Technology-Based Content through Virtual and Physical Modeling: A National Research Study

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Introduction

Visualization is becoming more prevalent as an application in science, engineering, and technology related professions. The analysis of static and dynamic graphical visualization provides data solutions and understandings that go beyond traditional forms of communication. Ahern (2007) asserted that development of visualizations through analysis exceeds simple generation of imagery and incorporates data exploration, visual code debugging, comparative analysis, quantitative analysis, and presentation graphics. Evidence of this is seen by current visualization projects at The National Center for Computational Sciences that cover a wide range of application areas including astrophysics, material science, climate dynamics, fusion, and turbulent combustion.

The use of visualization to convey scientific/technical content and research enhances viewers' abilities to identify and retain significant information that is not as straightforwardly permitted through traditional mediums (Bomphrey, 2006; Payri, Pastor, Garcia, &Pastor, 2007). Visualization allows for complex processes, often involving multiple models, scales, and disciplines, to be represented in a clear and direct manner (Schuchardt, Black, Chase, Elsethagen, & Sun, 2007). Visualization-based content through electronic representations highlights important features and processes that can be used for experimental verification (Debowska, Jakubowicz & Mazur, 1999). Scientific visualization allows investigators to construct meaning from large amounts of data (Robertson, Mackinlay, & Card, 1991). Meaning is constructed by taking advantage of the human perceptual structure through the use of animation and visualization to stimulate the cognitive identification of patterns in information. Investigating the presentation of information through a visual medium or by manipulating information through a visual-based application can be approached through the analysis of viewer preferences, learning perspectives, or viewer orientation. Examples of this include the animation synthesis research by Ong & Hilton in 2006 and the three-dimensional visualization application research by Fellner in 2007.

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The study of technology-based content and the application of conceptual modeling, data-driven visualizations, physical modeling, and presentations simultaneously promote technological, technical, and visual literacy (Clark & Ernst, 2006). Technological and visual literacy maintain a significant role in successful knowledge and skill development in technology-based career paths. Modeling, visualizing, and presentations reinforce the concepts of communication technology. This strengthens individual technological and scientific knowledge and ability while providing opportunities to firmly grasp the principles behind the technologies (Newhagen, 1996).

Written, spoken, and mathematical languages empower people to communicate ideas and analyze and understand simple and complex information. The same is true about graphic languages. Often it is through the use of graphic tools and the application of graphical skills that complex information becomes apparent and understandable. There is a distinct advantage in conceptualizing in one's mind an artifact such as a building, a mechanical system, or the multitude of variables in a scientific experiment when they are presented verbally, mathematically, or graphically.

Background and Purpose

The National Science Foundation awarded the Visualization in Technology Education Project (NSF# ESI-0137811) initial funding to develop and pilot test 12 units of instruction. The units were selected by surveying professionals in science and technology disciplines to identify the most pressing issues associated with emerging technologies. The selected topics were then developed into units by professionals in technology education, science education, graphics education, and psychology. The units utilize scientific visualization as the means of conveying technological and scientific concepts to students.

The Visualization in Technology Education units are based on benchmarks identified in the Standards for Technological Literacy (International Technology Education Association, 2000) and highlight National Science Education Standards (National Science Teachers Association, 1996) when appropriate. The units are specifically designed to provide technological experiences to students through the use and creation of visualizations. Each unit was designed to address technological competencies through learning, researching, and creating visualizations. A design brief format was developed for each unit of study to better facilitate this form of learning. Professionals in visualization assisted in the development of each topic's content so that not only the Standards for Technological Literacy are addressed, but the learner is led into the development and creation of visual-based representations.

The instructional units include agricultural and related biotechnologies, medical technologies, transportation technologies, information and communication technologies, and the principles of visualization skills (refer to Table 1 for the instructional units).

