Using Concept Maps in the Development of a Concept Inventory for Engineering Graphics

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Abstract

When creating a concept inventory for a new subject, it is important to ensure that the instrument is as comprehensive as possible. In engineering graphics, many of the skills being taught occur at the intersection of multiple topics. With this in mind, it can be helpful to have a tool to guide the creation and selection of items. Concept maps are graphical tools for organizing and representing knowledge. Researchers working on the engineering graphics concept inventory used concept maps to help identify and describe the relation of topics within engineering graphics, to frame the content and structure of the instrument.

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Introduction

Concept maps are widely applied within the field of education research, and are used in the assessment of student work and curricula (Besterfield-Sacre, Gerchak, Lyons, Shuman, & Wolfe, 2004; Castles & Lohani, 2010; Turns & Atman, 2000). Concepts maps can be used both in early phases of project development and also in assessing later stages of learning (DeFranco, Neill, & Clariana, 2011). Concept maps were used to help in the development of a concept inventory for engineering graphics in the earlier stages of the development process. Because the subjects taught in engineering graphics are inherently intertwined, the researchers may benefit from a more structured view of the items and topics.

Background

Previous papers describe earlier work on the creation of a concept inventory for engineering graphics (Nozaki et al., 2016a; Nozaki et al., 2016b; Sadowski & Sorby, 2013; Sadowski & Sorby, 2014). Currently, the preliminary instrument items and distractors are completed and have gone through an initial administration with ~1000 students (Nozaki et al., 2016a). Statistics describing the behavior of the items have been gathered and analyzed. These statistics will be used to inform the selection of items to be included on the initial version of a complete instrument.

Concepts can be described as sets that can be grouped together on the basis of shared characteristics, and which can be referenced by a particular name or symbol (Merrill & Tennyson, 1977). These sets can be comprised of a variety of entities; examples include symbols, events, methods and so forth. Previous work by the authors describe work on the identification and grouping of the pieces that comprise each set. Each constructed set evolved into a concept that would be covered by the final instrument. The topics in engineering graphics overlap, and there is debate on what completely constitutes a particular topic (Sadowski & Sorby, 2013). For example, two topics identified through the Delphi process included Visualizing in 2D and 3D and Mapping between 2D and 3D. The distinction between these two topics is sometimes difficult to discern as there is a great deal of overlap between them. Concept maps are graphical representations that show the arrangement of information within a subject (Greitzer, Soderholm, Darmofal, & Brodeur, 2002). Therefore, to help clarify the relationship of the engineering graphics topics to each other, concept maps were chosen to provide a visual image and structure to the concepts and topics. Generally speaking, concepts and topics are shown in a box or similar enclosed shape. Lines or arrows on the map represent the relationships between the topics. Arrows are an important feature of a concept maps, as they imply hierarchy or direction. Development of a concept map for engineering graphics will help the researchers to frame the items and instrument during the latter stages of instrument development. For an instrument to be valid, it must have an acceptable level of breadth and depth of topics measured (Moskal, Leydens, & Pavelich, 2002). Aligning the items with the concept map will allow the team to ensure appropriate coverage of the identified topics.

Methods

Members of the research team were briefed on the creation and use of concept maps. It was decided that each member of the team would create a map individually, with a goal of merging the ideas into one comprehensive map that could serve the use of the project. It was agreed that the 10 concepts identified in the previous Delphi study (Sadowski & Sorby, 2013) would serve as the starting point for the concept maps, with one Delphi defined concept to be defined per box. The topics that made up those concepts to be added based on their relationship to the concepts and to each other. Figure 1 shows the listing of the 10 concepts identified by the initial Delphi study.

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

Figure 1: Concepts Identified by Delphi Study

At a scheduled face-to-face meeting, the four individually created concept maps were compared and combined into a single map. So as to not make the process of combining the maps completely subjective, a rubric for evaluating concept maps was consulted. The integrated scoring rubric as described by Besterfield-Sacre et.al (2004) was used to guide the merging of individual maps. The rubric describes qualities of concept maps, as well as the interpretation of assigned scores. Examples of qualities are Structure, Organization, and Correctness. While it was possible to assign scores and rigorously analyze each member's map, a more holistic approach was taken. Having an established rubric permitted a focused discussion amongst the research team. Decisions were arrived at organically after open debate between all members. Frequent re-visiting of the rubric allowed intermittent checking of the emerging map. Figures 2 through Figure 4 show examples of individual concept maps as generated by the research team. Figure 5 is the completed version of the concept map as produced by the research team.

