# Developing a Concept Inventory for Engineering Design Graphics

*Sheryl A. Sorby*
*Engineering Education Innovation Center*
*The Ohio State University*

*Mary Sadowski*
*Purdue Extended Campus*
*Purdue University*

*Heidi Steinhauer*
*Engineering Fundamentals*
*Embry Riddle Aeronautical University*

*Nancy Study*
*School of Engineering*
*Penn State Erie*

***Abstract***

*Unlike many other foundational subjects in engineering including 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. It is important that graphics educators keep the fundamentals firmly situated in graphics education as they accommodate for new tools and methods in their curriculum. Unfortunately, there is little agreement about what constitutes the fundamentals in graphics education. Through this project, we plan to develop a concept inventory for engineering graphics that will include standardized items in the fundamentals of engineering graphics.*

**Introduction**

No other engineering course enrolls as many students per year as engineering graphics. At the university level engineering and engineering technology students are enrolled in graphics courses taught by both engineering and technology faculty. Students are also enrolled in graphics courses at high schools, community colleges, and technical trade schools. The proposed project could have a significant national impact by helping professors design courses for engineering and engineering technology students, high school teachers design courses to prepare their students for advanced study, and community college instructors prepare their students to matriculate to four-year engineering and engineering technology programs while ensuring the optimal graphics education for meeting current and future needs.

Science and engineering fields, including physics, mathematics, statistics, and engineering science, have developed concept inventories in recent years to define the fundamental concepts in those disciplines, particularly those concepts where students have difficulties in understanding or have strongly held, existing misconceptions.

Concept Inventories are standardized instruments that provide instructors with formative feedback needed to design their courses and to determine their students' understanding of the course fundamentals. In a previous project, a Delphi study was conducted to define the fundamentals in graphics education. We will use the results from this Delphi study to develop an appropriate Concept Inventory for engineering design graphics that will be of value to educators across a broad spectrum.

A concept inventory is an instrument that helps faculty identify concepts that students do not understand and decide which misconceptions are the most prevalent. The literature suggests the problem is much deeper than student misunderstanding or confusion; instead, much of students' constructed knowledge is based upon incorrect inferences drawn from their daily lives (Halloun & Hestenes, 1985; Hestenes et al., 1992; Olds et al., 2004; Steif & Dantzler, 2005; Streveler et al., 2008). These misconceptions are based upon "common sense" and as such are deeply held (Olkun, 2003). To address these misconceptions, faculty must first identify which concepts students don't understand; a well-developed concept inventory can provide faculty with this essential information. The Force Concept Inventory developed and implemented by Hestenes, Wells, and Swackhamer is considered the seminal work in the field. It was developed as a test to measure the discrepancies between students' misconceptions and Newtonian Force concepts (Hestenes, et. al., 1992). 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 at Arizona State began working on developing Concept Inventories in the engineering disciplines in 2000. As of 2003, no less than 15 concept inventories have been developed, including: materials, fluids, statics, heat transfer, chemistry, wave, computer engineering, dynamics, and electronics (Evans, et al., 2003).

A Concept Inventory for engineering graphics will identify "core" graphics topics so that educators could focus on these in their course design. A CI for engineering graphics 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 graphics Concept Inventory would also enable faculty at all levels to assess student understanding of the fundamental concepts in graphics to evaluate the effectiveness of the courses they teach and to make adjustments as necessary.

**Research Design**

This project will employ the "Assessment Triangle" methodology to develop the CI for Engineering Graphics. This method has been used in the development of the Thermal and Transport science Concept Inventory (Streveler, et al., 2011) and is described here. There are three corners aligned in developing the CI—the cognition corner, the observation corner, and the interpretation corner.

***The Cognition Corner.*** This corner includes the identification of the inventory domain. Specifically, what concepts will be measured by the instrument? This corner typically consists of two steps, with the first being the conduct of a Delphi Study among a diverse panel of experts. The second step in this corner is to conduct a literature search to validate the results from the Delphi Study. Through this literature review, we will seek to verify that others have reported that students have difficulty with the topics identified by the panel of experts. Once this step is complete, we will have a robust list of topics around which to build our Engineering Graphics Concept Inventory.

***The Observation Corner*.** In this assessment corner, the items for the CI will be constructed through a variety of steps outlined here.

