AC 2008-419: VISUAL SCIENCE AND STEM-BASED 6-12 EDUCATION

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VISUAL SCIENCE AND STEM-BASED 6-12 EDUCATION

Abstract

Visual science encompasses an array of content based on cognitive science, optics, computer science, engineering, and various other disciplines connecting the study and development of natural and man-made visual-based systems and their interactions. Engineering processes are major components of technology education curricula, and engineering itself is predicated on mathematical and scientific concepts, principles and skills. The integration of scientific, technological, and mathematical concepts, with the shared and required engineering processes, skills, and visualization abilities, are the focal points of this investigation. Abilities of students to visualize rotated three-dimensional objects are central to understanding and interpreting scientific, technological, and mathematical visual-based information.

Six-12 students’ spatial visualization rotation abilities were assessed. This investigation utilized the Purdue Spatial Visualization Test to assess visual aptitudes prior to the onset of instruction and then again after the completion of instruction while implementing a technology education scientific and technical visualization standards-based curriculum. Student participants experienced high degrees of spatial visualization enhancement measured by the Purdue Spatial Visualization assessment. Further Spatial Visualization data analysis uncovered interesting outcomes. Male scores reflected higher initial spatial visualization achievement than females, indicating that they may develop spatial abilities in earlier stages of mental development. Other similar findings are discussed in the study.

Study in engineering, mathematics, science, and technology-based content through scientific and technical visualization standards-based curriculum that applies conceptual and physical modeling, presentations, and data-driven visualizations supports the study and development of visual literacy and visual science in 6-12 educational environments. Investigation based on the visual sciences and their roles in education provide considerable measures of support for visual learning allowing for knowledge and skill expansion in science, technology, engineering, and mathematics.

Introduction

The use of visual-based systems in modern culture and education is becoming more prevalent, requiring schools to adapt their curricula and instructional practices accordingly. Visual literacy is becoming central to curricular initiatives as society begins to rely heavily on visualization and visual communication strategies. Education, aesthetics, communication, ethics, research, and other aspects of learning have placed emphasis on visual science and visual literacy as a response to our increasingly complex, highly visual, and interconnected society. Developing instructional materials and methods of instruction that develop visualization abilities, meeting the needs of technology educators, and preparing students for future careers in STEM areas are focal components of new research initiatives. The study of engineering and technology-based content and the application of conceptual modeling, data-driven visualizations, physical modeling, and presentations promote visual literacy. Visual and technical literacy maintain a significant role in successful knowledge and skill development in engineering and technology career paths. Data and information collected from focused investigations is beneficial to pre-engineering education.
and 6-12 outreach through the expansion of research and extension of knowledge. Research-based findings provide for the continued successes in engineering, technology, and society.

Data have indicated that students, especially women, are entering college with deficient visualization skills. Having deficient visualization skills may lead to students becoming discouraged and be the reason that many end up dropping out of science, technology, engineering, and mathematics-based majors. Visualization skills are especially important in technical professions such as engineering. Data have also indicated that well-developed visualization skills are important for developing an understanding in subjects such as basic and structural chemistry. Research on the progression of students through the educational system has indicated that students considering engineering as a career start preparing as early as elementary school. In order to better prepare students, it is essential that research endeavors provide empirical evidence for the types of instructional approaches and materials that are most likely to facilitate student learning and skill development.

Traditional approaches to learning often fail to define the relationships among concepts within a field of study and certainly fail to demonstrate relevance of learning in different fields. Highly visual modes that promote visual ability and skill present interconnectivity between disciplines such as science, technology, engineering, and mathematics. Spatial ability assists in recognizing, observing, recording, describing, classifying, and communicating two-dimensional and three-dimensional shapes, structures, orientations, and positions of objects, properties, or processes. Mental manipulation of these shapes, structures, orientations, and positions by rotation aid in the generation of mental representations.

Engineering processes are major components of technology education curricula, and engineering itself is predicated on mathematical and scientific concepts, principles and skills. Student visual ability and skill development has been a priority of technology, engineering, and graphics educators for many years. Central to visual ability is spatial visualization. Spatial visualization is a current area of interest in many disciplines, stemming from the documented relation spatial visualization ability has with success in mathematics, science, and engineering graphics. As a result, mathematics, science, and engineering graphics researchers are concentrating their efforts on devising ways to increase student spatial ability.

