WIP: 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 and education

BACKGROUND

Design Education Research

Current research in design education address both approaches to teaching and studies of design practice across expertise levels. Although a comprehensive review is outside the scope of this WIP, work related to teaching practices includes frameworks for curriculum design [1, 2], learning outcomes [3], and assessment instruments [4]. Such studies provide faculty with information about the structure, goals, outcomes, and assessments of design courses.

Work related to design practice includes studies of differences across experience levels (freshmen, seniors, experts) [5], the influence of reflection [6], and team self-evaluations versus observed performance [7]. Such work faculty understand engineering design behaviors at different levels of expertise and identify potential gaps in students' development of design practice.

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 even on their external behaviors vis-à-vis the engineering design process, but on their cognitive engagement with the fundamental activities of associating with defining product function, structure, and behavior. The approach used in this study applies the Function-Behavior-Structure ontology developed by Gero and colleagues [8] to address this engagement.

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 doing so, engineers frequently imagine and reason about both the physical components of a system and the symbolic representations of these components [10, 11]. Spatial reasoning tests, then, provide one mechanism to identify base similarities and differences among study participants. Standardized tests of spatial reasoning have the advantage of producing results that can be compared across space and time and across type of test subject. They thus allow researchers to compare, for example, engineers with the general populace, with other non-engineer designers and with themselves across an educational curriculum. In this study the measures of spatial reasoning abilities are external correlates to be tested as part of the study. The provide a basis for identify potential differences in innate design ability that might otherwise confound the findings of the longitudinal component of the work.

METHODS

The study involves students at a large mid-Atlantic land-grant university. The control group is a major focused on engineering mechanics. Its theoretical orientation focuses on mathematical modeling rather than design. In contrast, the experimental group 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 the design process), and the traditional engineering pre-requisites (e.g., calculus, physics, statics, etc.), these two cohorts have little curricular overlap.

To test spatial ability, the authors chose four tests: three from *Kit of Factor-Referenced Cognitive Tests* [12] (Paper

Folding Test (PFT), the Vandenberg-Kuse Mental Rotation Test (VMR), the Shepard-Metzler Mental Rotation Test (MRT)) and one that tests spatial relations, the Spatial Imagery Ability Test (SIA) [13], as this is one of a small number of such tests that can be self-administered. The four spatial ability tests were administered to all sophomore-level students of enrolled in both majors in the fall semester of 2009. While students were given the opportunity to not have their results included in the research study, all students were required to complete each of the four tests; their participation was accounted as a homework assignment.

The verbal protocol studies were conducted at the end of the fall semester of 2009, after students had completed their first set of courses in each major. 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-recorded; the recordings were then 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 ("engineering mechanics" labeled as cohort 1 and "mechanical engineering" labeled as cohort 2) attained the highest scores for the MRT followed by the SIA, the PFT, and the VMR test.
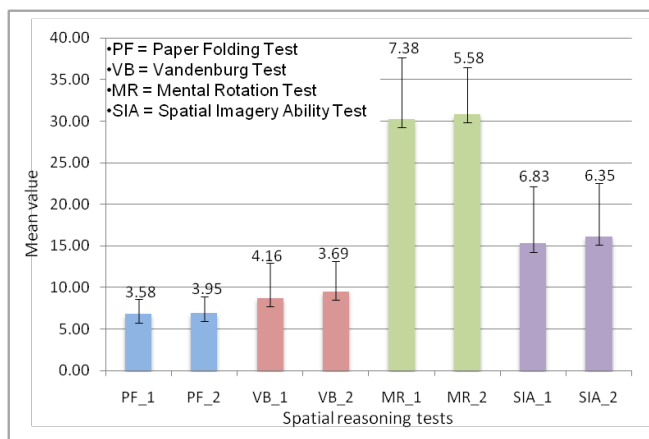

FIGURE 1. SPATIAL REASONING TEST RESULTS FOR BOTH COHORTS

Statistical 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

In order to study and compare cognitive differences of students over their undergraduate education a series of protocols will be carried out. Some preliminary results from the first set of protocols are presented here. Students formed teams of two and were all given the same set of design requirements. They were videoed while they were designing and the videos were transcribed and then segmented and 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 composed of sophomore ME students.

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 two teams are presented in Figures 2 and 3.
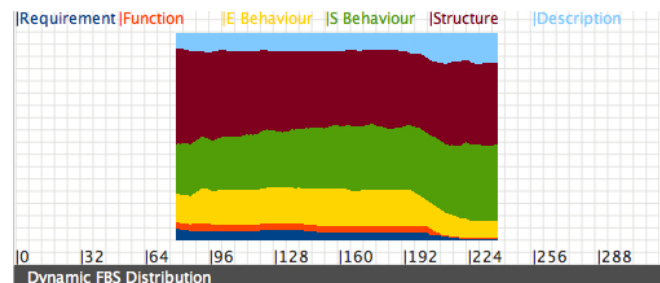

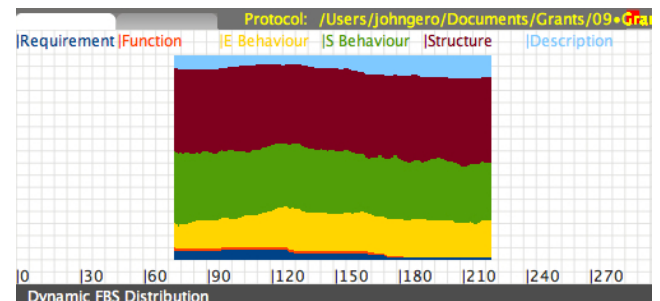**FIGURE 2.** TEAM 1: DISTRIBUTION OF DESIGN ISSUES

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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