AC 2012-3780: ELEMENTARY STUDENTS' ENGINEERING DESIGN PROCESS KNOWLEDGE: INSTRUMENT DEVELOPMENT AND PILOT TEST

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Abstract

This paper describes the development process of an instrument designed to assess elementary students' knowledge of the engineering design process. The instrument was adapted from another instrument used with college students and validated through an instruction-comparison study. We based the design of the instrument on the principle of aligning cognition, observation, and interpretation in developing an assessment. As a part of the validation process, we administered the instrument to 71 elementary students at the beginning and at the end of a school year. The instruction group consisted of 37 students who learned engineering content and the design process, while the other 34 students (the comparison group) did not participate in any engineering instruction. Quantitative analysis showed that the instruction group scored higher at the end of the school tear compared to the beginning of the school year. The comparison group did not show difference between pre test and post test.

Key Words: design process, instrument development

Introduction

Interest in introducing engineering concepts and teaching design as a process to elementary school aged children has continued to increase in recent years for a variety of factors. In some cases, stakeholders are concerned about students learning engineering content for a competitive advantage in the global marketplace [1, 2]. Other stakeholders are concerned by a decline in students' interest in pursuing engineering during and after college [3]. Still others are interested in promoting elementary engineering instruction in order to promote engineering and technological literacy [4, 5]. Recent studies have also provided evidence that learning engineering content, especially engineering design, can motivate children and help them learn science content [6]. One of the frameworks that researchers most often use to understand engineering design is to characterize the *process* involved. Educators have also considered learning design process as beneficial to students since design-based activities can support development of conceptual understanding of a domain and self-guided inquiry skills [7-10]. For example, Kolodner et al. [11] incorporated design process into inquiry-oriented middle school classrooms to help students become thinkers, learners, and decision-makers. The new report on engineering education also indicated that design process should be an important part of K-12 engineering learning [12]

Research Purpose

As more states are adding engineering content, including design, as part of their K-12 teaching standards, there is an urgent need to understand design learning at the K-12 level. While some efforts are focused more on developing the activities that students will participate in as they learn about the engineering design process [6, 13], in this paper we describe our efforts to develop an assessment instrument that can be used to examine the impact of these instructional activities. We ask the following research questions: How can design process learning be assessment be assessed with alignment to our understanding of design leaning? Does the evidence collected with this instrument capture the differences between students with different educational experience?

Instrument Development and Validation Process

Assessment Framework

In the development of the assessment instrument, we adopted Pellegrino et al.'s [14] framework describing assessment as "reasoning from evidence" consisted of three linking elements: cognition, observation, and interpretation. The framework was used extensively when structuring assessment, both on program assessment and classroom assessment. For example, the framework was used as a framing concept in evaluating young children's work [15] and in making sense of complex assessment [16].

Cognition refers to beliefs about how students learn [14]. Previous design research results suggest that the design process that students use might be indicative of the kinds of design thinking that they use or do not use, such as reflective practice [11]. Also, design language shapes the knowledge that students have about design [17]. We believed that design language also reflects the knowledge that students have about design. Thus students with a better understanding of the design process will give not only a more comprehensive view of the process but also exhibit deeper reasoning abilities. *Observation* refers to the task or situation that will prompt students to demonstrate the knowledge or skills [14]. We used a design scenario to prompt students' thinking and answering. *Interpretation* refers to a method of interpreting the performance to make sense of the observation gathered from the task. We referred to the content and the pedagogical perspectives of design learning when we interpret the data gathered, and we made a first attempt in developing a rubric for quantitative assessment. We asked the question: how can design process learning in elementary school be assessed with alignment to our understanding of design learning?

Content Development

In order to assess elementary students' design knowledge, we began our instrument development process by considering the *content* that the instrument would need to assess. While little research has been conducted to characterize elementary students' understanding of engineering design or their engineering design skills, the literature contains many examples of expert-novice studies comparing college students at different points in their college studies as well as comparing college students to practicing engineers [18-20]. From this review of the literature, we determined that the instrument would need to capture differences in students' understanding of problem scoping (i.e. problem definition, information gathering and problem framing activities), idea generation and iteration. Additionally, the instrument would need to capture students' understanding of design as a process rather than students' understanding of individual activities.

