What will you do to help elementary students who struggle in the engineering design process? Analysis of teachers' reflections. (Fundamental)

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Ms. Najah Naylor is a Computer Science Educator within the Philadelphia School District. She completed two master's degrees, one in Education and the other in Business Administration, and she is currently pursuing a doctorate degree in Organizational Leadership with a concentration in Education Administration. Naylor developed a passion for urban education as a teen student mentor over twenty years ago and enjoys integrating technology in the learning process. Currently, she serves on the BoD of Learn VR, a virtual reality organization that provides urban students learning experiences through the lens of virtual reality. Before becoming an Educator in the disciplines of business and technology, Naylor spent over ten years as a business leader in the telecommunications industry.

What will you do to help elementary students who struggle in the engineering design process? Analysis of teachers' reflections. (Fundamental)

Introduction

The next generation of STEM workers and leaders requires knowledge and skills in order to effectively contribute and compete in the global workforce [1], [2]. More importantly, the sustainability of our planet requires citizens who can work collaboratively to think critically, make ethical and moral decisions, and solve problems [3]. The science and engineering practices described by the Next Generation Science Standards [4] can provide a framework for teachers to engage their students in asking questions, defining problems, brainstorming, developing and testing models or prototypes, analyzing and revising models, using mathematics and computational thinking, and communicating solutions to problems. Some benefits of teaching the engineering design process (EDP) include helping students understand and improve their world, developing their problem solving skills and dispositions, and increasing motivation and engagement in the science, technology, engineering, and mathematics (STEM) subjects [5]. However, teachers mentioned the following challenges in terms of implementing EDP in their classrooms: (a) not having extra time to engage students in the design process, (b) limited resources and materials, (c) ways to facilitate student's varied ideas and designs, (d) ability to grade non-traditional assignments, and (e) helping students who are struggling with their design/project [5], [6]. Moreover, in the study conducted by Porter et al. [7], they found that planning open-ended design challenges pertinent to the curriculum is difficult for teachers, particularly those who are inexperienced in teaching EDP. Hsu, Purzer, and Cardella [8] conducted a separate study with 192 elementary classroom teachers that suggested a need to improve teachers' familiarity with EDP. In this study, Hsu et al. found that, while most teachers mentioned the importance of engineering and technology, they were relatively unfamiliar with these concepts. Additionally, moderately experienced teachers showed stereotypical views of engineering [8]. In particular, the study conducted by Cunningham et al. [9] found that teachers tended to define technology as tools, machines, computers and electronics before attending workshops focused on the EDP. After the workshops, however, they were more likely to define technology as a solution to a problem and as something that is designed or invented. The participating teachers also improved their knowledge of engineering from "building and constructing" to a systematic and iterative process of solving a problem [9].

In our graduate methods course, we engaged teachers in teaching and learning the EDP by supporting them to develop or adapt a unit to incorporate science inquiry and EDP practices that utilized STEM curricula and resources. Our study was guided by the following research questions:

1. To what extent, if any, do teachers' knowledge of the EDP change before and after the course?
2. In what ways, if any, do teachers' pedagogical moves to scaffold students' learning experiences of the EDP change at the end of the course?

Literature Review

The engineering design process (EDP) is an iterative decision-making process that utilizes foundational science, engineering and mathematics concepts to deconstruct problems in order to reach optimal solutions [10]. Engagement in this process increases students' propensity to approach problems using a variety of skills as well as various forms of thinking to include procedural, explicit and declarative knowledge along with analytical and creative thinking [11]. The EDP as a component of STEM curricula allows teachers in various disciplines to cultivate lifelong competences, and both critical thinking and metacognitive skills [12] that transforms the teaching and learning process into a co-learning practice.

