Initial Findings of High School Pre-engineering and Non-engineering Students' Design Cognition

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***Abstract*—This paper presents the initial findings of a design cognition study involving two groups of high school juniors: those who have taken pre-engineering courses and those who have not. Equal numbers of dyad teams from both groups engaged in design-only sessions in which they generated solutions in response to the same design challenge. The design sessions were video and audio recorded. The recordings were transcribed and then segmented and coded using the Function-Behavior-Structure (FBS) ontologically-based design issues and design processes coding scheme. The students' design cognition was measured from the distributions of the design issues and design processes. Both the design issues and design processes were compared between the two high school student groups. Additionally, the results of the analyses were compared to baseline undergraduate engineering students. The results of this study did not reveal significant differences in either design issues or processes between the two high school student groups. However, when compared with the baseline undergraduate engineering students, there were significant differences between these groups with respect both to issues and processes and to the cognitive effort in their problem/solutions spaces.**

Keywords—design cognition; design education; high school pre-engineering; verbal protocol analysis

I. BACKGROUND

Elementary and secondary students are engaging in engineering activities in formal and informal settings across the country. Engineering has also been making its way into elementary and secondary classrooms through numerous curricula and standards with design as the primary focus [1, 2]. Although engineering design is becoming more common and accessible in K-12 venues, how these students go about design in engineering is not readily understood [3-5]. The aim of this research study was to further characterize student design cognition when engaged in engineering design problems.

While engineering education literature in design has largely been dominated by discussions of pedagogical approaches, there have been several cognitive studies of designers aimed at elucidating design thinking behavior. The most prevalent research method currently being used for such work is protocol analysis [6], which has become the basis of many recent cognitive study of designers [7-11] The present study used protocol analysis as the experimental approach, founded on a design-ontology-based coding scheme derived from innovations in cognitive science. The coding scheme is based on a general design ontology, the Function-Behavior-Structure (FBS) ontology [12], which provides a design-based coding scheme (rather than either a task-based or an ad hoc scheme).

The FBS ontology models designing in terms of three classes of ontological variables, or design issues: 1) function, 2) behavior, and 3) structure plus requirements and design description (Figure 1). In this view, the goal of designing is to transform a set of requirements and functions into a set of design descriptions (D). The requirements (R) on a designed object come from outside the designer. The function (F) of a designed object is defined as its teleology; the behavior (B) of that object is either derived (Bs) or expected (Be) from the structure; and finally, the structure (S) represents the components of an object and their relationships. Moving between these issues involves eight processes, indicated by the numbers in Figure 1. The first five represent a pseudo-linear sequence: 1) formulation which transforms requirements into functions and functions into a set of expected behaviors; 2) synthesis, where a structure is proposed to fulfill the expected behaviors; 3) analysis of the structure to produce derived behavior; r) evaluation, which acts between the expected behavior and the behavior derived from structure; and 5)

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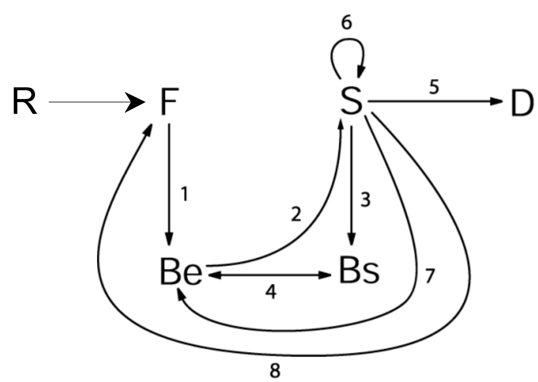
documentation, which produces the design description. Processes 6-8 then reflect the interative nature of design and represent three types of reformulation, also identified in Figure 1: 6) reformulation I – reformulation of structure, 7) reformulation II – reformulation of expected behavior, and 8) reformulation III – reformulation of function.

Fig. 1. Function Behavior Structure Ontology.



II. Methodology

A. Participants

Participating high school juniors in this longitudinal study were drawn from three rural mid-Atlantic high schools, all of which offered the same pre-engineering course series. Participants were solicited in the fall of their junior year and assigned to experiment and control groups, comprised of those with (experiment) and without (control) formal pre-engineering course experiences. Formal experiences ranged from one previous year of coursework to being enrolled in a pre-engineering course at the start of their junior year. Students in the control group had no such prior experiences. Both groups had the same number of students; the gender distribution of the experiment group being 64% male and 36% female, and the control group 65% male and 35% female.