Understanding how to create conditions and implement practices that support the development and expansion of visual ability and skill is a daunting challenge. There are numerous indicators of effectiveness of visual-based learning materials according to a research study conducted by Katsioloudis in 2006.

- the effective visual-based learning indicators included the amount of detail contained in the visualization used
- the method by which the visualized instruction is presented
- students’ interest and engagement
- the manner in which objectives are presented to the students
• the technique used to focus student attention on the essential learning characteristics in the visualization materials
• types of assessment employed to evaluate student learning
• instructors’ ability to effectively and efficiently understand integrated visual-based learning materials
• relevance of the materials
• direct correlations between the materials and the learning objective
• the level of the technology available to the student
• the hardware being used by the student
• teachers’ confidence in the area of visual teaching
• the amount of equipment
• training the instructor has with equipment
• learning styles of the students

There are considerations and an apparent method to the implementation of visual-based learning materials, but it is yet to be determined if visual-based learning materials contribute to the enhancement of student spatial ability. The intent of this study is to accomplish just that. Do standards-based visual learning materials enhance students’ abilities to visualize three-dimensional rotated objects? Each student interprets visual images through his or her own distinctive mental sieve based on background and experience. Visualization and interpretation is a developed skill, making improvement possible. The integration of scientific, technological, and mathematical concepts, with the shared and required engineering processes, skills, and visualization abilities, are fundamental to this investigation. Abilities of students to visualize rotated three-dimensional objects are central to understanding and interpreting this scientific, technological, and mathematical visual-based information.

Spatial Visualization Assessment
Spatial visualization involves mentally rotating, twisting, or inverting a perceived object. Research has shown that the Purdue Spatial Visualization Test - Visualization of Rotations measures spatial visualization ability. The Purdue Spatial Visualization Test - Visualization of Rotations is one assessment of the numerous Purdue Spatial Visualization Test measurement instruments. The rotations test assesses the abilities of students to visualize rotated three-dimensional objects. The test consists of thirty questions that call for students to employ their spatial abilities requiring students to study how a given object is rotated, visualize what a second object would look like when rotated in exactly the same manner as the previous object, and select the rotated object that depicts the second object rotated in the correct position from among five rotated object answer choices.
The Purdue Spatial Visualization Test - Visualization of Rotations is a widely known instrument that has been used in countless research studies. Its notoriety and use has much to do with its reliability and validity\textsuperscript{16}. Many studies conducted present findings indicating gender and age discrepancies on the Purdue Spatial Visualization Test - Visualization of Rotations \textsuperscript{4, 17, 18}.

**VisTE**

The VisTE (Visualization in Technology Education) Project was a three-year National Science Foundation funded instructional materials development project (ESI-0137811) which developed visualization-based materials based on the *Standards for Technological Literacy* for use in technology education grades 8-12. The goal of these materials was to integrate science and technology and promote technological literacy through the creation of student computer-generated visualizations. Over the three-year period, the project team developed and piloted 12 visual-based instructional units. The activities within each unit were visual-based, having students develop conceptual models that were static or dynamic. Also, students worked with data-driven models and image processing while developing presentation graphics. Usability and effectiveness data was collected, materials were revised, and the VisTE units were commercially published. Analyses of the instructional materials development project data uncovered that students who participated in the VisTE units significantly increased their knowledge in the areas of technology covered by the units\textsuperscript{3}. Table 1 indicates the types of visualizations created in each of the 12 units.

<table>
<thead>
<tr>
<th>Unit</th>
<th>Types of Visualization Created</th>
</tr>
</thead>
</table>
| Unit 1. Communications Technology: Introduction to Visualization | Graphing  
2D Conceptual Modeling  
Animation  
Presentation Graphics |
| Unit 2. Medical Technology: Imaging | Image Processing |
| Unit 3. Biotechnology: The PCR | 2D Conceptual Modeling  
Image Processing  
Animation |
| Unit 4. Transportation Technology: Visualizing Rocketry | 2D Data Modeling  
2D Conceptual Modeling  
Presentation Graphics  
Physical Modeling |
| Unit 5. Communications Technology: Introduction to 3D Modeling and Animation | 3D Conceptual Modeling  
Animation |
| Unit 6. Energy & Power Technology | Physical Modeling |
After fulfillment of the three-year VisTE project, the National Science Foundation granted a supplemental year of funding to explore the instructional materials beyond student knowledge and teacher usability. One of the investigational areas focused on VisTE’s impact on student spatial ability.