The EDP in elementary classrooms consists of a series of iterative components such as *Ask*, *Imagine*, *Plan*, *Create*, and *Improve* [9], which are applicable to problem solving and decision making processes in many disciplines. When considering the workforce and the five generations currently active in America's economy and workforce, students from all grade levels are the focus of educational, political and business leaders' appeal for increased 21st century competencies [13]. These leaders implore educators to incorporate problem solving, critical thinking, and collaboration skills into curricula in an effort to incite deeper learning. This deeper learning process cultivates a sort of mental agility, allowing students to transfer personal development learning skills into a range of situations, as opposed to developing expertise in a singular discipline or subject area without the ability to apply such skills to content beyond the scope of that one particular discipline [2]. In order to realize such a transfer of knowledge from teachers to students, teachers must first be equipped with knowledge, skills and an understanding of engineering and technology, thereby resulting in successful implementation of the EDP in teachers' classrooms [14].

Professional development programs and courses have been shown to help teachers develop their pedagogical content knowledge (PCK) in order to more successfully implement EDP in their classroom [15]. In particular, the K-12 Teacher Internship Program and Scientific Work Experiences Programs for Teachers (SWEPTs) aim to support preservice and in-service teachers with the implementation of STEM related concepts within their instructional practices [16]. This program was also designed to increase teachers' understanding of STEM education and EDP. Another program offered summer workshops that engaged teachers in the Engineering is Elementary curriculum, which helped to develop teacher knowledge and implementation of the EDP in the classroom, and also increased their students' knowledge of the EDP after one year of the project [17]. In a study conducted with middle school teachers in Boston Public School system [10], the researchers found that teachers showed mixed levels of subject matter knowledge of EDP, but were successful in constructing a prototype and redesign. Teachers also used examples and analogies that their students could relate to while teaching the EDP [10].

University methods courses have also shown a capacity to improve teachers' knowledge of the EDP, and to think of ways to incorporate the EDP in their classrooms [18]. Additionally, such methods courses were found to provide a pathway to significantly increase teachers' knowledge of physical science concepts (e.g., force, motion, energy conservation, and models) while engaging in the EDP [19]. Moreover, methods courses with a focus on the EDP can also support teachers' understanding of environmental and sustainability issues (e.g. sources of electrical energy in homes; practices of harvesting, selling and buying food; ways to travel to/from schools) [20]. One undergraduate course in Turkey focused on the EDP also strengthened teachers' awareness and intention to teach STEM subjects [21].

In a separate study [22] that incorporated both professional development and university courses, teachers of grades five and six demonstrated success with regard to incorporating the EDP in their lessons and aligning them with relevant process and content standards. However, these same teachers, during classroom observations, failed to give adequate consideration to the science concepts of their lessons, and their emphasis on the various steps of the EDP proved to be uneven: teachers gave more attention to the preliminary steps of the EDP (identifying the problem and planning) while spending less time on the later steps (testing, communicating results and revising) [22].

This mixed success with respect to the ability of university courses and professional development programs to prepare elementary teachers to engage students in the EDP demonstrates the need for further research on this topic. With this in mind, we developed a university level course in STEM methods for elementary teachers in the hope of answering the following: 1) To what extent, if any, do teachers' knowledge of the EDP change before and after the course? and 2) In what ways, if any, do teachers' pedagogical moves to scaffold students' learning experiences of the EDP change at the end of the course?

Methodology

In the present study, the second author developed and taught an *Introduction to STEM Education* course to elementary teachers, which was guided by the *Framework for K-12 Science Education* [12]. At the beginning and end of this course, an identical pre- and post-test was administered to the 17 participating teachers. This test, adapted from the Boston Museum of Science, Wong, and Bizuela [23] consisted of questions that were designed to illuminate both the teachers' *content knowledge* and *teaching knowledge* of the EDP. In order to answer our research questions, the responses to a rich, multi-step, open-ended question from this data set were analyzed and double coded by the first and third authors using a coding guide developed by the first author. We then calculated coding agreements [26] in order to establish the level of confidence we can have in our coding procedures.

