previously outlined). There is the additional benefit that the vehicle of creating scientific visualizations also emphasizes key computer skills for the 21st century. These skills include: data format standards and data exchange techniques, Internet-based data harvesting and research, 3-D modeling and animation, image processing, data input and output using numerous multimedia formats, and learning computer graphics hardware standards.

Although this new curriculum is developed as a vocational track, the concepts and information used throughout the curriculum can easily be integrated into mathematics, science, and technology education classes. Technology education teachers can use the curriculum structure, as well as its data or conceptual-based problems, to teach students ways to manipulate technical, mathematical, and science data and visually see the results. Therefore, technology education teachers can help students to develop visualization skills through classroom instruction and laboratory-based problems, and integrate technology in other scientific areas.

Application of Scientific Visualization

Scientific visualization is first placed in context with other technical graphic communication methods. The exploration of systems is introduced along with a review of the general types of systems that might be explored, analyzed, and presented using scientific visualization techniques. A foundation is built around understanding the different types of data variables, which may be used to describe both the probing, and recording techniques used on the system.

In creating a visualization, the initial design is typically driven by classifying graphics into two major categories. First, one must determine if the visualization is concept-driven or data-driven. A concept-driven visualization is typically generated from a concept or theory and not directly tied to any empirical data. It does not mean that there isn't 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 effects of harmonics in a suspension system on a car, it may be more effective to use diagrammatic techniques to represent the phenomena rather than to graph data values. 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 graphic elements is defined so that a graphic characteristic varies in some predetermined fashion.

The second category is whether the visualization is 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 also become factors in deciding on the dimensionality of the visualization. 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. The four visualization types are: 2-D concept-driven, 3-D concept-driven, 2-D data-driven, and 3-D data-driven. This matrix can be used to as means of classifying assignments and examples in the scientific visualization course. These visualization types are explored, analyzed and presented through multiple techniques that are used extensively in graphic communications. In order to support the curriculum, examples of activities using these different visualization techniques were developed and placed on a web site and CD-ROM for use by teachers (Wiebe & Clark, 1997). Below are the major categories that many of the activities fall into, along with some examples.

Graphing/Plotting

A taxonomy is presented to students that classifies visualization methods used, based on both the types of data variables used and the intended audience. In addition, the basic graphic elements in graph plotting are introduced along with a review of two-dimensional coordinate systems used for organizing the graphic elements. Graphing and plotting exercises are done based on a number of different application areas. In some cases, the data can be collected from experiments the students create. In other cases, the data may be gathered from both from print and electronic (e.g. Internet) sources. The primary focus in this section is 2-D graphing/plotting methods, manually done and using computer-based tools (Wiebe, 1997a).

Weather Data Exercise

The federal government's National Oceanic and Atmospheric (NOAA) is a rich source of both historic and current weather data from around the country. NOAA's National Climatic Data Center's (NCDC) web site contains access to local climatic data collected on an hourly basis at airports and other key weather stations (National Climatic Data Center, 1999). In this example, weather data was gathered from the Raleigh-Durham International Airport in North Carolina (Station: RDU, WBAN: 13722, Latitude: 35°52') and a station on the Ponape Caroline Island, Micronesia (Station: PTPN, WBAN: 40504, Latitude 6°58'). Presented in spreadsheet form, data such as the minimum, maximum, and average daily temperatures can be compared month-to-month, year-to-year, and from station-to-station. In the graph in Figure 2, the minimum/maximum daily temperatures for December of 1996 and 1997 at RDU are compared. In addition to looking at the variation at a single weather station, comparisons can also be made across stations. Figure 3 shows differences in minimum/maximum daily temperatures for December of 1997 for both the North Carolina and Micronesia stations. Besides an overall warmer temperature, there is also less spread between the minimum and maximum temperatures in a day or week. Is this due to its closer proximity to the equator, proximity to a large body of water, or other factors? Graphical comparisons can be made with other weather stations around the globe using a number of different graphing techniques to explore these questions. These graphs become vehicles both for making sense of numeric weather data and for challenging the student to come up with effective visualization methods integrating multivariate data.