Table 1
Visualization in technology education units

Unit 1: Communications Technology: Introduction to Visualization
Design process for graphic communication of technical and scientific information. Includes the inadvertent and purposeful graphical misrepresentation of information. Standard: Information and Communication Technologies of the Designed World.
Unit 2: Medical Technology: Imaging
History and societal ramifications of medical technology. Standards: Medical and Information and Communication Technologies of the Designed World.
Unit 3: Biotechnology: Polymerase Chain Reaction
History, social, and ethical implications of biotechnology and its application, especially relative to the polymerase chain reaction (PCR). Standard: Agricultural and Related Biotechnologies of the Designed World. .
Unit 4: Transportation Technology: Visualizing Rocketry
Basic aeronautical principles, the use of chemical reactions for rocket transport, and the application of Newtonian physics and mathematical tools in rocket design. Standards: Transportation Technologies and Information and Communication Technologies of the Designed World
Unit 5: Communications Technology – 3D Modeling and Animation
3D computer animation tools and use of object oriented graphics software to represent different types of pump technologies. Includes the mathematical and geometric basis for 3D modeling and animation. Standard: Information and Communication Technologies of the Designed World.
Unit 6: Energy and Power Technology
Forms of energy, law of conservation of energy, and the role that technological tools play in the transformation of energy from non-useful forms to useful forms. Includes renewable and nonrenewable energy resources. Standard: Energy and Power Technologies of the Designed World.
Unit 7: Bioprocessing
The use of bioprocessing technologies to produce the variety of products by the industrial, pharmaceutical, food, and environmental sectors. Standard: Agricultural and Related Biotechnologies of the Designed World.
Unit 8: Prosthetics
History, design, and construction related to prosthetics. Includes the societal implications of providing support for persons with disabilities.Standard: Medical Technologies of the Designed World.
Unit 9: Weather
Remote imaging technologies and data collection related to weather. Includes image measurement, sequencing, comparison, and enhancement as well as weather tracking. Hurricane Katrina and Rita are used as references.
Unit 10: Careers
Research and decision-making related to careers from a local to a global perspective. Includes working conditions, salary, educational requirements, and geographical considerations.

Table 1 (continued)
Visualization in technology education units

Unit 11: Nanotechnology
Nanotechnology with an emphasis on its multidisciplinary nature with the inclusion of fields such as chemistry, physics, biology, materials science, and engineering.
Unit 12: Biometrics
Biometric tools that include a wide range of biosecurity technologies that precisely confirm an individual's identity using physical or behavioral characteristics.

The twelve units are on six CDs (three instructor CDs and three student CDs). Each Visualization in Technology Education Instructor CD contains an overview of the unit materials, unit projects, teacher resources, and unit PowerPoint presentations. Areas of study within Visualization in Technology Education involve the use of science to create and develop visualizations to better explain a given topic. Numerous visualization techniques are used to effectively teach subject matter such as 2D illustrations composed through simple sketching software, 3D models generated with dynamic animation packages, and 2D graphing applications utilizing spreadsheets.

The purpose of these materials is twofold. The first is to focus on the skills, concepts, and principles inherent within the Standards for Technological Literacy – the de facto national standards for technology education in the United States. The second is to help students become better visual communicators and problem solvers.

Three overarching questions were addressed by both the original Visualization in Technology Education study, as well as the supplemental study. First, is the technological knowledge of students enhanced through the use of standards-based instructional materials? Second, can a student's preferred learning style serve as an indicator of spatial acuity? Third, do digital computing project-based activities improve technological competency? These questions resulted in thirteen hypotheses based on the goals approved by the National Science Foundation. The 13 hypotheses are presented in Table 2.

By the creation of visualizations, students learn to use different types of computer applications that will be useful as they select a direction for their future study. Also, areas within computational science, technology, and communication will be enhanced as they learn to communicate to a variety of audiences (Clark & Matthews, 2000). Students are not only developing visualization skills, but at the same time learning useful information and gaining skill sets that will make them better communicators and presenters. The overall design of Visualization in Technology Education materials is to link technology literacy standards to areas within scientific, visual, and spatial literacy through the understanding and development of knowledge and skills in scientific and technical visualization.

The outcomes, or final models, for activities within each unit can be conceptual or data-driven forms of communication. Conceptual modeling and data-driven modeling are the two fundamental types of visualizations that students create through the Visualization in Technology Education activities.

