Journal for Geometry and Graphics
Volume 4 (2000), No. 1, 89–98.

Scientific and Technical Visualization: A New Course Offering that Integrates Mathematics, Science, and Technology

Aaron C. Clark, Brian Matthews

Department of Mathematics, Science and Technology Education
College of Education and Psychology, North Carolina State University
Campus Box 7801, Raleigh, NC 27695-7801, USA
emails: aaron_clark@ncsu.edu, matthews@poe.coe.ncsu.edu

Abstract. This paper is an explanation of the Scientific and Technical Visualization project that North Carolina State University, the North Carolina State Department of Public Instruction, and Wake Technical Community College created as a joint effort funded by a Tech-Prep Innovation Grant. The purpose of this effort was to develop a model program to improve science and graphics instruction in North Carolina. This improvement consists of the use and integration of three specific components: the Scientific and Technical Visualization curriculum, Scientific and Technical Visualization tools, and technology.

Key Words: Scientific Visualization, Integration, Curriculum, Visualization.

MSC 1994: 51N05

1. The Scientific and Technical Visualization project

The Scientific and Technical Visualization project links scientific information and graphic literacy to form a secondary curriculum in scientific and technical visualization. The project integrates the knowledge obtained in science classes (i.e. biology, chemistry, and physics) with a visual skill development and understanding of science-related topics. It also enhances the scientific knowledge base of a student, while developing needed visualization skills and geometry-based relations. The goals for this Tech-Prep Innovation project are as follows:

- To establish scientific and technical visualization programs in school districts throughout the state.
- To establish and maintain a scientific and technical visualization web-site for the purpose of assisting and training science, vocational, and technology teachers.
- To provide a series of introductory and advanced scientific and technical visualization teacher workshops.

ISSN 1433-8157/$ 2.50

- To develop and distribute a curriculum and ancillary materials (e.g., teachers implementation guide, CD-ROM of scientific and technical visualization student activities, pre and post-test questions, and curriculum guide).
- To assess the effectiveness of scientific and technical visualization programs with regard to scientific literacy and visual skills attained by the participants.

Through this new curriculum, North Carolina students use analytical (i.e. geometry) and communication tools to gain a better understanding and appreciation of the sciences. Students will also develop skills that are in great demand in the rapidly expanding information and imaging technology industries. Upon successful completion of the program, students apply their newly acquired skills to further study the sciences, enter the workforce as graphic visualization technicians, or continue their study of scientific and technical visualization graphics at a post-secondary institution (Clark, Wiebe, & Shown [3]).

2. Outcomes of the Project

During the past two years, the project has produced several outcomes. These include multiple training workshops for teachers who were about to implement the new scientific and technical visualization curriculum, a curriculum blueprint and teacher guide, and a promotional video for explaining and promoting this new vocational area. Student outcomes include the advantage of using graphics versus text or numerical notation, and the advantages of using images. These two outcomes can greatly enhance the capacity for understanding complex relationships by students (Wiebe & Clark [10]). This is the principal reason technicians, engineers and scientists rely on images for understanding and explaining what would otherwise be incomprehensible concepts. Other program outcomes observed by scientific visualization teachers include an increased interest and understanding of geometry and science concepts; enhanced capabilities to visualize in both two (2-D) and three (3-D) dimensions; improved presentation skills as applied to mathematical and scientific concepts; higher competency in the use of the Internet for accessing, processing, and sharing information related to geometry and science (especially in obtaining available data sets); and a reduction in student remediation in the sciences.

Overall, the new curriculum allows our students to achieve a higher level of subject comprehension. The use of visual technology enhances learning by providing a better understanding of the topic as well as motivating students to study science related topics. In addition, scientific visualization prepares students to learn and work on their own. Such independence will be more important to the next generation of workers as the tools they use become more complex, and paradigms become more astute and move away from simple 2-D to a more complex 3-D mode of thinking. Scientific visualization using visual technology will provide a greater understanding of science-related subjects (see Fig. 1).