B. Research Design

This longitudinal study used a two-by-two factorial research design across two exogenous variables (design experience and maturity) to investigate high school student design practices over two years. This paper reports initial results of year one data collected from participating high school juniors. In this first year pairs of students (dyads) collaborated at a whiteboard to arrive at a solution to an engineering design challenge. The challenge asked students to design a device to assist physically impaired elderly nursing home residents in opening a stuck double-hung window without the use of an external energy source. This scenario has been used in prior studies and thus provides a meaningful basis for comparing findings across studies and populations.

Student dyads collaborated on the design challenge for 45 minutes and were instructed to provide a detailed sketch of their solution on the whiteboard. Each member of the dyad was equipped with a lapel microphone to ensure capture of quality audio. Two video recording devices located at different vantage points (whiteboard and general) captured student interactions. Video recordings captured student dyad engagement throughout the entire design-only session.

C. Data Analysis

The research team transcribed dyad verbalizations and entered them into spreadsheets, inserting individual student utterances verbatim into alternating rows. Adhering to the FBS coding scheme, independent coders concurrently analyzed each transcript and transformed individual utterances into single units, called segments, where each segment represented one and only one of the six possible design issues. Co-coders then met to discuss and arbitrate assigned codes for every segment until consensus was reached. The final protocols were analyzed using LINKODER (http://www.linkoder.com/) to generate descriptive statistics, probability analyses, and dynamic models reflective of the FBS ontology. Analyses were conducted to identify statistical differences in both design issues and processes between the experimental and control groups.

III. Results

Data were collected and analyzed for the first year only. The analysis compared pre-engineering (experiment) to non-engineering (control) high school students, and both groups to baseline results from undergraduate engineering students.

A. Pre-engineering versus Non-engineering Students

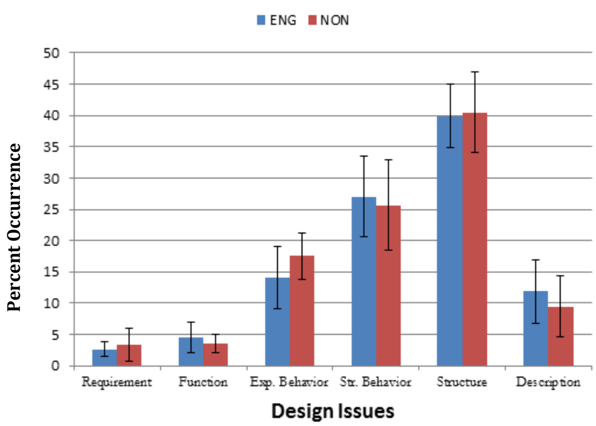
For each group, the percent of total segments associated with each design issue is shown in Figure 1. A *t*-test was performed on the experiment and control groups' design issues across an entire design session. There were no statistical differences found between these two groups, as indicated in Table I. There was also no significant difference in the cognitive effort expended in the problem and solution spaces as indicated by the Problem-Solution (P-S) Index, which reflects the relative effort designers spend on problem versus solution issues [11]. As with most designers, the high school students spent the highest cognitive effort on structure.

Similar results were found from the t-test comparing syntactic design processes between the experiment and control groups across the session. There were no statistical differences between experiment and control groups for the processes or the P-S processes Index, Table II. The percent occurrence for each design process can be found in Fig. 2 for both groups.

TABLE I. High School Students' Design Issues

Design Issues (Full Session): High School Eng vs Non		
Design Issue	***t-value (%)***	***p- value***
Requirement	-0.78	0.2403
Function	1.05	0.1538
Expected Behavior (Be)	-1.7	0.0532
Behavior from Structure (Bs)	0.43	0.3344
Structure	-0.23	0.4100

Design Issues (Full Session): High School Eng vs Non



Design Issue	*t-value (%)*	*p- value*
Description	1.09	0.1453
P-S Issue Index	-1.2	0.1234

Fig. 2. Percent Occurence of Design Issues between Pre-eng and Non-eng High School Students.
Note: Error bars represent standard deviation.