Technology educator volunteers were randomly selected from across the United States to field-test the VisTE instructional materials. To assist in the evaluation, a workshop was conducted before the field-test year to familiarize the teacher participants with the materials and data collection procedures. The five-day workshop consisted of both pedagogy and software skills associated with all VisTE units. Participating teachers were guided in the use of data collection instruments to be used throughout the coming school year associated with the project. Each field site administered the Purdue Spatial Visualization Test - Visualization of Rotations before beginning the VisTE instructional units and once again after the completion of the VisTE instructional units. A demographics survey was also added to the Purdue Spatial Visualization Test - Visualization of Rotations packet that assisted in collecting grade, gender, race/ethnicity, and geographical location information for the student participants.

The VisTE field test was composed of 14 teachers and 879 students. Five-hundred and twelve of the student participants had completed pretest/posttest information and scores for the Purdue Spatial Visualization Test - Visualization of Rotations submitted from their field site. The student participants...
range from grades 6 – 12. The field test student sample consists of a predominately male sample with 534 male participants and a representative ethnic distribution. The field test sites were relatively evenly geographically distributed. A majority of the students were 7th and 8th graders, male, white, and urban. At over 24 percent, black students are proportionally representative of the overall population percentage; other races/ethnic groups are underrepresented. Detailed demographical information can be found in Table 2. Although the grant originally was intended to reach students in grades 8 through 12, it was found that many of the eighth-grade teachers also taught sixth and seventh grades, because of the structure of the schools. In most schools, the eighth grade is part of junior high, consisting of sixth, seventh, and eighth grades.

<table>
<thead>
<tr>
<th>Grade</th>
<th>Gender</th>
<th>Race/Ethnicity</th>
<th>Geography</th>
</tr>
</thead>
<tbody>
<tr>
<td>6th graders</td>
<td>9.56% Male</td>
<td>60.75% Asian</td>
<td>5.39% Rural</td>
</tr>
<tr>
<td>7th graders</td>
<td>25.94% Female</td>
<td>36.63% Black</td>
<td>24.36% Suburban</td>
</tr>
<tr>
<td>8th graders</td>
<td>37.54% No response</td>
<td>2.62% Latino</td>
<td>2.11% Urban</td>
</tr>
<tr>
<td>9th graders</td>
<td>11.26%</td>
<td>Native American</td>
<td>0.94%</td>
</tr>
<tr>
<td>10th graders</td>
<td>3.87%</td>
<td>White</td>
<td>66.28%</td>
</tr>
<tr>
<td>11th graders</td>
<td>3.19%</td>
<td>Other</td>
<td>0.94%</td>
</tr>
<tr>
<td>12th graders</td>
<td>3.07%</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Unknown</td>
<td>5.57%</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

- Table 2: Student Demographics  N = 879

VisTE student participants experienced high degrees of spatial visualization enhancement measured by the Purdue Spatial Visualization Test - Visualization of Rotations. However, the improvement was found not to be statistically significant at the $\alpha = 0.05$ level for female participants (Table 3). Male VisTE participants experienced minimal degrees of spatial visualization enhancement. However, males achieved higher initially on the Purdue Spatial Visualization assessment than females. VisTE middle school student participants collectively experienced a degree of spatial visualization enhancement but not as high as VisTE high school student participants. As a group, neither middle school or high school participants experienced spatial visualization improvement found to be statistically significant at the $\alpha = 0.05$ level (Table 3).
### Table 3: Purdue Spatial Visualization Test - Visualization of Rotations Results