Our next step in our instrument development process was a review of existing instruments used to assess engineering design process knowledge. The Museum of Science, Boston, uses knowledge questions to assess elementary students' understanding of individual activities, but does not assess students' understanding of design as a process [21]. Other instruments were developed to support the data collection process to answer difference aspects of design learning in college: concept maps [22-25], simulation [26], knowledge test [27, 28], verbal protocol analysis [11, 19, 29], design journals [30, 31]. With our target population of elementary students, we have the following considerations. First, the task should be prompted. Second, the task should be stand-alone for teachers to use in the classroom. Based on these considerations, we identified an existing instrument as suited to adapt for our purpose. Bailey and his colleagues developed an instrument to prompt students to critique a design task laid out chronologically and presented as a Gantt chart [27]. Bailey has used this Design Process Knowledge task to identify differences between freshman and senior engineering students' understanding of design process. In order to further validate the instrument, Bailey also administered the task to practicing engineering and compared his findings to other published research on expert engineers' design practices [28].

We have changed the task's initial description to the level that is developmentally appropriate for elementary students (Please refer to Figure 1.). We have also replaced the Gantt chart with alternative pictures depicting a child's design process. Like Bailey's task, the main instructions remained the same; the students were asked to 1) comment on what is good about the design process and 2) comment on how the process can be improved. The changes made were reviewed by an external expert in K-12 engineering education research and an external expert who has served as an elementary science specialist.

Pilot Test

As a part of the validation process, we pilot tested the instrument with 71 elementary students before and after a school year. 37 students (the instruction group) received various degree of engineering instruction during the school year while the other 34 did not (the comparison group). We describe in the following part of this paper the details of the instruction-comparison pilot test and what it means in terms of instrument development.

Context of Teacher Professional Development

INSPIRE has been conducting week-long teacher professional development "Academies" since 2006. During the summer of 2007 a group of teachers from one school, along with their district Science Specialist, participated in the Academy and pursued a continuing collaborative relationship with INSPIRE. During the 2007-2008 year the collaboration led to an interest in implementing engineering education throughout the entire district. To partner in this effort, INSPIRE travelled to the district to conduct the regular week-long academy on site. INSPIRE accepted 32 (grade 2-4) teachers from seven of the 51 district elementary schools. The teachers implement various degrees of engineering lessons in the 2008 school year. To keep the data collection and analysis activities at a manageable level, three schools were selected for the research activities.

Student Participants

As previously noted, 37 students from the instruction group schools participated in the study. The students were selected to represent the 10 classrooms; four students were selected from each classroom based on sex (2 male, 2 female), parental and student assent and consent, and teacher discretion. During the school year, each teacher had implemented an Engineering is Elementary (EiE) unit [32], and some of these teachers chose to include additional engineering content. The EiE curriculum includes preparatory lessons that precede the EiE units and four-lesson units. Within the actual units, students read an engineering storybook in lesson one, learn about a specific engineering field in lesson two, collect and analyze scientific data in lesson three and complete an engineering design challenge in lesson four. Students practice reading, writing, mathematics and science skills integrated with the engineering skills and concepts that they are learning. The units are hands-on in nature, particularly lessons three and four.

As a comparison, the instrument was also administered to 34 students from matching grade levels who did not receive any engineering instruction. We refer to this group of students as the comparison group. The comparison group came from 9 classrooms and none of these teachers received any training in engineering education. The number of students in each classroom who participated in both tests is presented in Table 1.

