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Scientific Visualization: A New Basic in Design and Technology

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Abstract

Since 1995, the authors have been developing a new secondary school curriculum in Scientific Visualization. This curriculum is currently part of the Technology Education area in North Carolina, USA. The goal of this two-course curriculum is to help develop student's ability to communicate technical and scientific information to a variety of audiences. The development of this curriculum has been motivated by a belief that graphics, as a means of communication, has been growing rapidly as a means of communication worldwide, but has been largely neglected as a course of study in US secondary schools. This presentation will give an overview of the Scientific Visualization curriculum. As part of this overview, how this curriculum supports the goals of design and technology education and constructivist education philosophy will be presented.

Introduction

Scientific Visualization – the use of graphic communication principles to convey scientific and technical information – has the potential of having a large impact on the Technology Education curriculum in the US, serving as a basic course of study in Communications. Since 1995, the authors have been developing a new secondary school curriculum in Scientific Visualization. This curriculum is currently part of the Technology Education area in North Carolina, USA. The development of this curriculum was motivated by a belief that graphics is an important and growing field of communication. While most schools require written, verbal, and mathematical literacy, graphic literacy has not been a requirement.

The goal of this two-course curriculum is to help develop students' abilities to communicate technical and scientific information to a variety of audiences. Graphic design principles, along with 2-D and 3-D graphical techniques are used to represent data in visualizations. Visualizations can also be created representing science and technology concepts. Integrated into this new curriculum is the use of the design brief to promote the structuring of classroom activities around individual and group exploration of effective means of communicating scientific and technical information. By design, this curriculum integrates mathematics, science, and technology in a single curriculum.

Scientific and Technical Visualization Curriculum

Background of the curriculum

For the past four years, the authors, teachers, and administrators from North Carolina (USA) Public Schools have met to develop and improve a new sequence of courses in Scientific and Technical Visualization (PSNC, 1997). The main goal of these courses is to teach technical graphics to a diverse audience of high school students. The courses are designed to reflect a broader application of computer graphics techniques in the workplace and represent a rich area in which teachers from many disciplines can be involved. These courses complement, rather than replace, more mainstream technical graphics courses in architectural and mechanical drafting currently being taught through vocational education. Currently, there are twelve pilot sites in North Carolina teaching the Scientific and Technical Visualization Curriculum.

Example Activity

Simple machines is usually covered in the Principles of Technology curriculum in North Carolina (CORD, 1990). As a topic area, it serves a number of important goals: it provides an introduction to Newtonian physics, it involves key building blocks to more advanced mechanical technologies, and it is readily adaptable to lab-based activities. It is also a very appropriate activity for the Scientific and Technical Visualization curriculum.

Problem definition

The instructor provides an introduction to simple machines, giving the students an opportunity to explore the principle of transforming energy into work and the concept of mechanical advantage. Differing types of simple machines (e.g., screws, inclines, and pulleys) are discussed and demonstrated. Students are then given the problem of creating visualizations explaining the concepts of simple machines.

Information sources

With any visualization, information has to be gathered. This information usually takes two primary forms: background information on the scientific or technical topic to be visualized and data associated with the actual system being investigated.

In the case of creating a visualization on pulleys, key variables need to be identified. These variables will both define the system and organize data that might be collected or generated. In the case of pulleys, key variables might include the type of pulley, the force on the string that the person pulls and the force on the pulley from the hanging object (Figure 1).
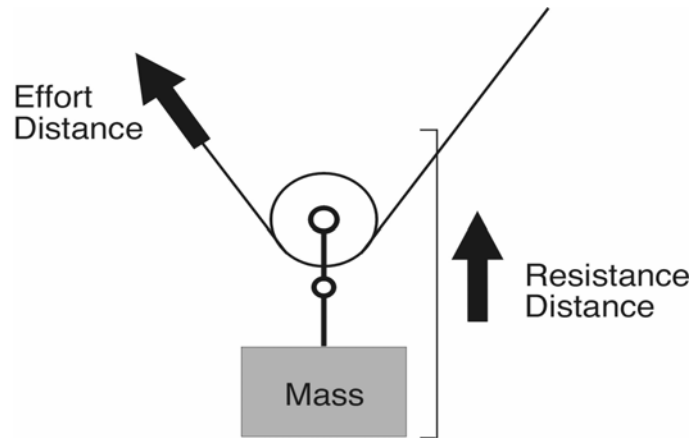
Figure 1. Schematic of a pulley system. This visualization can be used both to help the student organize other visualizations and be part of a final presentation.

