Parallels between Engineering Graphics and Data Visualization: A First Step toward Visualization Capacity Building in Engineering Graphics Design

Vetria L. Byrd

Purdue University

Introduction

The definition of visualization in engineering graphics has evolved over the years due in part to extensive research in visualization by the engineering design graphics profession. The literature indicate research in the areas of engineering graphics and the use of visualization has grown from improvement of visualization skills, and the development of visualization tools to the exploration of spatial ability and perception in engineering graphics.

The goals of this paper are three-fold: (1) to provide a high level overview of how the definition of visualization has historically been defined and shaped in engineering graphics, (2) provide an introduction to data visualization as a process, and (3) explore the parallels between the process of visualizing data and the engineering design process as first steps toward visualization capacity building in engineering design.

Literature Review

Visualization Skills Many people from very diverse disciplines have attempted to define the concept of visual literacy and as a result those representing the different disciplines and paradigms each interpret visual literacy in a way that reflects their contribution or way of thinking (Avgerinou et al., 1997). The use of and improvement of visualization skills is often thought of as visual literacy. Visual literacy is categorized into three areas: human abilities, teaching strategies and the promotion of ideas (Avgerinou et al., 1997). Broadly defined, visual literacy refers to the skills which enable an individual to understand and use visuals for intentional communication with others (Ausburn & Ausburn, 1978). For engineering graphics, visualization skills for engineering students is referred to as the ability to systematically manipulate objects and coordinate systems and the ability to interpret drawings (Crown, 2001).

Visualization Tools The field of engineering graphics has developed from the use of drafting table and T-squares to computer aided design drafting (CADD) (Crown, 2001). CADD software, which allows for the manipulation of a reference coordinate system (Crown2001), enhances the ability to visualize ideas (Roberson and Radcliffe, 2009) in engineering graphic design. CADD vendors create 2D and 3D software solutions to aide in the design process that allows for realistic renderings and communication of design ideas. 3D graphics software commonly employed in the design industry and for graphics and design teaching (Chang et al., 2016), are often difficult for students with limited "visualization skills" to retain visual information (Carroll, 1993). Research in developing spatial skills for engineering students (Sorby, 2009), (Veurink & Sorby, 2014) and spatial training (Martin-Gutierrez, et al., 2013) for students added another dimension to the role of visualization in engineering graphics design.

Exploration of Spatial Ability and Perception The history of spatial research in engineering design (described by Miller and Bertoline, 1991), briefly summarized here was spearheaded by Eliot and Smith (1983) who identified three major phases in the development of spatial testing, which in turn led to various theories and research investigations in spatial visualization:

> Phase 1 (1901-1938): Effort by psychologists to establish and identify the presence of a spatial factor.
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> Phase 2 (1938 – 1961) Eliot and Smith (1983) identified two major categories to describe several terms advocated by several researchers at the time to identify spatial factors and how they varied from each other: (1) The ability to recognize spatial configurations; and (2) the ability to mentally manipulate spatial configurations.
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> Phase 3 (1961-1982) Studies designed to determine the interrelation of spatial abilities with other abilities and the discovery of various sources of variance in testing of spatial abilities.

In 2001, Strong and Smith proposed an additional fourth phase to include the process of establishing computer technology effects on spatial skills and measurement of these skills. A significant amount of research has been done examining the role of spatial visualization ability, orthographic projection and perception in engineering design.

Scholars of engineering design research define visualization in various ways. Kelly (1928), described visualization as the ability to imagine the rotation of depicted objects, the folding and unfolding of flat patterns, and the relative changes of positions of objects in space. French (1951) described visualization as the ability to comprehend imaginary movement in three-dimensional space or to manipulate objects in imagination (pp. 3-4). McGee (1979) defined spatial visualization as the ability to mentally manipulate, rotate, twist, or invert pictorially presented visual stimuli. Miller and Bertoline (1991) described visualization as the ability to read and develop orthographic drawings or to solve descriptive geometry problems; that is if a student were able to develop orthographic or descriptive geometry drawings then the student had visualization ability.