2.1. Content Establishment and Resources

The primary goal of the project, to establish a scientific and technical visualization program in school districts throughout North Carolina, is still being realized. The North Carolina State Department of Public Instruction (NC-SDPI) wholeheartedly embraced the project in July of 1996, and later approved the curriculum for use throughout North Carolina in July of 1998 by instituting N.C. course codes 7901 and 7902. For two years, July 1, 1996 through June 30, 1998, high school teachers, college instructors, university professors, and state consultants

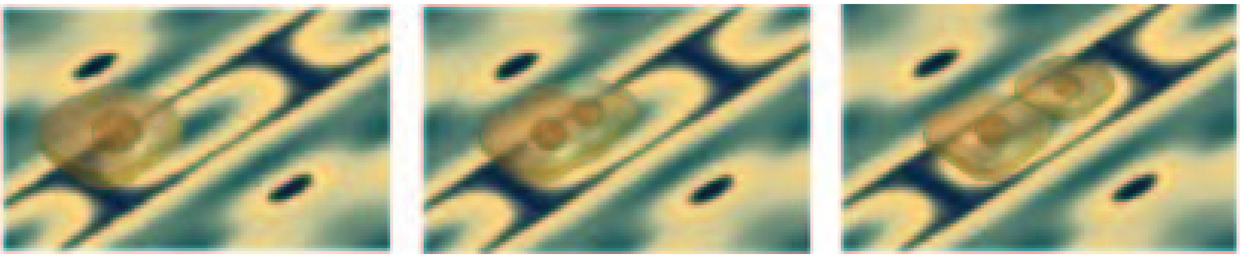

Figure 1: Cell division sequence using animation and video editing techniques (1998)

attended curriculum-writing sessions at NC-SDPI in Raleigh, North Carolina. This long, pedagogical, problem-based process proved to be the first testing ground for the scientific and technical visualization curriculum. The curriculum writing team not only had to produce a curriculum, but also had to establish relevant criteria and paradigms for the scientific visualization curriculum. This included determining why the curriculum was needed, where it was to be implemented, and how it should be used to enhance visual science teaching. In addition, to pilot test curriculum materials under classroom conditions, the project financed complete computer laboratories in a number of the North Carolina high schools used as pilot sites.

High schools, other than pilot schools, now teach visualization through science-related areas from a technical visualization perspective. Across the state, there are 24 new sites are testing and piloting the curriculum. These high schools programs have a variety of class sizes, from a single class of 16 students to several full classes of 20. Many of the high schools have two to five classes of varying sizes. As of the fall of 1999, more than 350 students are taking the new curriculum.

Once the curriculum was piloted, barriers to implementation began to form. The major barrier these pilot site teachers and students faced was minimal literature resources. Project coordinators looked at traditional drafting material but realized that no one source could fill the requirements of the curriculum. Resources needed to include a hybrid of literature from both the sciences and graphics areas. The curriculum writing team intends to rectify this over time, but at present, teachers are relying upon their mutual expertise to develop needed exercises and experiments. Drafting teachers are working with science teachers in creating visual experiments, and science teachers are providing content material and data.

2.2. Methods of Delivery

In order to sustain the curriculum project, a web-site to assist and train science, vocational and technology teachers was developed. North Carolina State University is currently preparing lesson plans for distribution over the World-Wide-Web with listserv access. To create the web-site, school site visits are being conducted where teachers and students engage in active lesson plan preparation. This web-site allows teachers to download, review, and test prepared materials. Each lesson plan placed on the web-site is based on a matrix of scientific visualization techniques, content area, and scientific visualization software tools.

Each of the lesson plans is field tested by pilot schools and revised as needed. All lesson plans and performance-based activities developed for the curriculum are in one of the four science related areas: physics, chemistry, earth and environmental sciences, and biology. Each of these areas address four sub-categories of scientific visualization techniques: 2-D data driven, 2-D concept driven, 3-D data driven, and 3-D concept driven (Fig. 2 shows an example of 3-D concept driven visualization). A concept-driven visualization is usually generated from the development of a concept or theory that does not require any empirical data. It does not mean that data does not exist, but this type of scientific concept does not require any to be understood. Data-driven visualization uses empirically or mathematically derived data to form the visualization. It is used to explore a specific relationship between data values and graphic elements. To determine if 2-D or 3-D graphic representations are appropriate, an evaluation process is made of both the information to be presented and the capabilities of the computer hardware and software being used.