Data on these variables can be collected in a number of different ways. One way is to empirically generate data by running actual experiments (Figure 2). Records of these experiments can be made holistically through video and by measuring and recording values. Data can also be generated theoretically using the appropriate mathematical equations and a calculator, a spreadsheet, or other appropriate computer-based tool. Theoretically and empirically derived values can also be compared to each other.
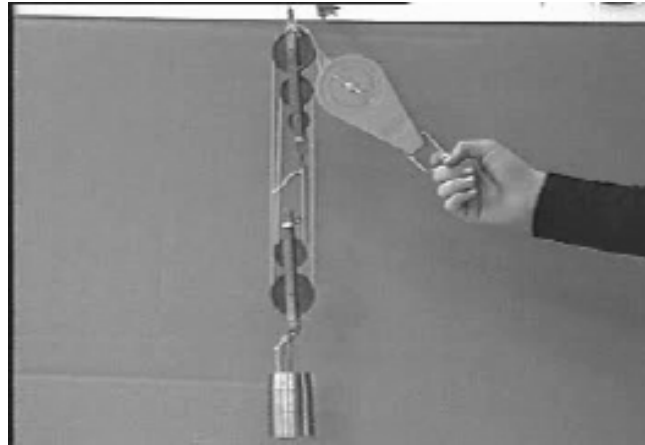

Figure 2. Video of a pulley system. This is a still from a digital video clip of the pulley system in operation.

Visualization methods

Students gather and synthesize information on simple machines to gain enough understanding to create a visualization explaining them. Decisions are made about how best to convey selected information about the system to the target audience. Already two possible visualization methods have been shown: static schematics of the pulley system
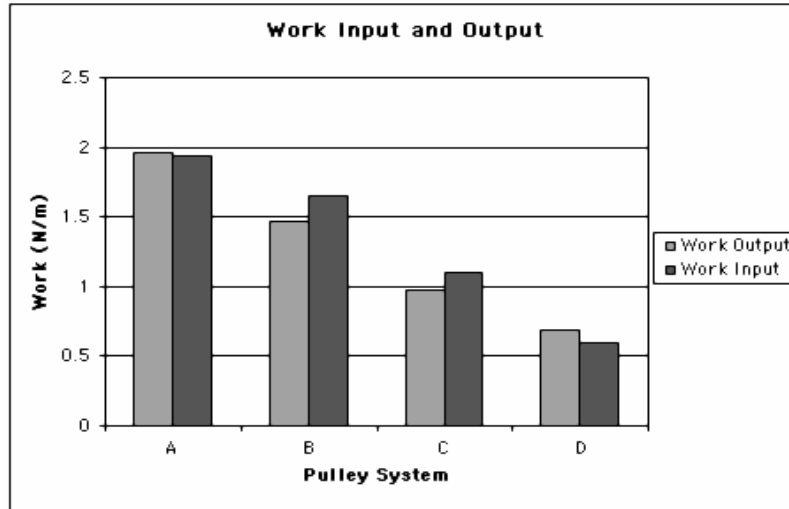
Figure 3. Graphed data from the pulley system. This graph represents empirical data collected from an experiment with the pulley system.

and archival video footage of an actual experiments. There are many other possibilities for visualization techniques. Identification of key system variables and the collection of empirical data will require creation of graphs of their data (Figure 3).

Final Synthesis

A final synthesis of the visualizations is produced near the end of the project period. Here, the individual visualizations need to be brought together into the medium for presentation (e.g., PowerPoint). Along with the visualizations students will create supporting text and secondary graphic elements to enhance the visualizations (Figure 4).

Figure 4. Pulley system slide. Text and graphics integrated in a slide from the final presentation of the pulley system principles.

Visualization design process

The design process plays a central role in the Scientific and Technical Visualization Curriculum. It is a goal of the curriculum to allow students to experience the design process in a way that mimics its manifestation in real world applications. At the same time, an explict design process also provides support for the successful solution of a visualization problem.

As the visualization project nears completion, the graphics will become more polished and representative of the final visualizations. An increasingly larger percentage of the content of the graphic represents communicative information in a form meant for the final audience. It is important for the students to understand the multiple iterations that a visualization might go through and the important role which each evolutionary graphic plays.

An important part of the visualization design process is an ongoing process of evaluation. Goal definition at the beginning of the design is the first step towards a final design. Students should have a clear idea of what the end goals of the project are. Similarly, visualization design heuristics used throughout the design process should also be benchmarks used for evaluation. Rather than wait for a single, formal evaluation at the end of the project, visualizations should be evaluated at all stages of their evolution.

Vocational Goals

Looking at the specific outcomes of this curriculum, students taking this curriculum will have developed competencies in a number of different technology-based areas:

Computer technology

Students use current computer hardware and software to create 2D and 3D visualizations. This creation process requires mastery of a wide variety of computer data input and output devices handling audio, video, static graphic, and alphanumeric-based information.

Data manipulation/management

In the creation of visualizations, data is typically transformed from one form to another. These transformations require knowledge and skills on a number of levels. Mathematical skills are often needed to transform numeric data into a more appropriate range of values for visualizing, often using spreadsheet tools. Geometric principles are used to spatially organize information on 2D planes and to project 3D objects into the 2D space of printed paper or computer screen.

