



Engineering Design Process Knowledge: Comparison between Teachers New to Engineering and More Experienced Teachers

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Abstract

Interest in introducing engineering concepts to elementary school aged children has continued to increase in recent years for a variety of factors, some of which include concerns of lacking STEM literacy and global competitiveness. Recent studies have provided evidence that learning through engineering design can promote deep approaches to learning. As more states are adding engineering content, including design, as part of their K-12 learning standards, there is a need to understand teachers' knowledge and concerns of incorporating engineering into classrooms. In this study, we ask the question: what aspects of an engineering design process do the teachers address in their responses to a design process knowledge task? How does previous professional development and engineering teaching experience affect teachers' knowledge of the engineering design process?

Fifty-nine in-service elementary teachers from second, third, and fourth grade classrooms in an urban school district attended a week-long workshop on how to incorporate engineering, technology, and design into their classrooms. Twenty-three of these teachers had attended a similar workshop the summer before (Cohort 1), and they also taught at least one unit and up to four units of the "Engineering is Elementary" curriculum during the school year. The other 36 teachers (Cohort 2) had not received any training, nor did they have experience in teaching engineering or design.

Before the beginning of the workshop, all of the teachers partook in a task of critiquing a Gantt chart showing the timeline of a student's engineering design process. The task is adapted from an instrument used to evaluate college engineering students' and professional engineers' knowledge of the engineering design process. The teachers commented on what was good about the process and what needed to be changed. Their responses were analyzed qualitatively regarding aspects of the engineering design process and then given quantitative scores.

A non-parametric Mann-Whitney test revealed that there was not a significant difference in the mean scores of Cohort 1 and Cohort 2, meaning that Cohort 1 teachers did not discuss more aspects of a design process than the Cohort 2 teachers. However, when we looked into different aspects of the engineering design process, the two groups' responses differed significantly in idea generation and time allocation. Other aspects of engineering design process, such as testing and improving, did not differ significantly. None but one Cohort 1 teacher commented on the problem definition stage of a design process.

The results suggested that Cohort 1 teachers were more aware of the time needed for the design activities in the classrooms than teachers who did not have design teaching experience. Time allotment issues should be addressed during engineering professional development activities.

Introduction

Interest in introducing engineering concepts, including engineering design, to elementary school aged children has continued to increase in recent years for a variety of factors, some of which include concerns of lacking STEM literacy and global competitiveness¹⁻³. Engineering design practice has been emphasized as one of the fundamental components of K-12 science and engineering education⁴.

Learning engineering has several benefits for children, including improved technological literacy. In addition, learning engineering also enhances children's learning. Students develop problem solving skills when a design-based learning approach is used in the classroom⁵. Also, engineering design projects enhance students' science content knowledge⁶⁻⁸ as well as skills in mathematics⁹.

As more and more states are adding engineering content into their K-12 learning standards¹⁰, effort needs to be made to prepare K-12 teachers to teach engineering content. Although K-12 teachers think it is important for students to learn engineering, they have low familiarity with its content^{11, 12}. Teachers¹³ and students¹⁴ often have misconception about engineering as mainly building and making. Teachers with such misconceptions are more likely to focus on building and making in classroom activities¹⁵. Therefore, it is important to assess teachers' knowledge of design and design process since those are correlated with how they actually lead design activities in classroom.

Study Setting

We (INSPIRE at Purdue University) have been collaborating with several elementary schools in an urban school district to infuse engineering into their second, third, the fourth grade curriculum. The support we provide includes teacher professional development, books, lesson plans, and staff support. The elementary teachers come to a week-long professional development workshop in the summer to learn about what engineering is, what engineers do, and how engineers use design process to solve real-world problems. Teachers learn to incorporate science and mathematics standards into the engineering curricula. They are also given opportunities to practice teaching engineering design process to young students at summer camps before using these new skills in their own classrooms. Teachers who come to the workshops are committed to teaching at least one and up to four lessons of the "Engineering is Elementary" curriculum in the coming school year.

The teachers take the "design process knowledge task" at the beginning of the summer workshop. (The development of the task is described in another paper¹⁶). We have been collecting data from several cohorts of teachers. In this paper, we are analyzing the data collected in summer of 2009. In this particular year, we had 59 teachers of two cohorts of participating in the workshop. Teachers of Cohort 1 (n=23) went to a similar workshop the summer before and had taught engineering in the 2008 school year. Teachers of Cohort 2 (n=36) were new to teaching engineering and had never received any professional development on engineering.

Research Question

In this study, we ask the questions:

- What aspects of an engineering design process do the teachers address in their responses to a design process knowledge task?
- How does previous professional development and engineering teaching experience affect teachers' knowledge of engineering design process?