Research on the development and assessment of enhancing 3D spatial visualization skills in spatial visualization abilities and work on perception have been extensive. Space constraints prevent a thorough review of this work, however, the contributions to the enhancement of 3D spatial visualization skills and perception have proven to enhance student success, particularly women, in engineering.

Visualization Process In engineering graphics design, often the term "spatial visualization" is used interchangeably or is combined with the broader terms of "visualization" or "spatial ability" making it difficult to discern the differences between them (Braukmann, 1991). Before exploring the topic of visualization further, it is necessary to explain, in the context of data visualization, what the author means by the term "visualization." Visualization is a process that transforms raw complex data into a visual representation for the purpose of gaining insight into what the data represents. Visualization aids in explaining complex concepts, analyzing data, discovery, decision making, and storytelling. Data visualization is a process that transforms data from a raw complex state into a visual representation for the purpose of gaining insight (Card et al., 1999) into what the data represents. The process of visualizing data (Fry, 2007) entails seven stages: (1)Acquire - acquiring and providing structure for the meaning of data, (2) Parse – provide some structure for the data's meaning, (3) Filter – remove all but the data of interest, (4) Mine – apply methods from statistics or data mining as a way to discern patterns, (5) Represent - choosing a basic visual model, (6) Refine – improve the basic representation to make it clearer and more visually engaging and lastly, (7) Interact - adding methods for manipulating the data. The process of visualizing data is iterative. The key is understanding what each stage represents, the tasks to be performed and the skills needed to prepare the data for the next stage.

Parallels between Data Visualization Process and the Engineering Graphics Process

The engineering process is specific to each project but generally speaking involves several steps to conceptualize, design and communicate design outputs. An engineering process (adapted from Lieu and Sorby (2015) and internet source) includes: (1) Identify – define the problem, (2) Explore - do background research, (3) Define - specify requirements, (4) Ideate - brainstorm, evaluate and choose a solution, (5) Prototype - develop and prototype solution, (6) Choose - determine final concept (7) Refine - do a detailed design, (8) Present - get feedback, (9) Implement – implement the detailed solution, (10) Test – does the solution work? (11) Iterate/Life Cycle- verify solutions meets requirements, communicate results. Several of these steps logically map to steps in the visualization process.

Discussion

The value of visualization is evident. The ultimate goal of the engineering design process is to develop devices where everything fits together and functions properly (Lieu and Sorby, 2015). The goal of the visualization process is to identify patterns and relationships that exist to show

how the data features fit together to tell an insightful story about the data. The parallels described above are further strengthened by CAD tools like Energy3D that has functionality that allows for the reconstruction of activities that can be closely examined using learning analytics, giving researchers considerable flexibility in data mining (Xie et al., 2014). Coupling data visualization with the engineering design process has the potential to further simplify and solidify complex concepts for students. The ability to go beyond being data consumers to having the visualization capacity (Byrd et al., 2016) (Byrd and Cottam, 2016) to understand the entire life cycle of data is a desired skill in workforce development.

Conclusions

There are synergistic parallels between the engineering design process and the process of visualizing data. Despite its many different definitions in engineering design, having an understanding on multiple levels of the role of data and how it is represented throughout the life cycle of the data will better serve students as they explore complex engineering concepts. The data visualization process and the engineering graphics process facilitate four critical areas: (1) collaboration and teamwork, (2) creativity and imagination, (3) critical thinking, and (4) problem solving. This paper has highlighted parallels between the two processes. Research is needed to explore the impact of integrating the data visualization process, from the perspective of understanding the data lifecycle, into the engineering design process on deeper learning and problem-solving to enhance engineering design courses as well as assessing the impact, if any, for students identified as having limited “visualization skills” as well as assess gender differences.

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