Lesson plans include additional scientific visualization resources helpful to students and teachers. These resources contain lists and links to web-sites that include scientific visualization techniques, scientific visualization content areas, and scientific visualization software tools.

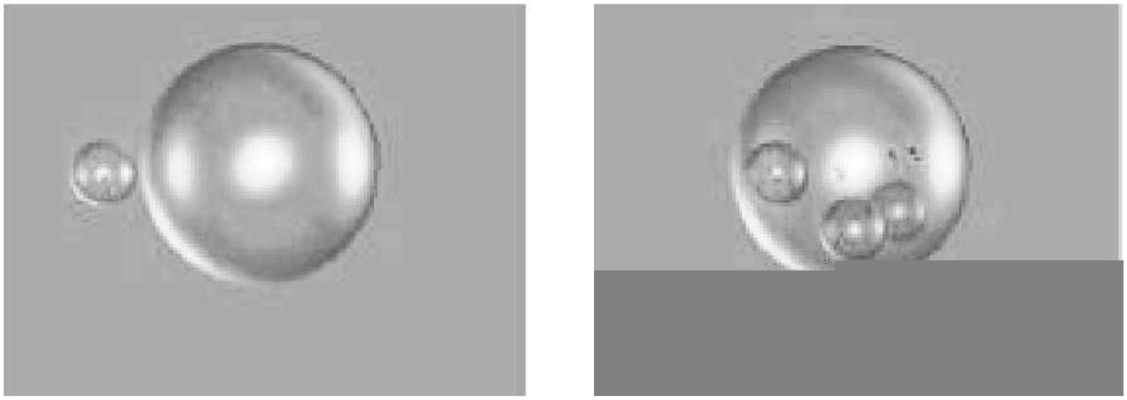

Figure 2: 3-D model of an Ebola virus sequence (1997)

2.3. Establishing a Web-site (www2.ncsu.edu/scivis)

The web-site started as an online summer workshop to train teachers in scientific visualization. Once trained, the teachers were then able to access and use the web-site examples in their classrooms. North Carolina State University is currently reworking the initial site. The new site encompasses all of the areas mentioned previously, but will also be a multimedia-based site with a full complement of curriculum materials and content notes for teachers. The web-site is updated as more data and example problems become available. It also includes related scientific and technical visualization sites, table of contents, e-mail link to send in queries, teacher training notes and laboratory activities, scientific visualization lesson plans, online blueprint and curriculum outline, scientific visualization software tools (shareware), frequently asked question (FAQ) page, reference lists, summaries of visits to pilot schools, dates of teacher training workshops, and career guidance notes (Wiebe & Clark [11]).

2.4. Professional Development Strategies

The Tech-Prep Innovation Grant funded workshops for the participating teachers to provided both skill and content knowledge. Pilot site teachers from both science and vocational disciplines had to participate in a series of introductory and advanced scientific and technical visualization workshops. These workshops provided realistic classroom examples for overcoming problems and how to use certain techniques within the curriculum to achieve results.

The scientific visualization-training timetable will continue to include scientific visualization basics. These basics include the use of graphing and image processing software, scientific probes for data collection, problem-based learning as a teaching method, and the use of 3-D modeling and animation software for conceptual modeling (see Fig. 3).