Table 2
Hypotheses for supplemental field-test year of the project

$H_0$1:	There are no differences in student pretest competency and student posttest competency in the 12 Visualization in Technology Education instructional units.
$H_0$2:	There are no differences in student spatial visualization pretest acuity and student spatial visualization posttest acuity.
$H_0$3:	There are no differences in female student spatial visualization pretest acuity and female student spatial visualization posttest acuity.
$H_0$4:	There are no differences in male student spatial visualization pretest acuity and male student spatial visualization posttest acuity.
$H_0$5:	There are no differences in rural area student spatial visualization pretest acuity and rural area student spatial visualization posttest acuity.
$H_0$6:	There are no differences in suburban area student spatial visualization pretest acuity and suburban area student spatial visualization posttest acuity.
$H_0$7:	There are no differences in urban area student spatial visualization pretest acuity and urban area student spatial visualization posttest acuity.
$H_0$8:	There are no differences in middle school student participants' spatial visualization pretest acuity and middle school student participants' spatial visualization posttest acuity.
$H_0$9:	There are no differences in high school student participants' spatial visualization pretest acuity and high school student participants' spatial visualization posttest acuity.
$H_0$10:	There are no differences in spatial visualization pretest acuity for student participants with predominant preferred visual learning styles and spatial visualization posttest acuity for student participants with predominant preferred visual learning styles.
$H_0$11:	There are no differences in spatial visualization pretest acuity for student participants with predominant preferred aural learning styles and spatial visualization posttest acuity for student participants with predominant preferred aural learning styles.
$H_0$12:	There are no differences in spatial visualization pretest acuity for student participants with predominant preferred reading/writing learning styles and spatial visualization posttest acuity for student participants with predominant preferred reading/writing learning styles.
$H_0$13:	There are no differences in spatial visualization pretest acuity for student participants with predominant preferred kinesthetic learning styles and spatial visualization posttest acuity for student participants with predominant preferred kinesthetic learning styles.

Conceptual models are created when an idea or process cannot be easily explained with words or mathematics but can be explained effectively using a picture or animation. Depending on the complexity of the topic, these models can be either two-dimensional or three-dimensional. Also, conceptual models are either static, such as a picture, or dynamic, as with an animation. Data-driven models summarize data sets to convey a large set of numerical information into a small concise way that is easily understood. Charts and graphs are typically used to show this type of information. Data-driven models can also be either two-dimensional or three-dimensional, based upon the number of independent variables to be shown. Regardless of whether the visualization is conceptual or data-driven, students need to know the best practices to show the information they are given in the Visualization in Technology Education activity and then develop a model and present it to the class using the appropriate software tools.

Modeling and visualization abilities are driven by spatial acuity (Sorby, 2006). Receptiveness to modeling and visualizing content presentations is largely dictated by learning experiences. This being the case, an investigation was needed that went beyond the assessment of technological content area competency gains through the use of the Visualization in Technology Education instructional materials. The evaluation of spatial acuity and learning preferences for student participants are important variables in visualization-based investigations (Sorby, 2000; Harris, Sadowski, & Birchman, 2006). The study of these variables allowed the researchers to investigate the spatial skill development of the students who used the Visualization in Technology Education materials.

Methodology

The primary purpose of this study was to examine the effectiveness of the visualization-based curriculum materials in teaching technology concepts as specified in the research questions stated earlier. Technology educators were selected from across the United States to pilot test the Visualization in Technology Education materials. They were solicited through the Southern Regional Education Board and the “High Schools That Work” program.

To assist in the evaluation of the materials, workshops were conducted before each pilot year to familiarize the participants with the materials and piloting procedures. In the fall and early spring of each pilot school year, multiple-choice tests were given before and after each unit to measure the extent to which students learned the content of the unit. The tests were developed and administered by the Research Triangle Institute, an external agency that conducts a wide range of research, including educational research. This institution also served as the evaluator for the project.

During the pilot testing some students participated in more than one Visualization in Technology Education unit. During the 2002–2003 school year, six Visualization in Technology Education teachers pilot tested the first four units. During the 2003–2004 school year, seven teachers were asked to pilot test the second four Visualization in Technology Education units. During the 2004–2005 school year, the seven pilot teachers tested all or a selected number of the last four units.