TABLE II. HIGH SCHOOL STUDENTS' DESIGN PROCESSES

Design Processes (Full Session): High School Eng vs Non		
Design Issue	*t-value (%)*	*p- value*
Formulation	1.22	0.1187
Synthesis	-1.01	0.1631
Analysis	1.48	0.0776
Evaluation	-0.16	0.4364
Documentation	0.82	0.2116
Reformuation I	-0.5	0.3119
Reformulation II	-1.59	0.0644
Reformulation III	0.55	0.2952
P-S Process Index	-0.92	0.1837

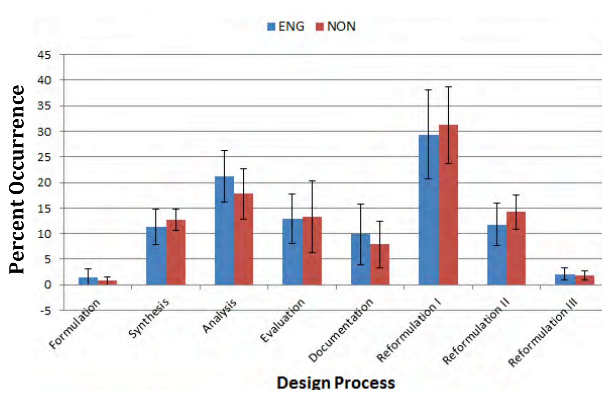


Fig. 3. Percent Occurence of Design Processes between Pre-eng and Non-eng High School Students.
Note: Error bars represent standard deviation.

B. High School versus Undergraduate Students

Both groups of high school students were then compared to undergraduate engineering students. These analyses included t-test, $p < 0.05$ for both the design issues (Table III) and syntactic processes (Table IV).

First, significant differences occurred for some design issues. Both the experiment and the control high school groups differed from the college engineering students with respect to function. The pre-engineering group was also significantly different for requirement, while the control group was significantly different for expected behavior, behavior derived from structure, and P-S Index.

Significant differences also occurred for some design processes. Both high school groups differed from the college engineering students' with respect to synthesis, analysis, reformulation II, and the P-S Index. The pre-engineering group also differed from the college students with respect to reformulation III, but no unique differences were identified for fhe control group.

TABLE III. HIGH SCHOOL VS. UNDERGRADUATE STUDENTS' DESIGN ISSUES

Design Issues (Full Session): High School vs. Undergraduate Design Issues				
	HS Pre-eng		**HS Non-eng**	
Design Issue	*t-value (%)*	*p- value*	*t-value (%)*	*p- value*
Requirement	2.02	0.028*	0.56	0.292
Function	-3.06	0.004*	-2.61	0.009*
Expected Behavior (Be)	-1.14	0.1339	-3.47	0.001*
Behavior from Structure (Bs)	1.49	0.076	1.84	0.041*
Structure	0.08	0.468	-0.013	0.449
Description	-0.18	0.428	0.84	0.206
P-S Issue Index	-1.4	0.089	-2.59	0.009*

*Denotes statistical significance < 0.05

TABLE IV. HIGH SCHOOL VS. UNDERGRADUATE STUDENTS' DESIGN PROCESSES

Design Issues (Full Session): High School vs. Undergraduate Design Processes				
	HS Pre-eng		**HS Non-eng**	
Design Issue	*t-value (%)*	*p- value*	*t-value (%)*	*p- value*
Formulation	-0.65	0.262	0.79	0.220
Synthesis	-2.38	0.014*	-4.13	<.001*
Analysis	2.54	0.010*	3.84	<.001*
Evaluation	-0.6	0.278	-0.62	0.271

Design Issues (Full Session): High School vs. Undergraduate Design Processes				
	HS Pre-eng		**HS Non-eng**	
Design Issue	***t-value (%)***	***p- value***	***t-value (%)***	***p- value***
Documentation	0.67	0.256	1.57	0.067
Reformuation I	1.01	0.163	0.52	0.304
Reformulation II	03.61	0.001*	-5.98	<.001*
Reformulation III	-1.79	0.045*	-1.34	0.099
P-S Process Index	-4.35	<.001*	-5.39	<.001*

* Denotes statistical significance $p < 0.05$

IV. Discussion and Conclusions

The preliminary results from the first year analysis did not show significant differences between the experiment and control groups. Demographic data were analyzed to further explore the lack of differentiation among the groups. Analysis of these data revealed that the majority of students in both groups had some degree of formal and/or informal design experience prior to their junior year. Most participated in technology education courses throughout middle school, or were involved with informal design competitions such as First Robotics or the Technology Student Association. Prior formal/informal exposure to such design experiences may well have provided a common foundation among students from both groups.

The analysis did reveal differences between the high school and college students, however. The undergraduate students spent more cognitive effort analyzing and less effort synthesizing. This result is congruent with the issues of expected behavior (Be) and behavior derived from structure (Bs). This finding is consistent with previous findings [10, 13].

Further data is being collected for the second year of this longitudinal study since the data in this analysis are from the first year only. As the high school pre-engineering engage in further engineering design experiences, it is anticipated that the results will be different on some levels.

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