Work in Progress - Studying Design Cognition to Improve Design Education

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Abstract - **This paper presents results from the first phase of a longitudinal study of design cognition. The project examines how engineering students develop design competencies over time by applying a task-independent approach to verbal protocol analysis based on the function-behavior-structure ontology. This analysis will be used to evaluate the effects of education on design cognition by following students in two curricula across three years (sophomore to senior). A large study pool from both programs completed spatial reasoning tests to determine overall population characteristics. A subset of this pool is now participating in verbal protocol studies in which students work in pairs to respond to a design scenario. This paper reports results of the spatial reasoning tests as well as preliminary results from the first set of protocol studies.**

Index Terms – Design cognition, verbal protocol studies, spatial reasoning, design education

BACKGROUND

Design Education Research

Research in design education address both approaches to teaching and studies of design practice. Although a comprehensive review is outside the scope of this WIP, work related to teaching includes frameworks for curriculum design [1, 2], learning outcomes [3], and assessment [4]. Such studies provide faculty with information about the structure, goals, outcomes, and assessments of design courses. Research on design practice, include differences across experience levels (freshmen, seniors, experts) [5], the influence of reflection [6], and self-evaluations versus observed performance [7]. Such work helps faculty understand design behaviors at different levels and identify potential gaps in students' development.

Yet more work remains in understanding both how students' design cognition develops and how curricula affect this development. To insure that knowledge and competencies gained in one context (e.g. a course) transfer to another (e.g. a workplace), researchers and practitioners alike need methods to assess the effects of pedagogies not only on students' design products or engineering design processes, but on their cognitive engagement with the fundamental process of defining product function, structure, and behavior. This study applies the Function-Behavior-Structure (FBS) ontology developed by Gero et al. [8] to address this engagement. The project involves a longitudinal study of design cognition students in two different majors. Each year (sophomore through senior), pairs of students will be given one hour to complete design task. The teams will be video-taped; the videos are transcribed, segmented, and coded using the ontologically-based FBS coding scheme [14. Rather than relying on the stages of the engineering design process, this ontology codes cognitive engagement with the design issues of requirements, function, expected behavior, structure, behavior from structure and description [9]. Spatial reasoning tests conducted at the beginning of the study provide a baseline comparison of students' abilities, and interviews conducted at the beginning of each design task provide insights into students' design learning opportunities inside and outside the classroom.

Spatial Reasoning

Spatial reasoning is concerned with the representation and use of objects and their relationships within a world conceived of both topologically and geometrically in two and three dimensions, with or without time as a fourth dimension. Spatial reasoning is critical to engineering design because design involves the creation of objects and their relationships to satisfy a set of requirements [9]. In this process, engineers frequently imagine and reason about both the physical components of a system and the symbolic representations of these components [10, 11]. Given the link between spatial reasoning and design, spatial reasoning provides one mechanism to compare study participants' baseline abilities. Standardized tests of spatial reasoning produce results that can be compared across space and time and across type of test subject. In this study. spatial reasoning abilities are external correlates tested as part of the study. They provide a basis for identifying potential differences in innate design ability that might otherwise confound the findings of the longitudinal data.

METHODS

The study involves students at a large mid-Atlantic land-grant university. The control group (Cohort 1) is a major focused on engineering mechanics. Its theoretical orientation focuses on mathematical modeling based on first principles. The experimental group (Cohort 2) is a mechanical engineering major that uses design as a context for its curriculum. Aside from a common first-year engineering sequence (which includes a module on design), and the traditional engineering pre-requisites (e.g., calculus, physics, statics,), the cohorts have little curricular overlap.

To test spatial ability, the authors chose four tests: three from *Kit of Factor-Referenced Cognitive Tests* [12] (the Paper Folding Test (PFT), the Vandenberg-Kuse Mental Rotation Test (VMR), the Shepard-Metzler Mental Rotation Test (MRT)), and the Spatial Imagery Ability Test (SIA) [13]. The tests were administered to all sophomore-level students of enrolled in both majors at the beginning of the fall 2009 semester, at the point at which students matriculate from general engineering into their chosen major. The tests were incorporated as course assignments, but students could exclude their results from the research study. Total study participants were N=27 in Cohort 1 and N=270 in Cohort 2.