In other words, we would like to investigate if and how Cohort 1 and Cohort 2 teachers that attended the 2009 summer engineering workshops understood the engineering design process differently. Also, we would like to explore if those differences have implications on classroom instruction and teacher professional development.

Method: Data Collection and Analysis

In order to assess elementary school teachers' understanding of the engineering design process, we are in the process of developing an instrument based on an existing instrument¹⁷ used to measure college students' understanding of the engineering design process by asking participants to complete a task of examining a students' design process. We have discussed the development of the task in a previous paper¹⁶.

The task description asked the teachers to do the following: "Imagine that you asked your students to design a container to keep an egg safe during an egg drop contest. Now imagine that we were able to capture one of the students' design process and create the following table showing the different activities that she/he engaged in, how much time was spent on each activity as well as the student's sequence of events." Then, the teachers were asked to comment on 1) what is good about the depicted process and 2) how the process can be improved.

Activity:	Time (e.g. hour 1, hour 2...)													
	1	2	3	4	5	6	7	8	9	10	11	12	13	14
Create many different concepts for the container through brainstorming	■													
Choose the most promising concepts	■	■												
Decide what materials are needed for the container			■	■	■	■	■	■						
Create a test-version of the container							■							
Test the test-version of the container								■	■	■	■			
Make changes to the container based on test results											■	■	■	
Build the final version of the container													■	■
Write up a summary describing the project														■

Figure 1. The design process the teachers were asked to comment on

Their qualitative responses to the two questions were coded with the eight aspects associated with an engineering design process model. Quantitatively, we chose to assess the responses dichotomously. A teacher's response either pertained to an aspect or it did not. Table 1 summarizes the rubrics used to evaluate the teachers' responses. Each teacher's total design

process score, with 8 being the highest possible score, refers to the number of concepts in his or her response. Please refer to Table 2 for detailed description of each coding category that describes an engineering design process concept.

The data were coded by one coder. However, the coder had gone through inter-coding reliability check with three other coders on similar data. Also, three rounds of coding were conducted to achieve intra-coder reliability.

When comparing the two cohorts of teachers, non-parametric tests were used since the nature of the data violated assumptions of parametric tests. All statistical tests were performed using SPSS statistical package version 20. A Mann-Whitney test was carried out to compare total scores of the two cohorts. Additionally, Pearson Chi-square tests for independence were used to determine if the two cohorts answered differently in each engineering design process concept. Yate's correction for continuity was used to compensate for the overestimate of the chi-square value. If any of the cells had a count of less than 5, a Fisher's exact test was used instead of Chi-square. Effect size was calculated where appropriate.

Table 1. Assessment rubrics

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

Table 2. Description and examples of coding categories

Code	Code Explanation: Indicating that the engineering design process should include...	Examples of specific terms that teachers used
Ask	Asking about the details of the problem and constraints	“He should spend more time research the problem.”
Imagine	Brainstorming ideas and picking a good idea	“It's good that many concepts were thought about before creating the test-version of the container.” “I like that the student brainstormed about the concept of the container and chose the most promising concept.”
Plan	Planning ahead, including making a list of the materials needed	“That he/she took a long time in deciding what materials are best for the project.” “This student took the necessary time to develop their concept of materials, and how to use them.”
Create	Creating and building	“I think the student should take more..building the container.” “I also think that the student should have spent more time creating their container.”
Test	Testing out the prototypes built	“Did the student test the final version? If not they should.” “I think they should have retested after they made their revisions and then built their prototype.”
Improve	Making the design even better	“I think the student should have tested the final version to see if it worked better.” “He/ she tested and made changes to the container and then build the final version.”
Document	Taking notes of what ideas came up and what was done	“I think that the student should be recording any data or observations that they may have noticed during the process in their science notebook.” “I think that the student should be recording any data or observations that they may have noticed during the process in their science notebook.”
Time	Allocating time for different design activities	“Spend less time on deciding what materials to use for the container.” “More time should have been spent brainstorming, creating the first test version, and reflecting in the summary.”

Results

The descriptive data showed that Cohort 1 ($M=3.69$, $SD=1.33$) performed better than cohort 2 ($M=3.11$, $SD=1.55$). However, a Mann-Whitney U test revealed no significant difference in the total design process scores of Cohort 1 ($Md=4$, $n=23$) and Cohort 2 ($Md=3$, $n=36$), $U=325$, $z=-1.42$, $p=0.16$, $r=0.19$. The effect size r was considered small to medium¹⁸.