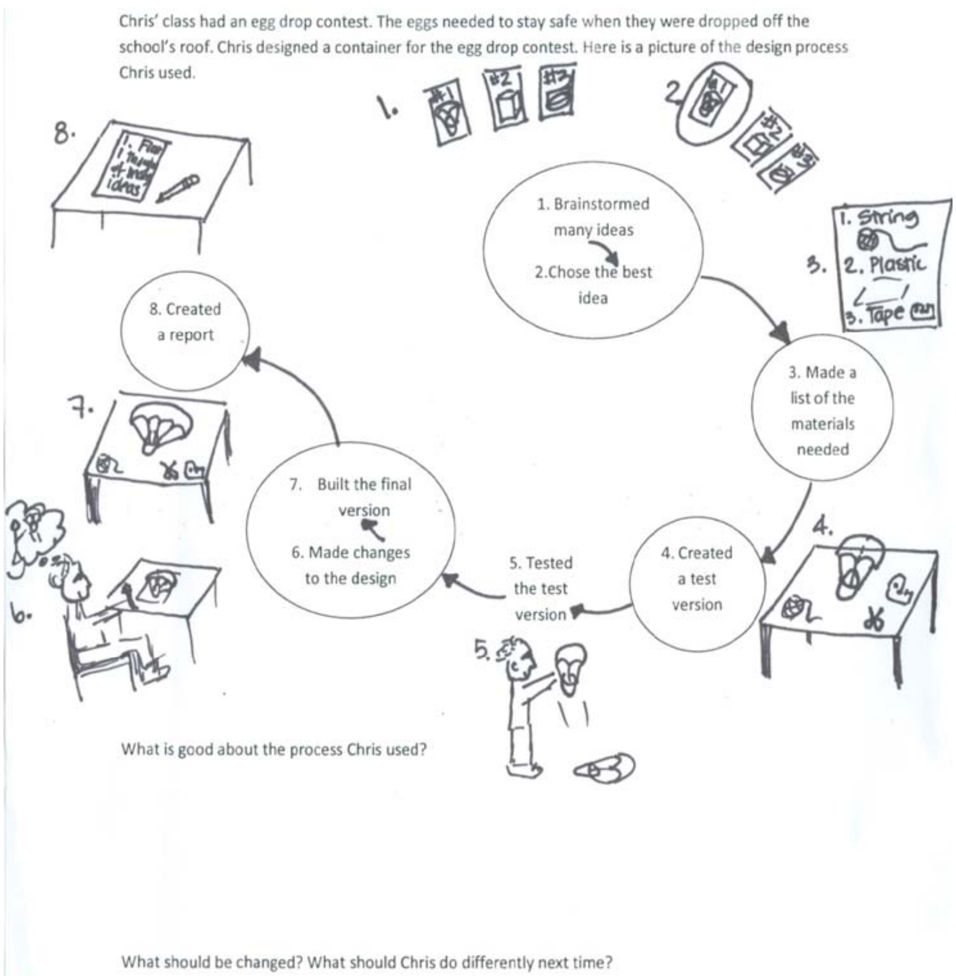

Figure 1. The instrument used to elicit children's responses

Data Collection and Analysis

Interviewers talked with students individually and showed them the illustration of a child's design process and prompted the students' responses. We refer to the group of students who received engineering instructions as the instruction group. These students were 2nd through 4th graders from 10 different classrooms with teachers who had attended a week-long teacher professional development program on implementing engineering content in K-12 classrooms.

The audio recordings of the interviews with the students were transcribed and analyzed using grounded method [33] by two independent coders. Differences in coding were resolved by consensus among the two coders. Seven coding categories emerged. We mapped five of the coding categories to the language used in the Engineering is Elementary design process model (Ask, Imagine, Plan, Create, Test, Improve). Please refer to Table 2 for the rubric and Table 3 for the definition and examples of each coding category. We calculated the number of design concepts in each student's response. The sum of the number of concepts was counted as each student's <u>total design process knowledge score</u>. The maximum score is 7.

Table 1: Study participants finishing both pre-test and post-test for each teacher represented in the table. The names of the schools and teachers are pseudonyms.

Group	**School**	**Teacher**	**Grade**	**Number of participants**
Instruction	Stanton	Anderson	2	3
		Cooper	3	4
		Junior	4	4
	Keckley	Mitchell	2	3
		Brown	3	4
		Hatt	4	4
	Walker	Cordroy	2	4
		Jacobs	2	4
		Barker	3	4
		Hanson	4	3
Comparison	Madison	Peterson	2	4
		Walters	3	4
		Summers	4	4
	Stowe	Spring	2	4
		Jackson	3	4
		Adams	4	2
	Lincoln	Crabtree	2	4
		Washington	3	4
		Monroe	4	4

Table 2: The dichotomous rubric used to score students responses

Design Activity	Ask	Imagine	Plan	Create	Test	Improve	Document
Present in response?	Y/N	Y/N	Y/N	Y/N	Y/N	Y/N	Y/N