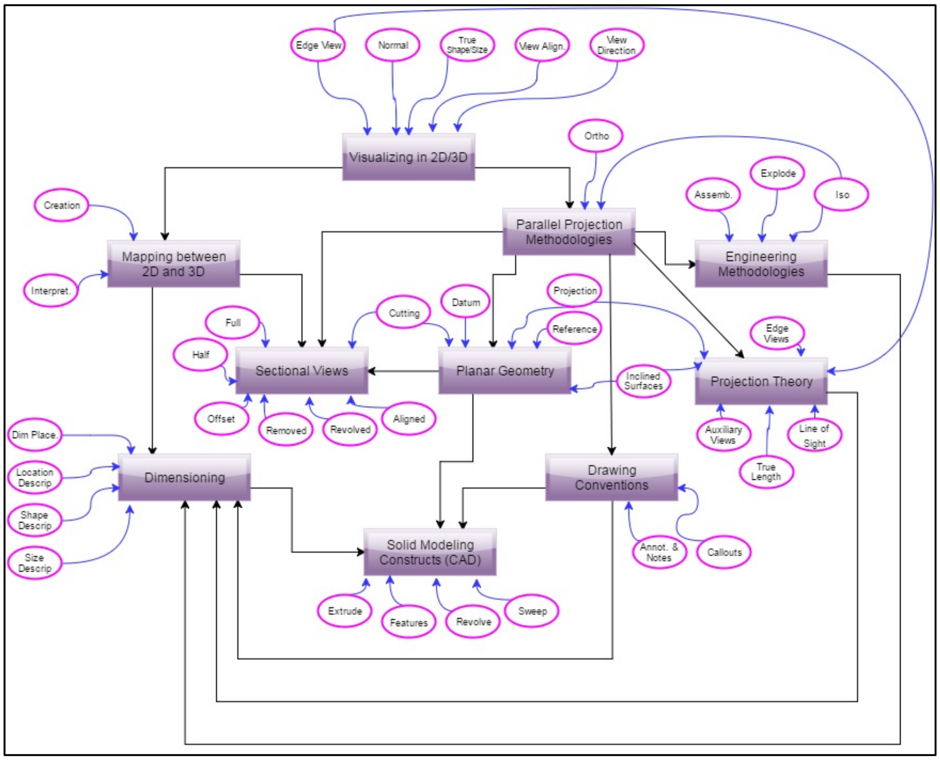

Figure 2: Individual Concept Map 1

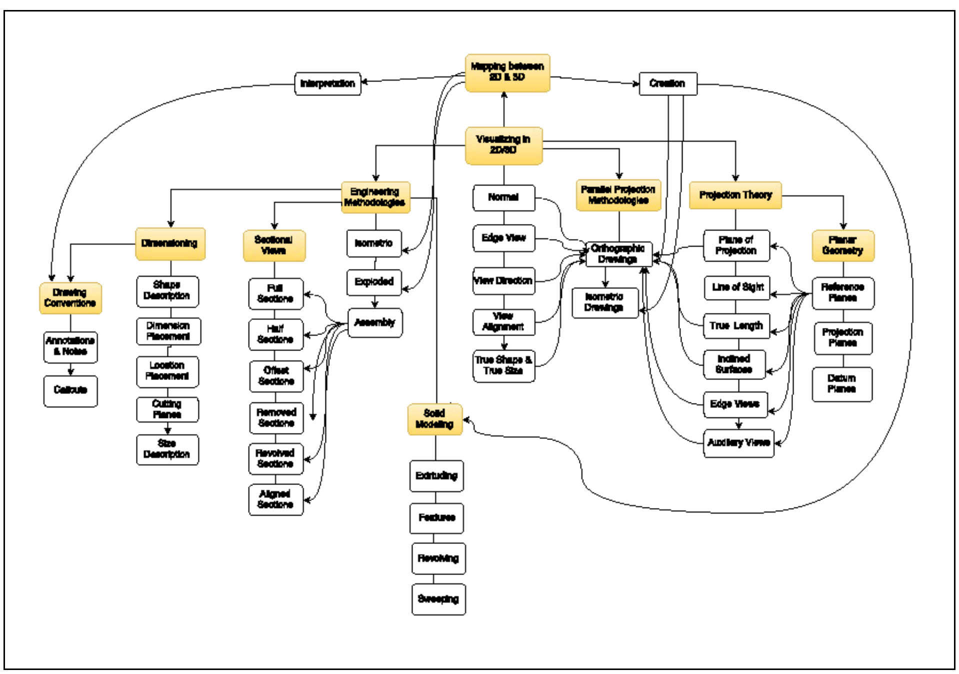

Figure 3: Individual Concept Map 2

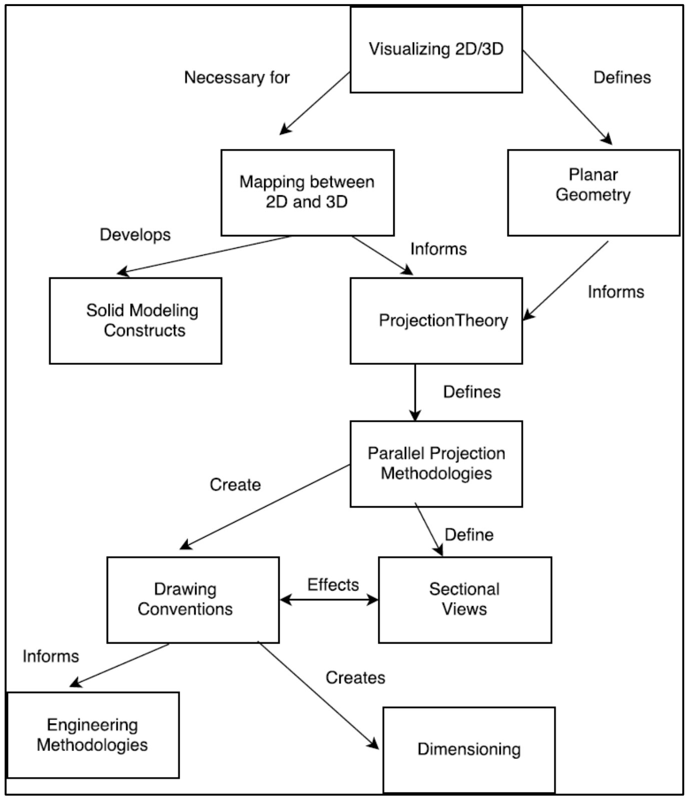

Figure 4: Individual Concept Map 3

Discussion

Close observation of the initial individual concept maps shows how they were used to create the final version. The most significant change occurred in the number and names of concepts. Previous work has described the reduction of certain concepts, while the descriptive statistics from the most recent testing of the items provided rationale for the reduction and renaming of the others. Any attempt to include the more detailed topics has been eliminated, leaving only the decided upon seven main concepts. In the final concept map, it was determined that the concept of conventions enveloped the three concepts of dimensioning, sections and engineering methodologies rather than standing as a separate concept. The final map utilized one way arrows and has a distinct hierarchal nature. This implies the importance or underpinnings of certain ideas, and how an understanding of higher order concepts would be necessary for application of concepts lower in the map. This flow supports the distribution of items amongst the topics. For example, the ability to understand and apply the concepts of dimensioning relies on having an understanding of both parallel projection methods and the ability to visualize and translate between 2D and 3D.