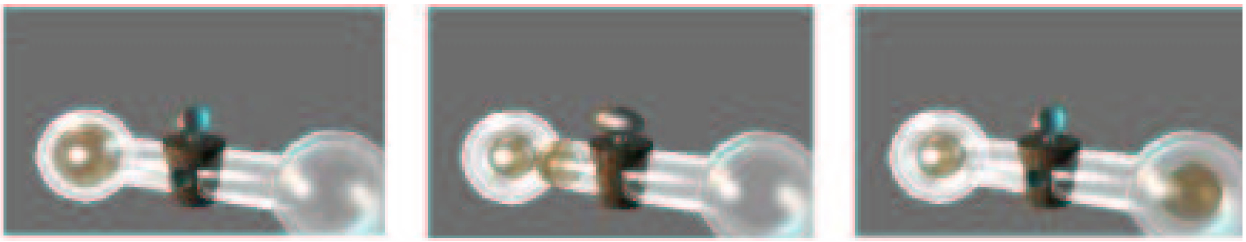

Figure 3: Gas flow animation sequence example (1997)

2.5. Teacher Support

To provide teacher support throughout North Carolina, the goal is to develop and distribute curriculum and ancillary materials such as a Teacher's Implementation Guide, a CD-ROM of scientific and technical visualization student activities, a curriculum guide, and test questions for assessment. University professionals intend to create a process of information exchange between teachers and researchers using the Internet. Using this technology allows educators to communicate on a weekly or as needed basis. The goal for these "net meetings" is to better facilitate the implementation of this curriculum by sharing ideas and concerns in a timely fashion. The project team feels that this type of "on demand" dialog will allow for better mentoring of teachers in their first years and therefore, provide a greater chance of success in the classroom.

2.6. Assessment

A final goal for the curriculum project is the assessment of the effectiveness of the scientific and technical visualization programs for improving scientific and visualization literacy. To achieve this goal, all high schools in North Carolina are being surveyed to determine if they are using, or intend to use, the scientific visualization curriculum. Schools will also be asked how they intend to implement the new curriculum over the next two years. The survey will determine the effectiveness of scientific and technical visualization programs in teaching visual scientific literacy. Randomly selected pilot sites that offer both architectural and mechanical drawing classes as well as the new scientific and technical visualization course will be tested for knowledge gained in visual literacy using a computer version of the Purdue Spatial Visualization Test (Branoff [1]).

3. Scientific and Technical Visualization — First Year Blueprint

The two-year curriculum uses four basic modules in the first year and six enhanced modules in the second year. The intent of each module is to have students identify (learn) and then apply the concepts and principles as the students progress through the curriculum. First-year modules include design and problem solving, basic computer knowledge and concepts, visualization principles, and the application of visualization principles (Wiebe [9]).

The design and problem-solving module allows students to brainstorm ideas and form a problem statement. The students will utilize research strategies, gathers data and then refine and implement the final process towards a visualization (Bertoline et al. [2]). The expected outcomes of this module are a student's ability to explain the concepts and principles of problem solving and design, and the application of problem solving techniques and design methodology. Students learn the basics and use of a formal design brief for all performance-based activities. Each student has to complete five mini-projects and one major project. Examples of topics include Bernoulli's Principle, gravity, cell theory, atomic (wave or quantum theory), magnetism, mechanics, stoicheometry, astronomy, and Newton's Laws of Motion.

The second module, basic computer knowledge and concepts, requires students to demonstrate and interpret basic computer skills and techniques. Most of the work for the scientific and technical visualization curriculum is computer-based. Therefore, students should be able to identify and explain basic computer terms and concepts. Once these basics are mastered, students must also be able to apply the concepts and principles to computer file management. All students are now required to learn computer basics even though most high schools achieve more than the required minimum as outlined in the curriculum (Matthews et al. [4]). The initial purpose here is to provide computer knowledge-based competencies that students should achieve upon completing the program.

The third module of the first year curriculum helps students learn visualization principles by having students interpret and apply visualization principles. The objectives for this module are that students be able to: interpret and apply visualization principles, identify and explain the application of descriptive systems for space and time, explain the fundamental concepts of shape description, identify and explain the visual properties of objects, describe visual methods for representing data-driven visualizations, and describe visual methods for representing concept-driven visualizations (Sorby & Bartmans [7]). This module builds on the use of graphical relationships, computer aided design, and 2-D and 3-D geometry. It allows a student to identify and explain scientific data by using visual properties to produce both data-driven and concept-driven visualizations (see Fig. 4).

