A Delphi Study as a First Step in Developing a Concept Inventory for Engineering Graphics

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Abstract

Unlike many other subjects in engineering such as statics, dynamics, or strength of materials, engineering graphics instruction has changed significantly over the past century. The primary reason for this change is the development of new graphical tools and methods at an increasingly rapid pace. In light of this, it is important that graphics educators keep sight of the fundamentals in graphics education and not rush to change for the sake of new tools. Unfortunately, there is little agreement about what constitutes the fundamentals in graphics education. Further, there appears to be a significant international disconnect among graphics educators regarding what should be included in graphics instruction. In other science and engineering fields, such as physics, mathematics, statistics, and engineering science, concept inventories have been developed in recent years to define the fundamental concepts in those disciplines. The concept inventories provide educators with a standardized instrument that they can use to help design their courses and to determine if their students understand the fundamentals. The authors of this paper propose to conduct a Delphi study to define the fundamentals in graphics education. A Delphi study is viewed by many as the first step in the development of a concept inventory. This paper outlines the proposed study and describes the necessary next steps in the process.

History

Engineering graphics began in the mid-eighteenth century when Gaspard Mongé developed a method of graphically describing three dimensional solids and spatial relationships by means of interrelated projections on a two dimensional drawing surface. Considered the inventor of descriptive geometry, Mongé, used his calculations to aid the accuracy of artillery fire. Descriptive geometry techniques required painstaking attention to detail through the use of drafting tools and is still a fundamental topic in many European engineering programs.

Engineering graphics in the United States was based on a more pragmatic approach and the direct method of descriptive geometry was developed at West Point in the late nineteenth century. In the beginning of the twentieth century, engineering graphics education in the United States had
a strong mechanical influence because mechanical engineering was the dominant discipline in teaching and developing the course topics. Most engineering schools required at least one engineering graphics course, many institutions required more than one, and many stand-alone engineering graphics departments existed. The early influence of mechanical engineering can still be seen in most engineering graphic textbooks today. (Pleck et al.) As shown in Figure 1, the history of engineering graphics has spanned more than a century and changed significantly over the decades.

![Figure 1. History of Engineering Graphics](image)

Throughout its history, engineering graphics has embraced the “tool of the day” migrating from hand-drafting tools such as T-squares and dividers to 2-D CAD software and finally to 3-D CAD fully integrated design systems. Graphics educators have discussed the benefits of one CAD package versus another; they have debated the need for inclusion of topics such as those found in traditional descriptive geometry; they have focused on local industry needs in designing their graphics courses; however, they have rarely, if ever, discussed the foundational concepts that should be included in a graphics course at any level. The Delphi study proposed here seeks to define these foundational concepts so that educators can design their courses to meet the needs of today’s students who will likely experience many changes in tools and graphics techniques over their careers.

**Concept Inventories**

A concept inventory is an instrument that helps faculty identify the concepts that their students do not understand and decide which misconceptions are the most prevalent. In addition, concept inventories can help define important fundamental topics for instruction and learning. The first concept inventory was the Force Concept Inventory developed and implemented by Hestenes
(1992) in the area of physics education. It was developed as a test to identify students’ misconceptions about Newtonian Force. Since the successful implementation of the Force Concept Inventory, there has been a strong interest in developing concept inventories for other STEM fields. The NSF-funded Foundation Coalition, headed by D. D. Evans (2003) at Arizona State, began working on developing concept inventories in the engineering disciplines in 2000. In the intervening years, a variety of concept inventories have been developed, including: materials, statics, heat transfer, chemistry, computer engineering, dynamics, and electronics.

The coalition stated in 2003 that “for the most part teaching of engineering subjects continues to be patterned after how instructors were taught when they were students of the subject rather then being informed by research of learning” (Evans et al.). They contended that reform in science, technology, engineering and mathematics (STEM) education is hampered partially due to the lack of good assessment instruments. Once implemented, the Force Concept Inventory assessment designed by Hestenes et al. stimulated a variety of reforms in physics education. “Such assessments can play an important part in relating teaching techniques to student learning.” (Hestenes) It is hoped that a concept inventory for graphics education can spur a similar movement of reform.

Figure 2 shows an example of an item found on the Force Concept Inventory. (Force Concept Inventory)

A golf ball driven down a fairway is observed to travel through the air with a trajectory (flight path) similar to that in the image below. Which following forces is(are) acting on the golf ball during its entire flight? 1. the force of gravity 2. the force of the “hit” 3. the force of air resistance

a. 1 only  
b. 1 and 2  
c. 1, 2 and 3  
d. 1 and 3  
e. 2 and 3

Figure 2. Force Concept Inventory Item
Figure 3 shows an example of an item from the Heat Transfer Concept Inventory.

(Heat Transfer Concept Inventory)

For the three configurations shown below, which is the correct statement about the fraction of the radiation emitted by surface 1 that is incident on surface 2. Surface 1 is the same size in each configuration.