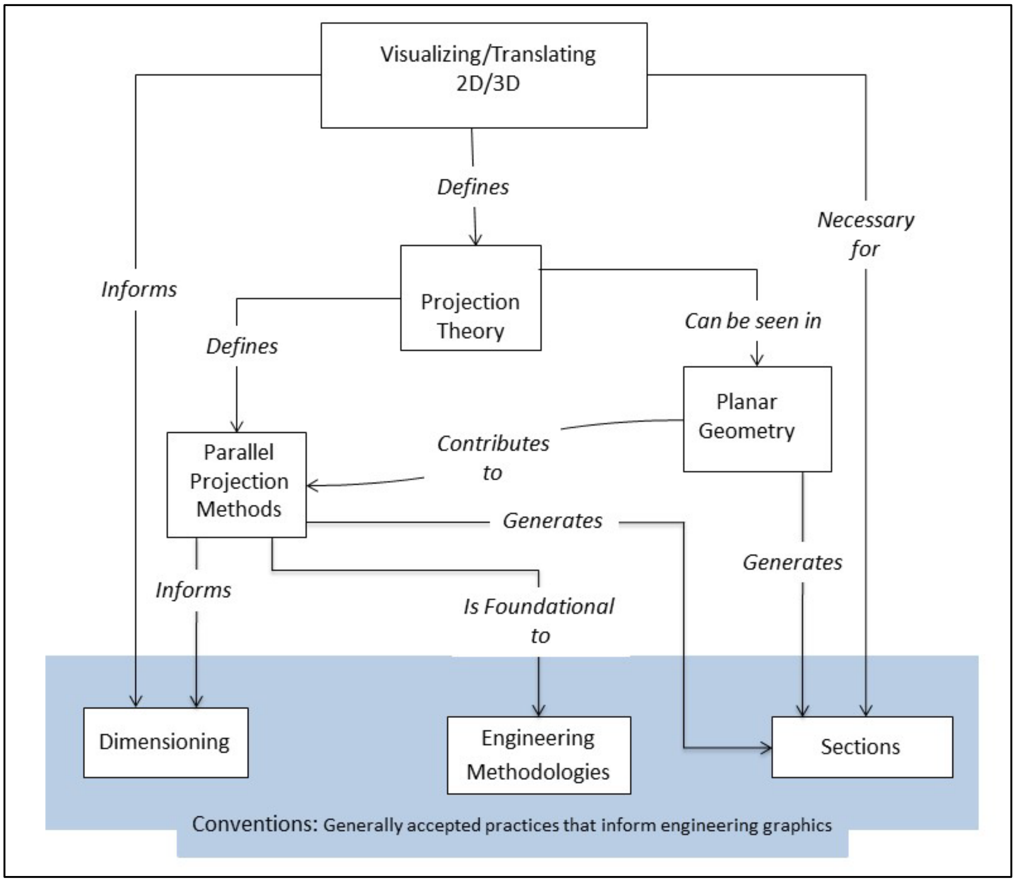

Figure 5: Final Concept Map Developed by the Team

Conclusion

Having a clearer, agreed upon understanding of the concepts that will be included in the instrument was a critical step in the development of the concept inventory. As an initial completed instrument is being compiled for testing in the upcoming fall semester, it is important to keep in mind the envisioned arrangement of concepts. The arrangement of the map can shape the selection of items that will be representative of each concept.

One predicted advantage of a well-constructed concept map will be in the validity testing of the instrument. Face validity of an instrument is the extent to which an instrument appears to measure the constructs it intends to measure (Gay, Mills, & Airasian, 2006). Comparing the depth and extent to which included items address the encompassed concepts will be more effective with the concepts and their interrelationships clearly identified. The map can also be used in the analysis of the instrument. One could look for correlations in performance between linked concepts for insights into issues with the instrument. For example, weak performances in disparate areas on the map could suggest poor internal validity, and may indicate systematic error with the instrument.

Additionally, patterns may emerge between concepts that reveal students' tendencies to have trouble with certain paths on the map. For example, if a participant that does poorly on items within the "Parallel Projections Methodology," one might look at the performance in the "Projection Theory" and "Planar Geometry" Concepts to make possible judgments as to contributing factors. This could then be used to inform pedagogical decision making and course content.

The use of concept maps to help develop a concept inventory for engineering graphics has been a productive and beneficial exercise. Mapping the interaction of the concepts ensures that the subject of graphics has been thoroughly considered and further ensures that the items in the instrument will address each of the concepts. More sophisticated analysis and revisiting the instrument may be a necessary step in the future.

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