The first set of verbal protocol studies were conducted at the end of the fall 2009 semester. Teams of two students were asked to design a device that would assist nursing home residents in raising and lowering double-hung windows. Each work session was video-taped; the tapes were transcribed and coded using the FBS protocol [9].

RESULTS

Spatial Reasoning

Figure 1 presents the results of the spatial reasoning tests for both cohorts. Both majors attained the highest scores for the MRT followed by the SIA, the PFT, and the VMR test.

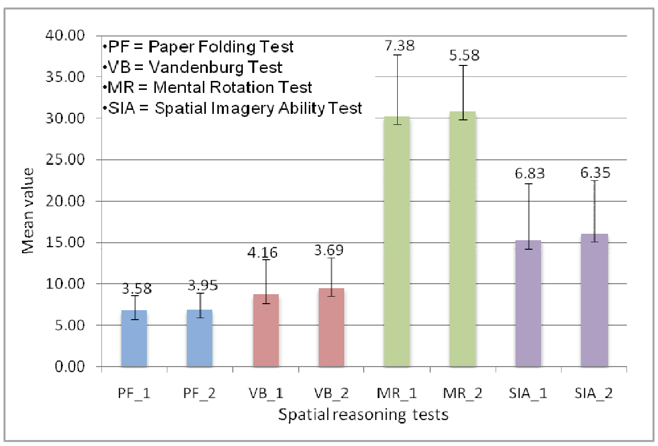

FIGURE 1. SPATIAL REASONING TEST RESULTS FOR BOTH COHORTS

Data analysis identified no statistically significant differences between groups, suggesting that the study participants have equivalent foundations in spatial cognitive ability. This baseline equality implies that changes in design cognition that emerge in subsequent phases are much more like to reflect the impact of curricular differences.

Preliminary Design Cognition Results

As noted above, the design task videos were coded using an ontologically-based coding scheme [14] founded on the FBS ontology which codes the design issues of requirements, function, expected behavior, structure, behavior from structure and description [9].

Table 1 shows the averages for the issues for two teams from Cohort 2 (mechanical engineering group).

TABLE 1. ISSUE DISTRIBUTIONS

Issue	Percentage	
	Team 1	Team 8
Requirements	3.1	2.3
Function	1.8	1.0
Expected behavior	10.7	15.3
Behavior from structure	30.5	31.5
Structure	43.3	41.2
Description	10.4	8.8

A window of length equal to half the number of segments is slid across the protocol segments one segment at a time, commencing with segment 1, to produce an averaged distribution of design issues across the protocol. The length of the window changes the granularity of the average. The averaged distributions of design issues over the design sessions for the two teams are presented in Figures 2 and 3.

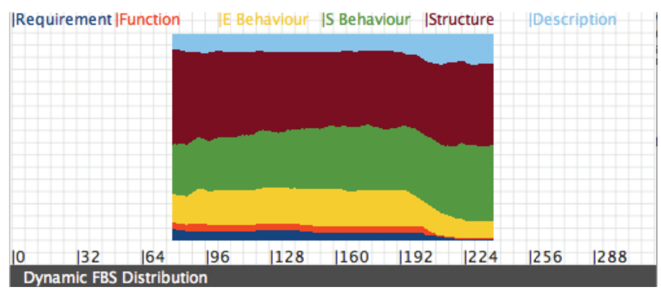

FIGURE 2. TEAM 1: DISTRIBUTION OF DESIGN ISSUES

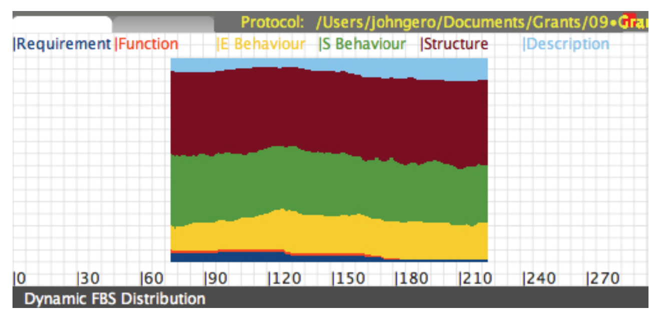

FIGURE 3. TEAM 8: DISTRIBUTION OF DESIGN ISSUES

Qualitatively it can be observed that there is similarity in the design cognition of the two teams. It will be left to a later paper to carry out a statistical correlation analysis of their similarity. Results for eight other design teams, one of which is the control, are currently being processed.

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