Table 3: Definition and examples of each coding category

	Category Explanation: Indicating that design process should include….	Examples of specific terms that children used
Ask	Asking about the details of the problem and constraints	• We asked questions about how is it going to make it more soft or is it going to be like a real egg
Imagine	Brainstorming ideas and picking a good idea	• He thought about it. Because if you think about it and drew it, it helps you better to pick which one and helps you do good. • He wrote down his ideas and he picked one of them • He's brainstorming and trying very hard
Plan	Planning ahead, including the materials needed for finishing the design	• he said he what was going to before he started doing all this • He made a list of the materials he may need like a bucket
Create	Creating and building	• He created something • He built it differently
Improve	Making the design even better	• If it didn't work too well, she might want to make a few more changes than she did • He improved it • He was fixing his project he was redoing it to make it not break the egg
Test	Testing out the prototypes built	• You don't know if it works if you don't test them. • He tested the test version…. So he can see what he needs to add
Document	Taking notes of what ideas came up and what was done	• He wrote a report about it… So that ummm everybody else knows. • He's supposed to write what he think. Then if he forget, he can read his list.

Results

We used non-parametric tests because our data violate the assumptions of parametric tests (normality and continuity of the data). We conducted a Mann-Whitney test using SPSS version 19 to compare the instruction group and the comparison group at the pre-test. At a significance level of 0.05, the pre-test total scores did not reveal significant difference between the two groups (U=700.00, z=0.845, p=0.40). Then, we compared the pre-test total scores to the post-test total scores for the two groups respectively. By the end of the school year, the instruction group scored significantly higher in the post test compared to the pre test as revealed by a Wilcoxon signed rank test (U=293.00, z=2.09, p=0.037, r=0.24). By contrast, the comparison group did not score differently in the pre test and the post test (U=144.00, z=1.48, p=0.138). Please refer to Table 4 for the descriptive statistics. Figure 2 shows the change in mean total scores for the two groups.

Table 4: Descriptive statistics of the total design scores of the two groups on pre- and post-test

	pre-test			post-test		
	M	SD	Mdn	M	SD	Mdn
Instruction(n=37)	1.57	1.46	1	2.24	1.46	2
Comparison(n=34)	1.21	1.10	1	1.56	1.44	1

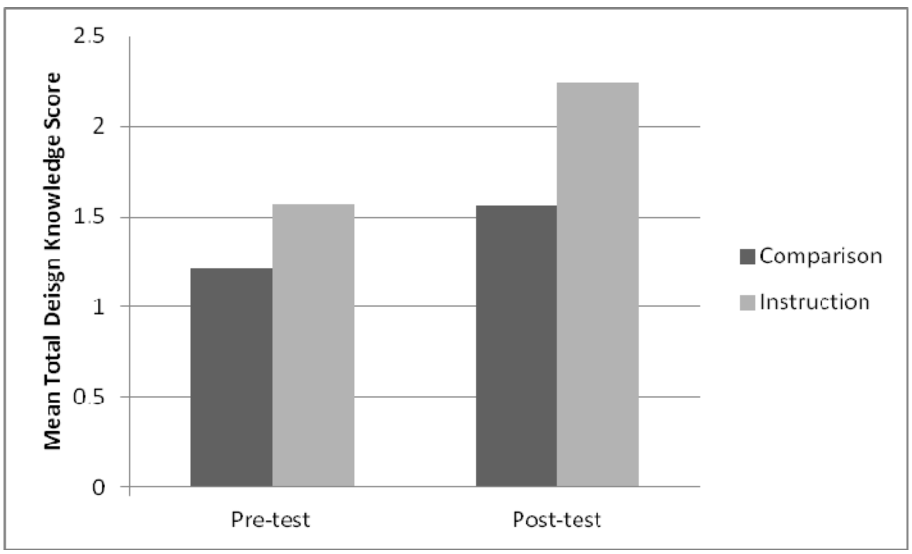

Figure 2: Comparison of pre- and post-test mean scores of the comparison and the instruction group

Because we are in the stage of validating our instrument, the results of how students did on each category is not conclusive (Please see Figure 3 for the percentages of students mentioning each concept in (i) pre-test group, (ii) post-test comparison group, (iii) post-test instruction group.) However, we have noted that in contrast to all other categories that have improved in the post test, few students commented on the aspect of “ask”- asking in order to understand the problem and the constraints. This is the case with both groups in pre-test and post-test.

