The Development of a Concept Inventory for Engineering Graphics

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***Abstract*— A concept inventory is an instrument that helps identify concepts that students do not understand, and identify which misconceptions are the most prevailing. Concept Inventories can also be used in course design to identify potential topics and aid in assessment. Misconceptions can be deep-seated ideas and therefore challenging to overcome in terms of learning. The use of a quality inventory in engineering graphics may help address such matters. Presently, there exists no nationally normed and validated instrument that can be used in engineering graphics courses to assess misconceptions and competencies.**

In a previous project, a Delphi Study was used to help identify fundamental topics in the area of engineering graphics. The research team collaborated to produce items that attempted to address these concepts. Piloting these initial items helped improve the item stems and provided a starting point on the formation of distractors. Revised items were compiled into a trial instrument, from which data is being collected at the time of paper submission. Analysis will be conducted on the results of the trial instruments and further refinement will occur.

Keywords—engineering graphics; engineering education; concept inventory

I. Introduction

Teaching methods in engineering graphics are constantly changing. As technology evolves, so do the ways in which engineering students learn about engineering graphics. Instruction is often focused on the techniques used to create graphic representations, instead of the underlying concepts. It is equally important that students be familiar with current technologies, as well as develop an understanding of the methods being employed. It is generally agreed that students should be capable of a certain level of proficiency in standard practices and understanding of topics. Discrepancy in the latter can lead to nonconformities in educational practices, and decreased effectiveness in graphics education [5]. Without a standardized course of study to inform graphics pedagogy, it is up to institutions and instructors to ensure students' mastery and understanding of graphics concepts. Variation within the breadth and depth of both graphics instruction and student understanding are to be expected between populations, and one could imagine the potential benefits that availability of an instrument that can effectively and consistently gauge the understanding of students could provide.

II. Background

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. Concept Inventories are also used to identify important topics for a course and to aid instructors as they assess the educational outcomes for their specific course. The first concept inventory was the Force Concept Inventory developed and implemented by Hestenes. It was developed as a test to identify students' misconceptions about Newtonian Force [4]. Once implemented, the Force Concept Inventory assessment stimulated a variety of reforms in physics education [4]. "Such assessments can play an important part in relating teaching

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techniques to student learning" [1]. 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. The Coalition contended that reform in Science, Technology, Engineering and Math (STEM) education is hampered partially due to the lack of good assessment instruments. It is anticipated that the development of a concept inventory for engineering graphics will result in similar reforms in graphics courses, where instructors will recognize the value of instruction that focuses on fundamentals rather than the "tool of the day."

To be effective, development of a concept inventory like the Graphics Concept Inventory must involve aligning the three assessment corners of the "assessment triangle." This model was proposed by a National Research Council panel of assessment experts who suggested that three interrelated elements must be addressed to create a high quality assessment instrument [2]. These elements focus on cognition, observation, and interpretation elements as defined by Streveler [3]. The cognition corner of the triangle refers to 'a theory or set of beliefs about how students represent knowledge and develop competence in a subject domain' [3]. The observation corner represents the kinds of tasks that will make up the assessment itself. The interpretation corner 'encompasses all the methods and tools used to reason from fallible observations' that have been made in response to the tasks defined by the observation corner of the triangle. Beliefs about how students learn about a domain of interest must be consistent with the kinds of assessment tasks that are created and with the methods used to analyze the results of the assessment. The interpretation of assessment results can then provide valuable information about how students learn the target domain, which is the underlying purpose of developing and using the concept inventory [3].

Having a framework in place from the early stages of the project is crucial for effective instrument development, as it will provide necessary structure and guidance. In regards to the cognition corner, the research team must be familiar with the content area in order to understand how students are able to demonstrate ability in graphics. For the observation corner, the research team should have an understanding of what types of items could be included on an instrument that may best exhibit students' capabilities in particular concepts. Lastly, the interpretation corner will be the team's ability to make use of the instrument to inform practice. The research team is comprised of members who are graphics professionals familiar with the content area and have experience working with students in engineering graphics courses, which satisfies the needs of the cognition corner. The focus at this point in the project lifespan is concentrating on the observation corner, where items are developed that may best indicate students' misconceptions and understanding of a particular concept. Future work will focus on the interpretation corner.

III. Process to Date

A. *Delphi Study*

In a previous project, a Delphi Study was conducted to help identify core topics in engineering graphics. The Delphi Technique, in which subject matter experts are consulted collectively, was used. The first round took place at a workshop consisting of graphics professionals and resulted in a total of 120 unique topics. Through subsequent rounds of the Delphi process, the original 120 topics were reduced to 37 topics that coalesced to the 10 concepts listed in Table 1. These concepts served as the constructs for the development of the engineering graphics concept inventory [6].

B. *Initial Pilot Study*

Using the concepts identified in the Delphi Study as a basis, work on item creation began. Whenever possible, these questions were intended to address only one concept. An open-ended format was selected for the pilot questions in order to better observe the conceptions held by participants, who were all students enrolled in introductory engineering graphics courses at three different universities. A total of 60 pilot items were drafted. Not all items could be tested on every student participant due to classroom time constraints. The items were compiled into different sized packets based on the time available for testing at each participating institution. A testing protocol was established by the group so all packets in the pilot study were administered in a uniform fashion. Pilot responses from all institutions were collected and the results aggregated. The responses were coded by the researchers to look for misconception trends [7]. Examples of an open ended question from the pilot study (Figure 2), the expected solution (Figure 3), and a sample of an incorrect student response (Figure 4) are shown.