Through analysis of the data collected in the pilot study on units 1 to 12, it was found that students who participated in the Visualization in Technology Education units significantly increased their knowledge in the areas of technology covered by the units. In addition, teachers rated all of the twelve units as effective in enhancing students' understanding of the intended learning goals and objectives. This rating was consistent with the results of the student test scores.

Supplemental Research Study

In 2005 the Visualization in Technology Education project was granted an additional year (2005-2006) to field-test the units while collecting data. To further disseminate the Visualization in Technology Education materials, a workshop was conducted in July 2005, randomly selecting 14 volunteers from across the United States to test the materials in their final, published form.

Assessments

In the fall and early spring of the 2005-2006 school year, three assessments were administered at each of the 14 field test sites. One assessment consisted of the pre-assessments and post assessments for each unit. These instruments included 20 multiple choice questions and were intended to measure student knowledge gained after the completion of the unit and were directly correlated to the Standards for Technological Literacy (ITEA, 2000). As mentioned earlier, the instruments were developed by the Research Triangle Institute.

The second assessment was the Mental Rotation Test from the Purdue Spatial Visualization Test. This instrument assesses the ability of students to visualize three-dimensional objects after they have been rotated. It presents a three-dimensional drawing of an object. Five possible drawings of that object are presented, one of which accurately shows the object after is has been rotated to a new position. This test was used to determine if students improved their visualization capabilities as a result of using the Visualization in Technology Education instructional materials.

The third assessment was the VARK Questionnaire to measure the dominant learning style of a subject with respect to four dimensions: **V**isual, **A**ural, **R**ead/write, or **K**inesthetic. The primary reason for administering the VARK Questionnaire was to determine learning style preferences relative to spatial visualization, orientation, and acuity. The VARK Questionnaire is composed of 16 questions that require the student to choose the statement that best explains their learning style preference (Fleming, 2006). If more than one choice matches their perception, then more than one statement can be selected.

Fleming (1995) identified visual learners, coded with "V" by the VARK Questionnaire, as those who prefer information to appear in the form of graphs, charts, and flow diagrams. The most familiar method for information transfer in our society is speech. Speech is recognized through hearing and is consequently coded as aural (A) by the VARK questionnaire. Respondents with a preference for accessing information from written words would be coded as Read/writers

(R) since they prefer reading and writing for information acquisition. Those who prefer using all their senses (touch, hearing, smell, taste, and sight) are considered kinesthetic (K) learners. They prefer tangible, multi-sensory experiences in their learning.

In both the original research study and the supplemental research study, comparison groups were not utilized. Through the use of comparison groups, the researchers would have been able to identify more distinctive academic performance increases over non-visualization based strategies. However, student academic knowledge gains were uncovered in the single treatment group that included the pre/post testing approach.

Demographics

The field test population across the 14 sites included 879 students. No teacher or student participants that took part in the pilot test were permitted to participate in the field test study. The student participants ranged from grades six

Table 3
Student Participant Demographics (n = 879)

	n	**%**
Gender		
Male	534	60.75
Female	322	36.63
Missing	23	2.62
Grade		
6th	84	9.56
7th	228	25.94
8th	330	37.54
9th	99	11.26
10th	34	3.87
11th	28	3.19
12th	27	3.07
Missing	49	5.57
Ethnicity		
Asian	47	5.39
Black	214	24.36
Latino	19	2.11
Native American	8	0.94
White	583	66.28
Other	8	0.94
Geography		
Rural	297	33.79
Suburban	203	23.09
Urban	379	43.12

to 12. The field test sample was predominately male (534 = 61%). The ethnic distribution was representative as was the geographical distribution among rural, suburban, and urban areas.

Data Analysis

Collectively, student participants experienced statistically significant technological content knowledge gains in10 of the 12 Visualization in Technology Education instructional units as they relate to understanding the Standards for Technological Literacy-based content (Table 4). In Unit 4, Transportation Rocketry, and Unit 5, 3D Modeling, students experienced a notable improvement in technological content knowledge but the difference was not statistically significant at the $\alpha = 0.05$ level.