The final module in the first year curriculum is the application of visualization principles. The purpose is to have students apply 2-D and 3-D visualization techniques. Students are expected to design and evaluate a simple visualization and produce both computer-based, concept-driven models and data driven visualizations (Senay & Ignatius [6]). At the end of this experience, they are expected to be able to transfer computer based visualizations to an output device such as a VHS tape or CD-ROM [5].

4. Scientific and Technical Visualization — Second Year Blueprint

The second year curriculum builds on the pedagogical, performance, psychomotor and metacognitive skills of the first-year core modules with an emphasis on image processing skills. Second-year modules include advanced principles of scientific visualization, 2-D area rendering techniques, advanced 3-D modeling and visualization techniques, multimedia presentation techniques, a culminating design project, and production of a portfolio.

The purpose of the advanced principles of scientific visualization module is to allow a student to demonstrate and interpret more in-depth principles and practices of scientific visualization. The students will review empirical, theoretical and computationally derived visualizations, and apply the use of a design brief. Students also analyze science and design concepts which include independent and dependent variables, cause and effect relationships,

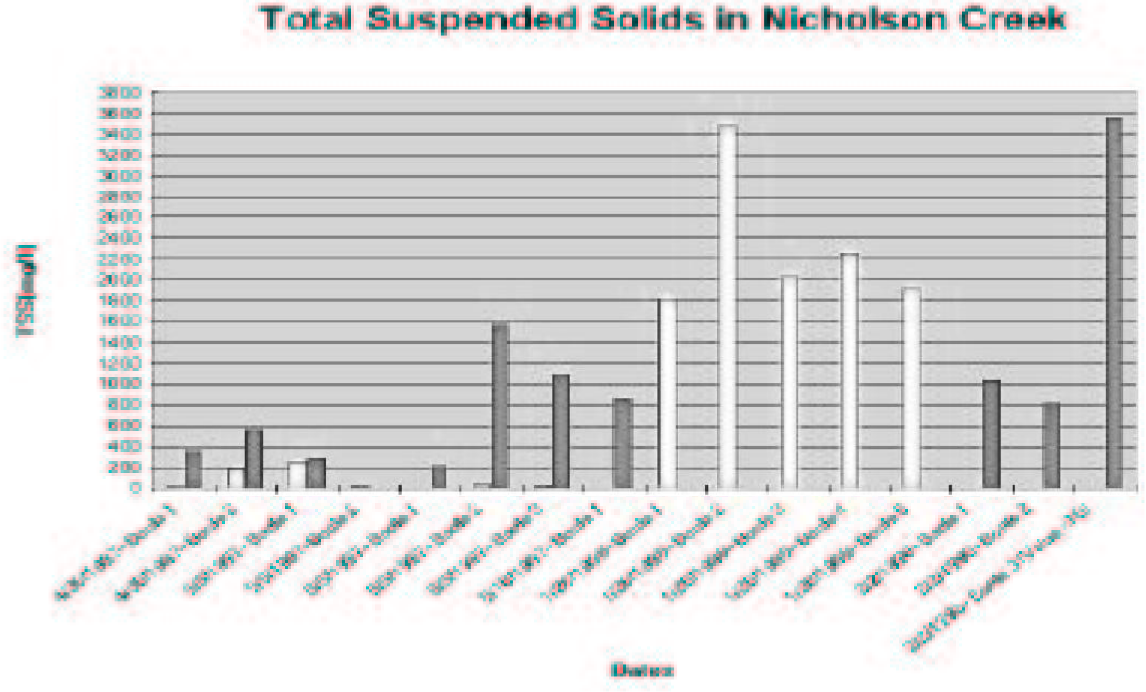

Figure 4: Suspended solids content (Data-Driven Visualization 1998)

statistical analysis processes and procedures, theoretical versus empirical data, and encoding methods. These concepts, along with the use of a design brief, allows students to apply the concepts of depth, area and volume, shape of pattern coding, line weight and placement, and scale transformation.

The second module allows a student to interpret, identify, and apply 2-D area rendering techniques. These include density slicing, pixel mathematics, and regional calculations as applied to image processing techniques. Some examples include the use of cloud patterns for atmospheric data; current flow and ocean temperature for ocean current data; vegetation and elevation for terrain data modeling; and the use of CAT (computed axial tomography) scans, MRI (magnetic resonance imaging), and X-rays for medical rendering applications. The students should use LUT (color lookup table) techniques and apply image-processing techniques (Tufte [8]).