<table>
<thead>
<tr>
<th>Group</th>
<th>D.F.</th>
<th>t statistic</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>All Students</td>
<td>512</td>
<td>1.94</td>
<td>0.0532</td>
</tr>
<tr>
<td>Female Students</td>
<td>182</td>
<td>3.39</td>
<td>0.0009</td>
</tr>
<tr>
<td>Male Students</td>
<td>329</td>
<td>0.07</td>
<td>0.9439</td>
</tr>
<tr>
<td>Middle School Students</td>
<td>362</td>
<td>1.19</td>
<td>0.2333</td>
</tr>
<tr>
<td>High School Students</td>
<td>149</td>
<td>1.78</td>
<td>0.0763</td>
</tr>
</tbody>
</table>

### Conclusions

Findings from this study confirm much of what previous research has established concerning visual acuity based on gender and age. However, this research presents the possibility that with properly implemented visual-based learning materials, visual abilities can be enhanced and the existing gender and age discrepancies will be alleviated. Further research pertaining to effective visual-based learning indicators and effective visual ability and skill building elements in visual materials needs to be done.

The findings from these types of research studies will provide educators with known effective techniques and materials they can use to help meet the challenges they face in the formation of environments that are conducive to student development. Continued research will also provide future materials developers with a foundation from which to develop curricula.

Technological changes are increasing in rate and impact, and therefore technology educators are constantly challenged with providing instruction on technologies that are new and ever changing. These challenges act as the stimulus for potential directions of research in education. Meeting these challenges requires technology educators to master new material on topics they may have never received training on themselves and also develop instructional practices that facilitate student learning of emerging technologies in ways that promote technological literacy. One way to help technology educators meet the challenge is to provide teachers with a method of instruction which has empirical support for being an effective method to facilitate student learning, knowledge transfer, and promote scientific and technical literacy.

Visualization-based learning is an active and constructive approach to learning. While data already promote the use of visual methods of presenting instruction in an effort to meet the needs of the diverse learning styles represented in today’s classrooms, educators have not yet tapped the true potential of visualization-based learning. More specifically, rather than educators using visual aids to teach while students learn individually or in collaborative groups, visualization-based learning engages the student and promotes learning by having students create their own graphical representations of learning.
Visualization-based learning not only provides students with an active and constructive medium with which to develop and synthesize their own learning, it also promotes good design, visualization, and problem solving skills. Creating a graphical representation involves mastering the content which is to be presented and also requires the learner to complete an analytical process in order to determine the most appropriate type of graphical representation. The first step in the analytical process is for the student to classify the type of information they are working with. This decision will help the student determine what type of graphic they should design. Graphics can be classified into two major categories: data-driven and concept-driven. Data-driven graphics are based on numerical or quantitative types of information. Concept-driven graphics are based on conceptualizations of models or processes and are more qualitative in nature.

Another part of the analytical process involves identifying the intended audience. Completing this step requires the student to take into account differences in cognitive abilities for different ages of potential target audiences. Completing this step helps the student determine the level and amount of information they should present. For example, designing a graphical representation of how simple machines work would have a very different outcome if the graphic was to be used to teach third graders rather than high school seniors. The graphic developed for teaching high school seniors might emphasize the role of Newtonian physics whereas the graphic for teaching third graders might emphasize how the different components are assembled.

Visualization-based learning has the potential to enhance student learning in technology education as well as assist in the development of spatial acuity. However, data are needed to provide empirical support for visual-based learning as an effective instructional practice and also to support the continued development of visual-based instructional materials.

Overall, more research is needed in areas related to visualization and its role in pre-engineering education. As engineering and design become more prevalent in the public schools, the need to have visual literacy increases in the curricula we offer to students. Considering this, the authors of this study recommend that more research is needed on how to develop good visual-based materials, as well as increase student visual skill within all levels of 6-12. Also, more research is needed on developing new and better instruments to gauge visual skill development, particularly for populations in elementary and secondary schools. The influence of the visual media that students interact with everyday needs to be researched in order to see how information from these areas can be harnessed to improve visual skills. Finally, more investigation on what makes a person visually literate, as well as technologically literate, needs to be emphasized in STEM research. Considering all of the above, the authors of this study see the need to offer more visual literacy to students in 6-12 as the 21st century quickly becomes the visual age.

**Bibliography**