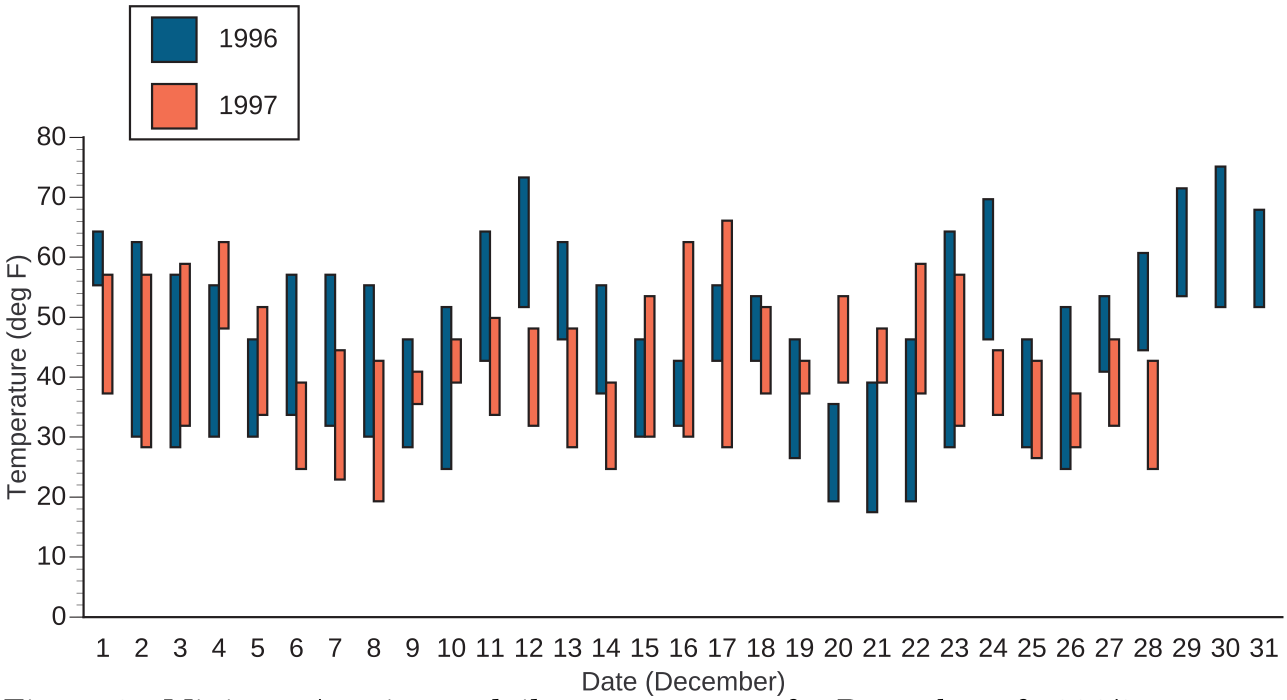

Figure 2. Minimum/maximum daily temperatures for December of 1996/97

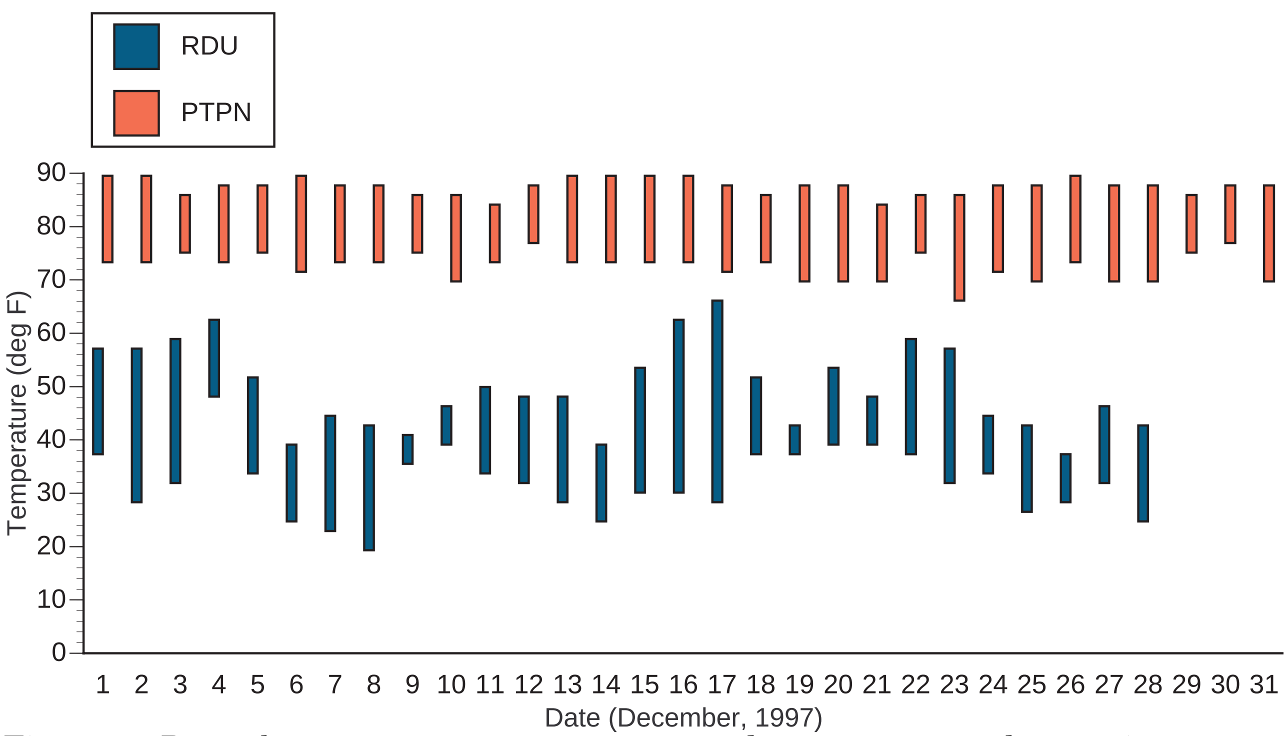

Figure 3. December 1997 temperatures compared across two weather stations at markedly different locations on the globe.

Image Processing

This area focuses on area rendering techniques using image-processing techniques. Also included is an introduction to color theory: both its perceptual basis and computer-based generation methods. Through the use of image processing software, the basic principles of how such software is designed and functions is explored. Image processing exercises are based on data gathered both from images created by the students (either using all digital or a combination of photographic and digital methods) and with images acquired through the Internet. Throughout this section, techniques used by professions that rely on image processing techniques (i.e. medical and earth sciences) are examined (Wiebe, 1997c).

MRI Scan Problem

With this problem, students are given a series of magnetic resonance imaging scans of a human head (see Figure 4). Within these images, a large cavity is identified where cerebrospinal fluid flows through ventricles (shown as the lightest color in Figure 4). This region is highlighted by selecting and manipulating the pixel values of this region in each of the slices using image processing techniques. When the region is highlighted in all of the appropriate sections, this region in each of the slices is recompiled and an animation created of the region being rotated. This exercise not only allows students to explore image processing techniques and learn about human anatomy, but also lets them apply sectioning and projection techniques in ways they would not have a chance to in a traditional technical graphics class.