Table 4
t-test for unit content knowledge

Unit	*N*	*M*	*SD*	*df*	*t*	*p*
1. Communications Technology: Introduction to Visualization	88					
Pretest		3.98	2.28	84	7.84	<.0001
Posttest		6.26	2.13			
2. Medical Technology: Imaging	88					
Pretest		6.72	2.22	83	5.61	<.0001
Posttest		9.58	4.00			
3. Biotechnology: The PCR	49					
Pretest		5.73	2.21	45	3.18	0.0027
Posttest		8.00	5.17			
4. Transportation Technology: Visualizing Rocketry	115					
Pretest		7.84	3.82	106	1.04	0.3028
Posttest		8.17	4.45			
5. Communications Technology: Introduction to 3D Modeling and Animation	35					
Pretest		4.70	1.79	28	1.05	0.3046
Posttest		5.34	1.23			

Table 4 (continued)
t-test for unit content knowledge

Unit	*N*	*M*	*SD*	*df*	*t*	*p*
6. Energy & Power Technology	93					
Pretest		7.48	3.31	84	7.01	<.0001
Posttest		14.01	8.06			
7. Bioprocessing	35					
Pretest		5.86	2.68	34	7.8	<.0001
Posttest		13.51	5.07			
8. Prosthetics	98					
Pretest		7.25	3.63	86	6.43	<.0001
Posttest		10.36	3.90			
9. Weather	128					
Pretest		3.43	1.71	113	2.39	0.0187
Posttest		3.93	2.21			
10. Nanotechnology	23					
Pretest		5.35	1.94	22	5.54	<.0001
Posttest		8.91	2.98			
11. Biometrics	47					
Pretest		5.38	1.95	42	4.6	<.0001
Posttest		7.22	2.00			
12. Careers & Technology	75					
Pretest		7.00	3.25	68	12.8	<.0001
Posttest		11.12	2.61			

Student participants in the Visualization in Technology Education showed spatial visualization enhancement as measured by the Purdue Spatial Visualization Test. However, the improvement was not found statistically significant at the $\alpha = 0.05$ level (Table 5).

Table 5
t-test for Overall Purdue Spatial Visualization Test (n = 572)

	M	*SD*	*df*	*t*	*p*
Pretest	12.85	6.54	512	1.94	0.053
Posttest	13.56	6.87			

Female participants in the Visualization in Technology Education program showed a high degree of spatial visualization enhancement as measured by the Purdue Spatial Visualization assessment. The improvement was found to be statistically significant at the $\alpha = 0.05$ level (Table 6). Male participants showed minimal spatial visualization enhancement measured by the Purdue Spatial Visualization assessment. The improvement was found not to be statistically significant at the α = 0.05 level (Table 6). However, males achieved higher initially on the Purdue Spatial Visualization assessment than females, suggesting a possible ceiling effect.

Table 6
t-test for overall Purdue Spatial Visualization Test by gender

Gender	***N***	***M***	***SD***	***df***	***t***	***p***
Male	362					
Pretest		13.38	6.85	329	0.07	0.944
Posttest		14.31	7.33			
Female	210					
Pretest		11.16	5.59	182	3.39	<0.001
Posttest		12.28	5.79			

Participants from rural, suburban, and urban schools in the Visualization in Technology Education program showed spatial visualization enhancement as measured by the Purdue Spatial Visualization assessment. However, the improvement was found not to be statistically significant at the α = 0.05 level (Table 7).

Table 7
t-test for Purdue Spatial Visualization Test based on geography

Location	***N***	***M***	***SD***	***df***	***t***	***p***
Rural	158					
Pretest		13.82	5.72	153	1.83	0.068
Posttest		15.00	5.93			
Suburban	118					
Pretest		17.74	7.59	102	1.5	0.137
Posttest		18.67	6.73			
Urban	296					
Pretest		12.99	6.32	255	0.49	0.623
Posttest		14.44	6.84			

Middle and high school participants in the Visualization in Technology Education program showed spatial visualization enhancement as measured by the Purdue Spatial Visualization assessment. However, the improvement was found not to be statistically significant at the α = 0.05 level (Table 8).