Discussions

The two groups of students did not exhibit statistically significant differences at the beginning of the school year. The instruction group showed significant improvement at the end of the school year while the comparison group did not. The results of the pilot test suggested that the instrument and the rubric were able to reflect the difference that one group did receive instruction on engineering and design, while the other group did not. While the results shows promises that the instrument has the power to capture students' design process knowledge, we are in the process of collecting and analyzing more data. We hope that the larger data set would provide opportunities for better statistical analysis to address questions arising from other factors such as interviewer differences and grade level differences.

There are many possible reasons that might explain the increase of scores in both instruction and comparison groups. The students may have shown gains from pre-test to post-test because of their previous experience with the task; they may have shown gains that are attributable to the other instruction (not engineering related) that they received, or they may have shown gains simply because of an increase in maturity (i.e. they were 8 months older). Furthermore, we argue that the process of interviewing is an intervention itself.

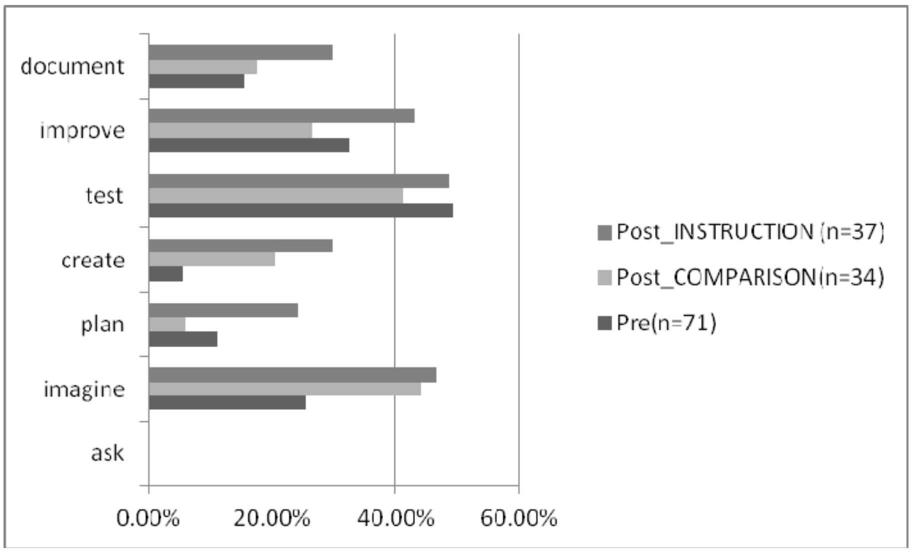

Figure 3. Pecentages of students in each group mentioning respective design process concepts

In the process of developing this instrument, we considered the validity [34]and reliability of the instrument [34]. In the content aspect of validity, we considered the relevance of content and task to the target population of elementary students, reviewed existing instruments, and adapted a suitable instrument to suit the cognitive ability of our population. In the substantive aspect of validity, there is empirical evidence to show that when university students and practitioners engage in this task, they are exhibiting behaviors that are consistent with their design process knowledge and skills [28]. We also know that the patterns exhibited by the elementary school students are consistent with the patterns of expert-novice differences exhibited by other groups. For the generalizability aspect of validity, we provide specifics of our participants for future studies to interpret across population groups and settings. For the structural aspect of validity, we conducted a pilot test to explore and evaluate how the scoring structure reflects students gained understanding in design.

As for the consideration of reliability of the instrument, we address inter-rater reliability by using two coders. What we have not addressed are: (i) test-retest reliability and (ii) parallel form reliability. The former will be addressed with investigating consistency between the pre-test and post-test score of the comparison group. We will address the latter by conducting concurrent observation of students doing design to address the external aspect of construct validity [34]. Also, we plan to establish rubric with respect to the complexity of students' reasoning.

The instrument has the potential to provide information on the content and pedagogy aspect of design learning. For example, the instrument can be used to assess students' naturalistic learning progression of design process, which is crucial for designing developmentally appropriate content for engineering design learning. Also, as a form of formative assessment, the teachers can adjust activities in the next engineering unit to emphasize the aspects of design process that students exhibit more difficulty learning.

While we still have further work to do in terms of refining the instrument and administering it to larger groups of elementary school students, the interview data has already provided some interesting examples of what some students learned about the design process. We believe that after completing further revisions to the instrument, this instrument may be useful for capturing what students learn about the engineering design process by participating in design-based instruction or as a form of formative assessment to give teachers feedback on future instructions. This would complement the progress that our community has made in documenting the benefits of design-based instruction for students' science learning.

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