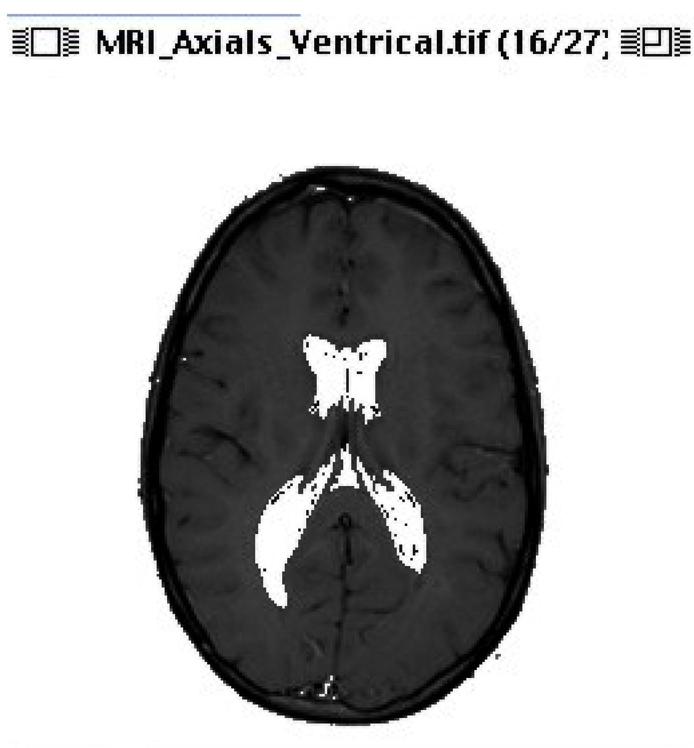

Figure 4. A single image of a MRI scan from a stack of 27 images. The ventricular cavity is highlighted in white.

Animation, Modeling, and Simulation

Two major new areas are introduced in this area: dynamic visualization and 3-D modeling techniques. Dynamic visualization through animation and simulation shows how the change in a system over time either predefined or as a real-time response to user input can be represented. Two-dimensional simulation is explored using software tools modeling either physical (e.g. dynamic mechanism motion) or conceptual (e.g. model of a virus) systems. Similarly, 3-D modeling tools can be used to create representations of systems, which can then be manipulated to represent some process. The 3-D model can be the basis of a static image or used for animations to represent a dynamic process. Coupled with the creation of 3-D models is an introduction to rendering techniques, including proper use of lighting, color, and camera position (Wiebe, 1997b).

Newtonian Physics Problem

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 spatial coordinate values both as independent and dependent variables. These values can not only be represented in traditional graphs, but also as symbolic models. In this sample problem, students take theoretically derived data to create an animation of a cannonball - given an initial velocity and vector - being shot from a cannon and model it in a 3-D modeling and animation package (See Figure 5). This exercise represents a blend of concept-driven and data-driven visualization. Besides creating a pictorial view of the ball trajectory, animations from orthographic viewpoints (i.e., top, front, side) of the trajectory can be created to isolate movement along pairs of coordinate axes. This allows students to visually identify along which axes acceleration is taking place.

<u>Figure 5</u>. Physics problem example. A cannonball, given an initial velocity and direction, is tracked through space.

Presentation and Publication

This last area focuses on the integration of information used to represent and analyze a system into a form that can be presented to an audience. Information sources include textual and numeric data in addition to the graphics created as part of the visualization. The focus is on the clear and concise presentation of necessary information to the intended audience. Exercises use multimedia presentation software that integrates text with both static and dynamic graphics (see Figure 6). This last area can be used as part of a capstone project encompassing both the scientific visualization course and other related courses. The presentation process emphasizes the use of multi-media formats being integrated into a project that extends from a comprehensive study about a given scientific subject.