In the third module of the second year, students demonstrate and apply advanced 3-D visualization techniques and apply both static and animation modeling techniques (see Fig. 5). The fourth module moves into multimedia presentation techniques. For example, students interpret, apply, and produce integrated multimedia visualizations. The fifth module allows a student to create a complex visualization. In this penultimate module, the student is expected to research and design a complex visualization and give a final presentation. Finally, in preparation for job and university applications, the final module is portfolio production. Each student is expected to prepare a portfolio of his or her accumulated scientific visualizations [5].

5. Implications Upon Vocational/Technical Education

Many implications can be drawn from the development of this new curriculum to the teaching of visual science. Although many can be discussed, the authors feel the two most important

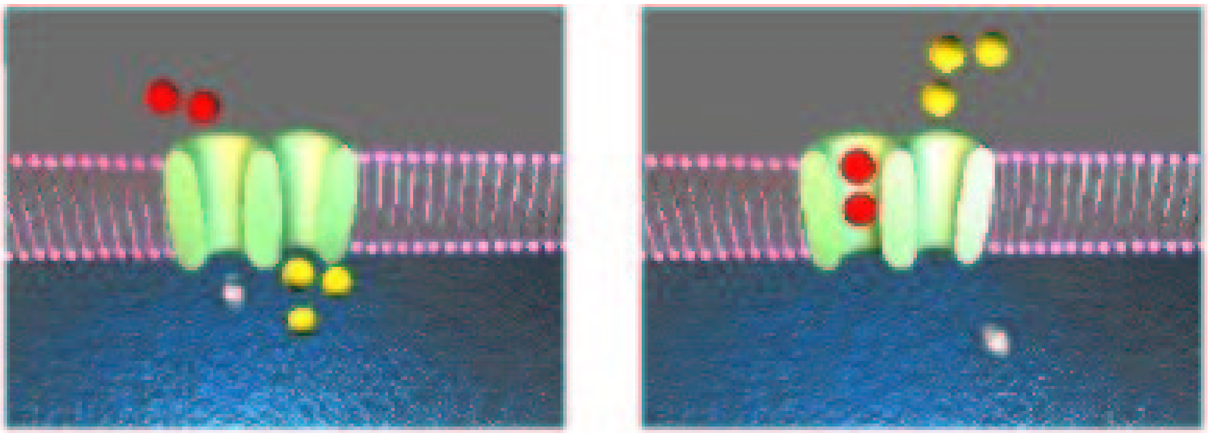

Figure 5: A nakpump animation example (1998)

implications center around relevance and student populations. The first implication is that educators in technical graphics must realize that innovations in graphic communications are placed into the workforce every year. If vocational and technical educators are to reach these new markets (i.e. scientific visualization), educators must first change their perception as to what constitutes a graphics course at the secondary and post-secondary levels. Graphic professionals must recognize that our society is changing due to the advent of new and better technology. Coinciding with these changes are better and enhanced ways to analyze and work with data. If technical graphics educators are to stay current with technologies and trends, they must accept change in our curricula focus. This can only happen if vocational and technical educators embrace these emerging curricula areas like scientific visualization. That, plus the use of visual science, can help guide the development and understanding of the visualization needs of professionals outside traditional engineering/technology.

The second implication this new curriculum has for education is related to students' needs. This curriculum offers relevant information based on student's chosen field of study. Currently, most students planning to major in an engineering or technology related fields often have little or no background in engineering or technical graphics when they graduate from high school. Many students in high school cannot take a drafting course because it does not fit the academic or college bound schedule. If high school students do take a drafting course, most likely it is centered on architectural or mechanical drawing. These same students may or may not see the relevance of taking a course not directly related to their career plans (Wiebe & Clark [11]). Although the traditional areas of drafting can be used to improve students' visualization abilities, their understanding of how to use graphics to solve problems or how to present information in other areas may be limited. Focusing our classes only on traditional engineering/technical graphics may be a deterrent to some students that want to major in other engineering areas or fields related to the sciences (i.e. chemistry, physics, mathematics, biology, environmental, forestry, etc.).