1. Draft open-ended questions about the concepts.
2. Solicit students who will be paid for their work and answer questions both in think-aloud problem solving sessions and in written form.
3. Using the student responses from the open-ended questions, we will convert the questions to multiple-choice items with distractors that include the common incorrect answers provided by the students during the think aloud sessions. Of primary interest is the identification of the student reasoning behind the incorrect answers, as this will provide meaningful distractors that identify not only that students have a misconception but what specifically that misconception is. These multiple choice responses will be beta-tested. In each case, at least three items will be developed for each fundamental concept to determine which items are more effective than others for ultimate inclusion on the CI for Engineering Graphics.
4. Conduct a content validity study among the surviving items. A panel of graphics educator-experts will revise the questions and determine if each item assesses the concept it is designed to assess.
5. Revise items based on the expert feedback, student feedback, the statistical performance (Interpretation Corner, described subsequently), and beta-test the final items with students.

***Interpretation Corner.*** The final assessment corner in the development of a CI relates to the statistical testing of the instrument. We will apply classical test theory and item response theory statistical analyses to the items on the CI before finalizing the instrument.

Classical test theory is predicated on two variables—reliability and validity. Reliability is the repeatability of an instrument (Moskal, Leydens, & Pavelich, 2002: Steif & Dantzler, 2005). In other words, if you use the same instrument multiple times, do you get the same or similar results each time? In order to have an instrument that is of use to the graphics community at large, it must be reliable. If a student can score poorly one day and earn a nearly perfect score the next, instructors will not find the results believable.

Validity is the accuracy of the instrument. One form of validity is content validity (Step 4, Observation Corner); however, there are others including construct validity testing which. attempts to answer the question: "Does the instrument measure the concepts we think it is measuring?" Criterion validity is the predictive ability between the instrument and another performance score (Moskal et al., 2002; Steif & Dantzler, 2005).

Item Response Theory is another statistical method used to model responses to determine the relative difficulty of items on the instrument. Item difficulty is an important parameter on a CI test because it will be an indicator of whether an item is too easy or too difficult to be of use in predicting student learning of fundamental concepts—if an item is too easy, everyone answers correctly indicating that the item is of not much use in discriminating between experts and novices; if an item is too difficult then random guessing will predominate and again it will not be possible to discern levels of expertise.

Based on the statistical analyses, we will revise and/or replace items and distractors as needed to ultimately develop a tool for future researchers in graphics education at all levels of the educational spectrum.

**References**


Evans, D.L., Gray, G.L., Krause, S., Martin, J., Midkiff, C., Notaros, B.M., … Wage, K. (2003). *Progress on concept inventory assessment tools.* Paper presented at the ASEE Frontiers in Education Conference, Boulder, CO.

Halloun, I.A., & Hestenes, D. (1985). The initial knowledge state of college physics students. *American Journal of Physics. 53(11)*, 1043-1055.

Hestenes, D., Wells, M., & Swackhamer, G. (1992). Force Concept Inventory. Physics Teacher 30(3), pp. 141-158.

Moskal, B.M., Leydens, J.A., & Pavelich, M.J. (2002). Validity, reliability, and the assessment of engineering education. *Journal of Engineering Education, 9*(3), 3512-354.

Olds, B.M., Streveler, R.A., & Miller, R.A. (2004). *Preliminary reesults from the development of a concept inventory in thermal and transport science.* Paper presented at the ASEE Annual Conference and Exposition, Salt Lake City, UT.

Olkun, H.D., (2003). Making connections: Improving spatial abilites with engineering drawing activities. *International Journal of Mathematics Teaching and Learning.*

Steif, P.S., & Dantzler, J.A. (2005). A statics conceot inventory: Development and psychometric analysis. *Journal of Engineering Education, 96*(4), 363-371.

Streveler, R.A., Litzinger, T.A., Miller, R.A., & Steif, P.S.. (2008). Learning conceptual knowledge in the engineering sciences: Overview and future research directions. *Journal of Engineering Education, 99*(3), 279-294.

Streveler, R. A., Miller, R. L., Santiago-Roman, A. I., Nelson, M. A., Geist, M. R., & Olds, B. M. (2011). Rigorous Methodology for Concept Inventory Development: Using the 'Assessment Triangle' to Develop and Test the Thermal and Transport Science Concept Inventory (TTCI), International Journal of Engineering Education 27 (5), 968-984.