Visualization design skills

Students need to apply higher order critical thinking skills to the development of appropriate visualization solutions. Above all else, visualizations are judged on the basis of how effectively they communicate the necessary information to their target audience.

As a whole, this curriculum has a number of unique elements that set it apart from other courses in technology education or more traditional vocational programs as they are

taught in the US. First, unlike many technology-related curricula, science and technology play a central role in both the creation of the product and the product itself. Second, the design process – as it is applied in the real world – plays a central role in the curriculum. Neither the path to design solution nor the ultimate solution is predefined for many of the activities in this curriculum. Finally, this curriculum is uniquely multidisciplinary. These classes are ideally suited to be team taught by instructors from a variety of backgrounds. Teachers from science, technology, graphic arts, technical graphics (drafting), industrial design, graphic design, along with many other disciplines can play a role in teaching this curriculum.

Scientific and Technical Visualization in the Classroom

For any educational philosophy to be effective, it must be translated into practice in the classroom. Appropriately, there has been effort to take current thoughts on constructivist philosophy and transform them into classroom practice (Appleton, 1993). This translation is not always smooth and often involves compromises on the more idealized philosophical elements (Ritchie & Baylor, 1997). Returning to the Scientific and Technical Visualization curriculum, it is worth looking at how well constructivist principles mesh with this curriculum. Based on the structure of the curriculum and how it is currently being taught at the pilot sites, there is close alignment with a number of constructivist principles.

The reality of teaching a pilot curriculum in what was largely a brand new subject area meant that most of the pilot teachers were not able to present themselves as absolute authorities on the subject matter to be covered in the class. Teachers in the pilot project talked of being forced to take the primary role of facilitators of a class-wide discovery of this new curriculum. In this environment, learners, instead of being passive receptacles of knowledge, are actively involved in sense making at an individual level (von Glaserfeld, 1987). Even as the curriculum becomes better established, the curriculum supports a lab-based environment that minimizes the amount of time a teacher needs to engage in traditional lecture-based activities. Through the course of the year, the teacher cycles between presenter of canonical knowledge and facilitator of its application through each module. In addition, there is the larger cycle of moving from more to less presentation of knowledge to facilitating the students acquisition of it. Also overarching this larger cycle is the integration of more and more elements of the design process.

Approaches to constructivism which focus largely on individual knowledge construction often miss is the fact that the meaning being made through activities does not happen in isolation, but in a social context (Magadla, 1996). In the visualization curriculum, this guidance can be provided in a variety of social groupings. In some cases, specific knowledge can be transmitted by the teacher to the class as a whole. In many situations, activities are less structured. Where appropriate, groups of students may come together to work on acquiring and testing the knowledge needed to come up with a solution. This is likely to be a combination of cooperative and collaborative work. For example, students may cooperatively try and come to an understanding of the science/technology concepts underlying the visualization they are to create. When it comes time to produce the time-consuming visualizations, they divide the graphics-generation tasks among

individuals. Whenever appropriate the teacher-as-facilitator can join groups to ask questions and evaluate progress.

Ongoing evaluation becomes a critical component of the visualization activities. Evaluation has to take place on a number of levels. First, there has to be some assessment of whether the student has successfully grasped the underlying science/technology concept that the visualization is about. Here, the product becomes a point of reflection of personal constructions of knowledge (Blunden, 1997). These graphics can be used for individual reflection, part of group negotiation of knowledge, or in discourse with the teacher. In all cases, the requirement of committing ideas to a graphic becomes a unique hallmark of this curriculum. Whereas many other courses of study may use verbal or written communication for this knowledge representation, the visualization curriculum uses graphics as its primary, though not exclusive, form.

Part of the initial problem definition is the identification of the final audience (context of use) for the visualization. As much as possible, this audience should be used to help evaluate the visualizations (Liu, 1998). This means that in addition to having earlier iterations of a visualization critiqued by peers and the instructor, more finalized versions might also be critiqued by individuals outside of the classroom. Using outsiders, including working professionals in the scientific/technical field in which the visualization is based, also helps support authentic practice (Roth, Bowen & McGinn, 1999).

Finally, students need to be evaluated on how well they were able to apply the tools used to create the visualizations. In principle, mastery of the underlying technology should be evident in the final product (Lewis, Petrina & Hill, 1998). In the visualization curriculum, success or failure is unlikely to be a binary proposition. Earlier activities may focus more on applying these tools in a discrete fashion, making it easier for the student to reflect on the outcome and judge their own success. Students should be able to make use of multiple resources (e.g., knowledgeable peers, tutorials, and the teacher) for developing understanding of the capabilities and appropriate application of these tools. In later assignments, evaluation of understanding and use of these tools will be based more on a measure against of the goals of the project, and the judgement of the intended audience as to its success.

Acknowledgements

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