At the post-secondary level, the same situation may exist for students choosing a course based upon its relevance to their chosen field of study. Graphic communication professionals in higher education deem many things important in the instructional content for an introductory graphics course. Many of the course competencies focus on an understanding of the standards and conventional practices followed by most engineering professions. Although these competencies are important to many engineering areas (i.e., mechanical, industrial, aerospace, civil, and architectural), not all fields of engineering generally use these standards and practices.

The major goal of improving students' ability to visualize using geometry and projection theory is important for all students, regardless of what their major or degree they seek. By focusing on scientific data and problem sets, as opposed to traditional mechanical drawing problems, a larger population of students can be reached and served by engineering/technical graphics programs. The authors of this curriculum feel that courses at the post-secondary level that use scientific data and concepts, and focus on both data and conceptual modeling, better serve those students in disciplines related to the sciences (e.g. chemistry, physics, mathematics, biology, environmental, forestry).

All students need the visual skills taught in our geometry and traditional engineering/ technical graphic courses, but the use of content related to science-oriented problems reaches a broader population. It should be noted that a scientific visualization course is not designed to replace existing courses, but supplement them, so that engineering/technical graphics educators can reach a population of students that has been neglected in the area of visual science. Our goal should be to include all discipline areas in learning to visualize data and concepts, and in helping all students learn to understand and appreciate the processes and practices of visualization.

In conclusion, it is our goal in the engineering/technical graphics professions to seek new endeavors in the teaching and understanding of visualizations. New courses, such as scientific visualization, help us reach more students and aid their understanding of visual science. As our society, industries, and culture become more dependent on visual information, our profession should guide students into the twenty-first century, which many expect to be the "visual-age".

References

[1] T. Branoff: *The effects of adding coordinate axes to a mental rotations task in measuring spatial visualization ability in introductory undergraduate technical graphics courses.* Engineering Design Graphics Journal **62** (2), 16–34 (1998).

[2] G.R. Bertoline, E.N. Wiebe, C. Miller, J.L. Mohler: *Technical Graphics Communications.* 2nd ed., WCB/McGraw Hill, Burr Ridge, IL, 1997.

[3] A.C. Clark, E.N. Wiebe, T. Shown: *Future directions for graphics: A look at the new technical graphics curriculum in NC high schools.* Proc. 51st Mid-Year Meeting, Engineering Design Graphics Division of ASEE, 1996.

[4] B. Matthews, G. Head et al.: *AutoCAD 3-D Companion.* Ventana Press, Carrboro, NC, 1995.

[5] NC-SDPI North Carolina State Department of Public Instruction: *Scientific and Technical Visualization I and II*, Document No. T&I 9722. State of North Carolina, 1998.

[6] H. Senay, E. Ignatius: *Rules and principles of scientific data visualization.* Paper presented at the State of the art in data visualization (ACM) SIGGRAPH Course Notes (27), 1990.

[7] S.A. Sorby, B.G. Bartmans: *An introduction to 3-D spatial visualization – A pregraphics course.* Proc. 6th ICECGDG, Tokyo 1994, 820–824.

[8] E.R. Tufte: *The visual display of quantitative information.* Graphics Press, Cheshire, CT, 1983.

[9] E.N. Wiebe: *Scientific visualization: An experimental introductory course for scientific and engineering students.* Engineering Design Graphics Journal **56** (1), 39–44 (1992).

[10] E.N. Wiebe, A.C. Clark: *Evolving technical graphics in the high schools: A new curriculum in scientific visualization.* Proc. 52nd Mid-Year Meeting, Engineering Design Graphics Division, ASEE, 1997.

[11] E.N. Wiebe, A.C. Clark: *Evolving technical graphics in the high schools: A new curriculum in scientific visualization.* Engineering Design Graphics Journal **62** (2), 4–15, 1998.

Received April 28, 1999; final form February 11, 2000