There was no statistically significant difference among Visualization in Technology Education participants relative to their preferred learning style and gains on Purdue Spatial Visualization assessment (Table 9). Eighty-eight student participants did not complete the VARK Questionnaire.

Table 8
t-test for Purdue Spatial Visualization Test

Level	*n*	*M*	*SD*	*df*	*t*	*p*
Middle School	410					
Pretest		11.35	5.58	375	1.19	0.233
Posttest		12.00	6.31			
High School	162					
Pretest		17.51	7.11	136	1.78	0.076
Posttest		17.51	6.67			

Table 9
t-test between VARK preferred learning styles and Purdue Spatial Visualization (n=572)

Learning Styles	*M*	*SD*	*df*	*t*	*p*
Visual					
Pretest	0.71	4.50	149	0.23	0.819
Posttest	0.90	5.00			
Aural					
Pretest	0.97	3.51	82	-0.19	0.850
Posttest	0.80	4.05			
Read/Write					
Pretest	0.37	3.70	94	1.14	0.257
Posttest	1.36	4.22			
Kinesthetic					
Pretest	0.80	4.33	95	0.39	0.696
Posttest	1.20	4.94			

Conclusions and Recommendations

This study contributes to the findings established by previous Visualization in Technology Education research that individual technological and scientific knowledge and abilities can be strengthened through the study and creation of visualizations (Clark & Ernst, 2006; Ernst & Clark, 2007). From the analyses of the Visualization in Technology Education field test data, it was found that students who participated in the program significantly increased their knowledge in the areas of technology in 10 of the 12 units. In Unit 4, Transportation Rocketry, and Unit 5, 3D Modeling, students showed some gain in technological content knowledge but the gain was not statistically significant. An observational follow-up on these two units revealed that some teacher participants reverted to traditional methods instead of those prescribed by the project. Both Rocketry and 3D modeling have a relatively long history in technology education as a means of conveying important concepts and principles. This content can be deepened and strengthened through virtual means with activities that apply mathematical (geometric), aeronautical, and physics principles. However, this can be accomplished only if the teacher follows the prescribed instructional and laboratory practices. With the exception of these two units, this study supports the conclusions of previous research that showed student retention of information is enhanced through scientific visualization (see Bomphrey, 2006; Payri, Pastor, Garcia, &Pastor, 2007).

Females showed higher gains than males on the Purdue Spatial Visualization Test and thus showed higher visual acuity gains. However, male participants had higher initial spatial abilities than females. There are a number of reasons why this occurred such as different opportunities to manipulate 3D objects and preferences for certain types of activities. However, none was measured by this study.

There was a continuous increase in initial spatial ability with increasing grade level. This was expected, of course, due simply to increasing maturity and increased opportunity to manipulate 3D objects. Based on the researchers' informal observations, an increase in the inclusion of virtual-based activities would have developed the spatial acuity of the participants even more. Some of the instructional units relied on physical rather than virtual modeling activities. This was done to appeal to a larger variety of learner style preferences. However, there is evidence by Sorby (2000) that virtual object manipulation is most effective in enhancing spatial acuity.

The preferred learning styles of the participants were rather evenly distributed by gender and grade level. Those who had Reading/writing as their preferred learning style showed slightly greater gains in spatial visualization than those with Visual, Aural, or Kinesthetic learning styles.

The researchers found indirect relationships between technological literacy, visualization, and learning styles. Learning styles and their relationship to visual experiences is complex. The findings from this study did not find a relationship between learning style and the utilization of visualizations. Thus, the study reinforced the notion that many students prefer multi-modal forms of learning, even if they have a dominant learning style preference. More research is needed to find better ways to link students learning styles to the type of materials and activities typically found in technology education courses.

The abilities to problem-solve and think critically can be augmented in technology education curricula through the design and the creation of visualizations. This study showed that the use of digital media, combined with standards-based content, produces materials that can meet the Standards for Technological Literacy. The results of this study support further use of this new and innovative form of instruction.

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