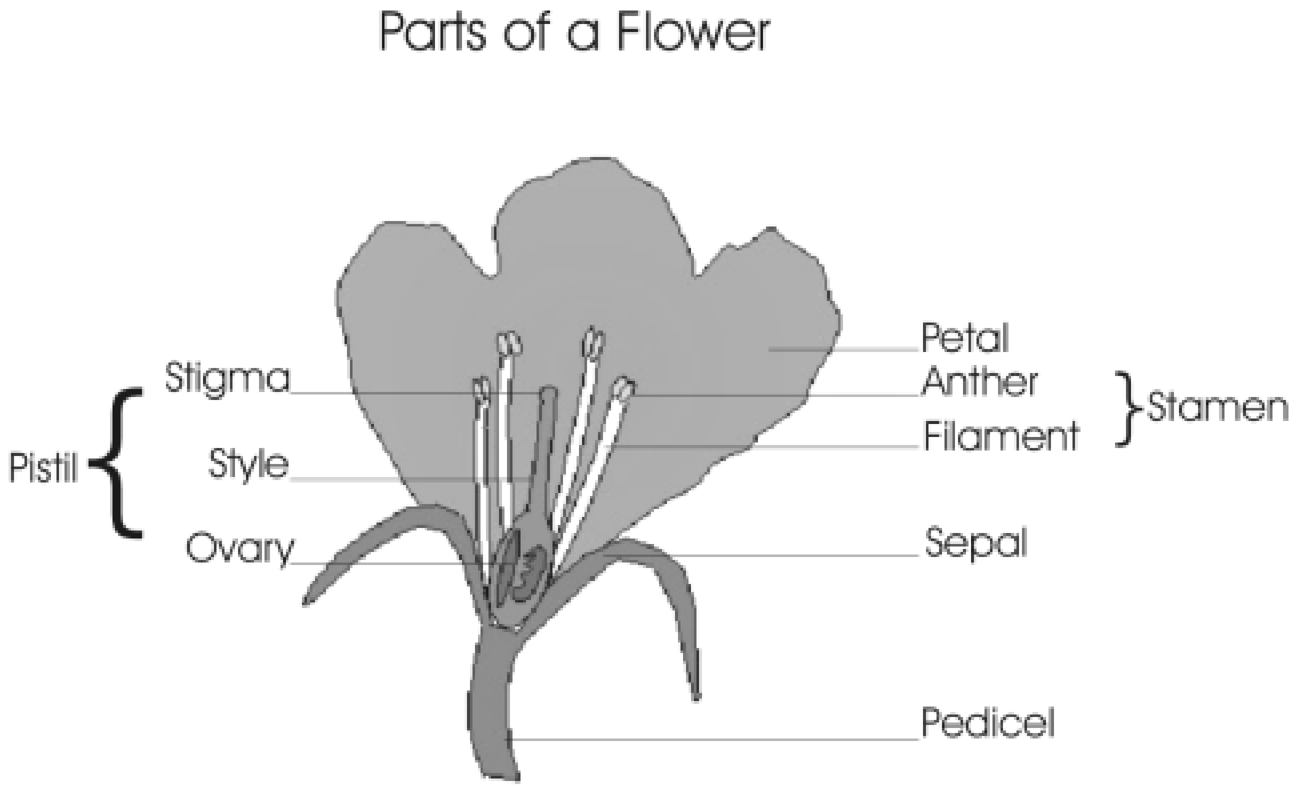

Figure 6. Final Presentation Example. An illustration of the parts of a flower is integrated with text labels.

Vocational and Technology Education's Role within Scientific Visualization

Vocational and technology education within North Carolina and across the nation has many things to consider during the development and implementation of this new curriculum. First, scientific visualization is not limited to vocational students; and all students in engineering, scientific, and technological areas can use visualization techniques. Therefore, technical graphics programs should include scientific visualization and teach students how visualization skills can be used outside of traditional engineering fields. Since one of our goals in vocational and technology education is to integrate our curriculum content with general education in order to establish technological literacy, scientific visualization will broaden our technical graphics curriculum and prepare students to integrate visualization skills in other professions (e.g., chemistry, medicine, biology, physics, meteorology, agriculture).

Second, vocational and technology educators need to consider the demand for a technical graphics teacher to teach this type of curriculum and team-teach with other educators from other disciplines. Science teachers know the content, but vocational and technology teachers know the processes for visualization. Scientific visualization with its content and visual processes requires integrating both the academic and vocational areas. Thus, technical graphics teachers need training in this new integrated approach to teaching. They will also need updated skills to include new software and scientific content that are directly related to the curriculum.

Finally, technical graphic educators that are educated in two and four-year technical graphics programs need to include this new content into their existing curricula. Upon graduating with a degree in any type of graphic communications program, it is expected that the graduate understands the many forms and processes where visualization is being used. It is the role of the college and university graphic educators to include this new content area and better prepare their graduates for employment, not only in the traditional technical graphics area, but for the emerging areas within scientific visualization. Our responsibility as vocational, technical, and technology educators at the post-secondary level in graphic communications is to educate our students in the skills and knowledge needed for the 21st century.

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