TABLE I. IDENTIFIED CONCEPTS

Visualizing in 2D and 3D	Projection Theory
Mapping between 2D and 3D	Parallel Projection Methodologies
Planar Graphical Elements	Drawing Conventions
Sectional Views	Dimensioning
Methodologies for Object Representation	Solid Modeling Constructs

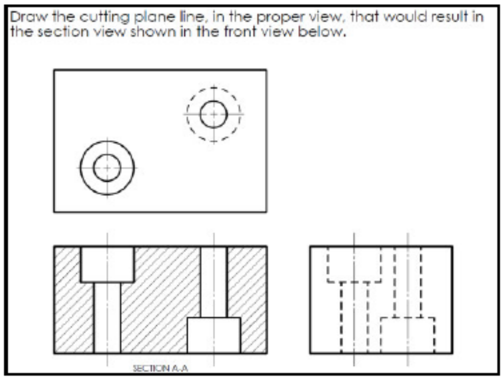

Fig. 2. Example of Open Ended Item

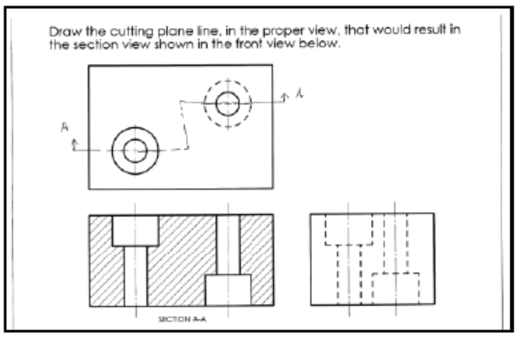

Fig. 3. Intended Solution for Pilot Item

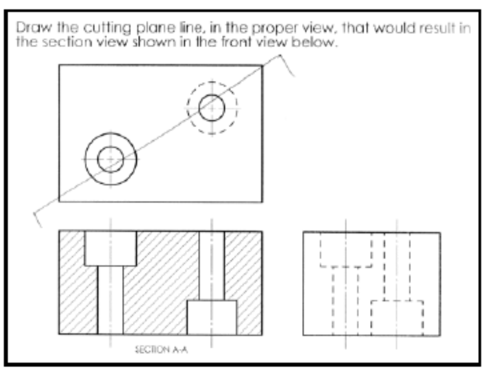

Fig. 4. Example of Incorrect Participant Response

C. *Drafting Distractors and Testing*

With the data from the pilot study coded, work began on drafting potential distractors. The researchers reviewed the data from the pilot study, individually wrote potential distractors for each item using the open-ended student responses as a guide, then met as a group and selected the three most appropriate distractors. As is common on concept inventories, items will be multiple choice with 4 possible answers, thus three distractors are needed per item. The selected distractors were typically similar to the three most prevalent incorrect coded responses from the pilot study.

The results from this work yielded approximately 70 items with distractors. The items with distractors were consistently formatted and prepared for electronic distribution to participating institutions. Figure 5 shows an example of a completed instrument item. To comply with time allotments granted by the participating institutions, three versions of a pilot instrument consisting of 25 items each were created. To maximize versatility and application, the instrument was compiled electronically using a platform that is independent of institution specific learning management systems. This has allowed for increased distribution amongst participating institutions, more versatility in data collection and analytics, and better ability to address administrative issues from a central standpoint. The sorting of items between versions was done so that there was an even representation of identified concepts in each version. Approximately 1000 participants across 4 institutions will have completed the initial pilot instrument at the time of presentation at the conference.

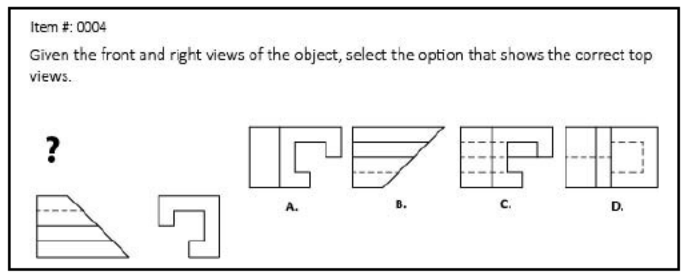

Fig. 5. Example Completed Instrument Item

IV. Current Status

Once responses from the latest round of testing are compiled, Item Response Theory and Classical Test Theory will be the basis for analyzing student responses. The intent is to have a range of abilities be measured by the completed instrument, and not just the categorization of high performers. It is of importance to the study that items with high discrimination and reliability be included in later versions of the Concept Inventory. This will help to ensure cogency and ultimate usefulness of the instrument. Preference for item inclusion will also be given to those items that best isolate individual constructs. Because of the nature of engineering graphics, it is possible that certain items will not wholly and uniquely address an isolated construct. The work on the study thus far has shown that while this may be a possibility, it is not beyond reason to be able to further distill items and distractors to an acceptable level.

V. Future Plans

So far the research team has made significant progress in completion of two of the three corners of the assessment triangle (cognition and observation). Future activities in the project will focus on completing the tasks associated with the third corner of the triangle (interpretation). The types of analysis left to complete are: 1) a face validity study whereby experts in the graphics field examine items to determine if they are assessing the concepts they are intended to asses, 2) a content validity study whereby student scores on the Concept Inventory are correlated with grades earned on typical graphics test items, 3) an external validity study to determine if results are generalizable across different institutions, 4) Item Response Theory (IRT) analysis to determine the relative difficulty of items, and 5) standard reliability testing to determine if the instrument is consistent in its measurement of graphics concepts. The project is funded for a three-year lifespan, and is currently near the end of year two. Over the next year, we will complete the statistical analysis required in the interpretation corner of the assessment triangle. The instrument will then be administered to a large number of students across several institutions to determine its generalizability and reliability on a larger scale.

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