We looked into the aspects of the design process that differed between the two groups. Pearson Chi-square tests for independence with Yate's correction indicated significant association between teacher cohort and responses on "imagine" ($X^2(1,n=59)=3.74$, $p=0.05$, $phi=-0.29$) and time ($X^2(1,n=59)=4.44$, $p=0.03$, $phi=-0.32$). The value of phi indicated medium effect size. Cohort 1 teachers were more likely to comment on the "imagine" and "time" aspects of the engineering design process than Cohort 2 teachers. The number of the teachers that mentioned each design process category and the percentage within their cohort group is presented in Table 3.

Table 3. Number and percentage of teacher mentioning each aspect of design process within their cohort group. An asterisk (*) indicates that particular concept is significant in Pearson Chi-square tests. The percentage was calculated in relation to the size of each cohort group.

	Cohort 1(n=23)		Cohort 2 (n=36)	
Ask	n= 1	4.35%	n= 0	0.00%
Imagine*	n=13	56.52%	n=10	27.78%
Plan	n= 8	34.78%	n= 9	25.00%
Create	n=11	47.83%	n=12	33.33%
Test	n=16	69.57%	n=27	75.00%
Improve	n= 9	39.13%	n=20	55.56%
Time*	n=22	95.65%	n=25	69.44%
Document	n= 5	21.74%	n= 9	25.00%

Discussions and Implications

Although Cohort 1 teachers were able to comment on more aspect of the engineering design process than Cohort 2 teachers, the difference was not significant as indicated by the non-parametric Mann-Whitney test. We noted that non-parametric tests tend to have less power to reject null-hypothesis. Therefore, we also computed effect sizes for each procedure. The effect size of the difference between the two groups was small to medium.

More importantly, when we looked at each design process concept, we found that Cohort 1 teachers did significantly better than Cohort 2 teachers in the "imagine" and "time" category. The "imagine" category refers to their comments on the need to brainstorm ideas at the beginning of the project. Studies have shown that children have the tendency to start building the first idea that comes to their mind and skipping the initial steps of the design process¹⁹. More Cohort 1 teachers were able to pay attention to the shorter amount of brainstorming time described in the task. According to the Knowledge, Attitudes, and Behavior Framework²⁰, this was an indication that Cohort 1 teachers had recognized brainstorming as an important part of

the engineering design process and would be more likely to lead their students through the design process with brainstorming.

Almost all teachers in Cohort 1 commented on the “time” aspect of the engineering design process. They commented on time appropriation for different aspect of the design process: whether more or less should be spent on certain process steps. These teachers have had experience working with students in the classrooms on at least one design projects and time management during projects have been identified by the teachers as an important aspect. Note that almost 70% of the Cohort 2 teachers also commented on the “time” aspect. Teachers have had concerns that engineering design projects would take too much time and would add burden to the already saturated schedule^{21, 22}. Therefore, professional development efforts need to address these concerns. Some ways to attend to the concerns on time management issues include (i) linking other standards, such as mathematics, science, or reading, with design projects and (ii) including examples of how these standards can be incorporated into different stages of the engineering design process.

The design process concept that most Cohort 2 teachers commented on was “test” as shown in Table 3. This result is congruent with findings and observation of previous studies stating that physically building and testing is teachers’ focus of engineering design^{13, 15}.

One aspect of the design process that is often overlooked is “ask”, the problem scoping phase of the engineering design process in which information about problems and solution is gathered. Real-life design problems are mostly ill-defined²³, contrasting most problems in the elementary science and mathematics curriculum. The observation that the elementary teachers addressed “ask” infrequently was consistent with the behavior of college engineering students^{24, 25}. Introducing ill-defined problems provides the opportunities for students to learn to gather information, evaluate situations, and reasonably scope the design problem, and thus should be a part of engineering instructions. We have since further emphasized “ask” in our subsequent workshops based on these observations we made from the design process knowledge task. One method that we use to help teachers develop problem scoping skills is to have conversations about the design problems that possible solutions address.

In conclusion, we did not find significant differences between the total design process knowledge scores of the two cohorts of teachers that attended our 2009 workshop. However, Cohort 1 teachers commented more on the “imagine” and “time” aspect of the design process. Other observation includes that “test” is the most commented aspect of the design process amongst Cohort 2 teacher. In addition, “ask” is the least commented aspect for both cohorts of teachers. We discuss significance of these results in relation to previous literature. We also comment on how these results have implications on teacher professional development. Using assessment such as the design process knowledge task can provide useful feedback on teachers’ understanding to workshop facilitators.

Limit of the study include the fact that that we did not triangulate the teachers’ response with other forms of data, such as classroom observations of how teachers appropriate time and what they emphasize when they lead design activities. Validity of using the design process knowledge task could be further established with data triangulation.

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