The fraction of the radiation emitted by surface 1 that is incident on surface 2 is:

1. greatest for configuration A
2. greatest for configuration B
3. greatest for configuration C
4. the same for all configurations

Figure 3. Heat Transfer Concept Inventory Item

The Sorby Test

In 1998, Sorby (along with Mike Young), developed a test as a placement exam for introductory engineering graphics. The test was aimed at first-year engineering students who had taken drafting courses in high school. The items on the test closely mirrored content from the engineering graphics courses found at Michigan Tech at that time. A passing grade on the test enabled students to “place out” of first-year graphics courses at Michigan Tech, although very few of them were able to do so, likely due to a mismatch between the content of high school drafting courses and engineering graphics at the university level. The test consists of 50 items. Some of the items assess a person’s basic level of visualization ability and others assess their understanding of engineering drawing conventions. The test showed good reliability (KR20~0.8); however, it was never validated on a national basis and it included many items that would not be considered suitable for a true concept inventory. Despite this, the test has been used for assessment purposes in engineering graphics courses at Michigan Tech, Rensselaer Polytechnic Institute, and The Ohio
State University since its development. In pre-/post-testing at these sites, it was typically found that students showed statistically significant gains over the course of a term while enrolled in engineering graphics.

**Communication Graphics Concept Inventory**

Our ultimate goal is to develop an instrument which measures students’ conceptual knowledge of graphic communication. According to Allen (2006), the ultimate goal is to develop an instrument which is recognized on a national level as a useful tool for monitoring student learning or on an individual or classroom basis to comparing scores across universities.

Concept inventories are excellent instruments with which to validate the effectiveness of new teaching methodologies and curricular innovations. They can be used to assess student learning and to validate the effectiveness of new methodologies. In many established disciplines, professors teach in the manner in which they learned the subject and while the focus of graphics communication has changed over the years, it is entirely possible that graphics is being instructed in the same way it was taught many years ago. A concept inventory is also a useful tool in helping to define a “discipline.” The concepts tested on a concept inventory are typically thought of as fundamental to the discipline itself—if a particular topic is not found on a concept inventory, this often implies that it is of less importance in the grand scheme of things. Being able to focus on the important, fundamental concepts is important in an era of ever-tightening curricula.

**Need for a Concept Inventory in Graphics Education**

Engineering graphics is one of the highest enrollment courses in all of the STEM fields. Graphics is typically still a requirement for most engineering disciplines, particularly for mechanical and civil engineering. Common first-year engineering programs such as those at Virginia Tech, Texas A&M, Purdue, Ohio State and others contain a strong graphics component. In addition, graphics is taught in pre-engineering and in engineering technology programs at community colleges as well as in high schools. High school graphics is often taught aimed primarily at students who intend to become technicians and is typically taught in a traditional manner, with hand-drafting predominating. No consensus regarding optimal content for graphics courses exists, resulting in a large degree of variation among courses across the country. There is also a large disconnect between graphics in the high school, in the community college, and in the university system. The lack of uniformity in graphics courses is likely due to a lack of an acceptable instrument for assessing fundamental learning in graphics courses. A concept inventory for engineering graphics would assist educators at all levels in two areas: course design and course assessment.
A concept inventory for engineering graphics would identify “core” graphics topics so that educators could focus on these in their course design. A concept inventory would lead to a better connection between graphics courses at all levels, ensuring that high school and community college courses better map to the expectations of university-level graphics courses. A concept inventory would also enable faculty to assess student understanding of fundamental concepts in graphics to evaluate the effectiveness of the courses they teach and to make adjustments as necessary.

**Delphi Technique**

A Delphi study is a consensus-building forecasting technique that has been used by organizations, agencies, and corporations for making predictions, identifying priorities, and setting agendas (Sadowski). Although this technique was developed in the “business world,” a number of educational leaders including Clark & Scales (1999); Paige, Duggar, & Wolansky (1996); Volk (1993); Zargari, Campbell, & Savage (1995); and Sorby et al. (2005) have suggested its use in the design of curricula and programs. In this context, a Delphi study typically consists of four rounds, conducted with a panel of experts, to reach consensus on defining the important elements of a curriculum or the important concepts to be included in a concept inventory. A Delphi study also lends itself to reaching consensus without a need for face-to-face meetings among panel members, making the study relatively easy to implement through mail or online surveys, especially for a panel with broad geographic representation among its members. Over the next year or so, we will employ the Delphi technique in the identification of concepts for the concept inventory for graphic communications.

**Conclusion**

Engineering graphics is one of the most widely taught subjects in engineering with courses at universities, community colleges, and high schools. Graphics is typically part of the engineering and engineering technology programs as well as related programs such as construction management and many vocational fields. Inclusion of graphics topics in the curriculum has been greatly reduced over the years as engineering programs have struggled to accommodate deeper and deeper cuts in credits to graduation. Tools used in graphics education are constantly and rapidly changing. It is likely that between the time when a student matriculates into a program and the time when s/he graduates that the “tool of choice” will have changed. For this reason, it is necessary to have our graphics courses focus on the fundamentals, i.e., to make our courses “tool resistant.” Further, as graphics content is whittled away, we need to make sure that we retain fundamental concepts in order to prepare our students for careers in the coming years. In order for
this to happen, graphics educators must have a clear idea of what the fundamentals are and how to assess their teaching with respect to these fundamentals. To this end, a concept inventory fills a gap in graphics education and a Delphi study is the logical first step in the development of this important assessment tool.

References