Research Setting, Course and Participants. Our study was conducted during the 3-credit course, *Introduction to STEM Education*, taught by the second author for 15 weeks in a small liberal arts college in the mid-Atlantic region of the United States. Throughout this graduate methods course, teachers were introduced to the science and engineering practices, crosscutting concepts, and core ideas outlined in the *Framework for K-12 Science Education* [12]. Specifically, the *Framework* guided the educational experiences and assignments of our teachers in the course: (a) defining problems, (b) developing and using models, (c) planning and carrying out investigations, (d) analyzing and interpreting data, (e) using mathematics and computational thinking, (f) designing solutions, (g) engaging in argument from evidence, and (h) obtaining, evaluating, and communicating information [12]. For example, in one of the instructional activities in the course (adapted from *Design Squad's Rubber-Band Car*), teachers learned the concepts of forces, motion, and energy transformations by working in groups to design a rubber-band powered car. Their objective was to design a car that can travel the farthest distance propelled by a rubber band. They worked in groups; discussed their prior knowledge about force, motion and energy; created a model that their group investigated; and made predictions based on their initial conceptual models. One group decided to investigate the effect of the number of rubber-bands to increase the car's elastic potential energy, a second group used different materials and shapes to reduce the car's weight, while a third group looked at the effects of changing the surface friction between the floor and wheels. After the investigations, each group analyzed their data and presented their findings in front of the class. Teachers revised their prototypes and conducted additional investigations based on evidence and findings from other groups. The lesson ended in a competition, evaluation of the different model cars, discussion of findings, and reflection of content and pedagogical learning.

Specific course objectives included: (a) developing or adapting a unit to incorporate science inquiry and EDP practices, (b) creating assessments to analyze students' conceptual understandings and difficulties in science, (c) implement and reflect on instruction, (d) utilize STEM curricula and resources, and (e) incorporate physical science concepts. The four core assignments consisted of writing a teaching statement, developing and implementing a STEM unit, writing reflections after watching video-captured instruction that focused on science or engineering lessons, and pre-and post-tests.

Participants in this study included 17 practicing elementary school teachers from a suburban school district with about 8,000 students in preK-12, 26% students of color, and 8% of students receiving free and reduced lunch. Of the 17 participants, 13 teachers had seven or more years of teaching experience, while four teachers had six or fewer years of teaching. Additionally, the teachers had varying backgrounds, with a majority (70%) having degrees in early childhood and elementary education. Others reported previous degrees or certifications in literacy, marketing and communications, mathematics, history, Spanish, and the Arts.

Data. In order to answer our research questions, we gathered data from identical pre- and post-tests administered at the beginning and end of the course to all 17 participants. The test was designed to measure participants' understanding of the EDP and how it can be implemented in elementary classrooms. For the purposes of this study, we analyzed data from one open-ended question, adapted from Boston Museum of Science et al. [23], that contained four distinct parts:

> *Read the following scenario and answer the questions below:*
> *On the border of Tibet and Nepal, among the beautiful Himalayas, lies the highest mountain in the world, Mount Everest. Often referred to as "The Top of the World," Mount Everest's peak stands at about 8,850 meters (29,035 feet) above sea level. Imagine standing atop a stack of 5,000 people piled head-to-toe! That is about what it would be like to stand on the summit of Mount Everest. An adventure team from your school has read about some famous mountaineers who have managed to summit this great peak, and the team wants to take on the challenge for themselves.*
>
> *Your job is to design and create a coat to protect your team members from Everest's year-round harsh, frigid weather conditions. In January, the coldest month, the summit temperatures average from -33°F and can drop as low as -76°F. In July, the warmest month, the average summit temperature is -2°F. At no time of the year does the temperature on the summit rise above freezing.*

A: List and describe the steps you are going to take to design and create a type of coat for your team members.

B: You provided this design challenge for your students to solve. One group started to create the coat as soon as they receive the materials.
a) What steps did they skip?
b) What advice would you give them?

C: A different group of students is having some trouble because they could not agree on the color and materials to use for the coat. What advice would you give them to resolve this issue?

Data Analysis. The data were analyzed using a method of quantitative analysis of qualitative data in which qualitative codes were generated through open coding and then distilled into a coding manual which was used to quantify the frequency with which the various themes appeared in the data set [24]. In order to answer our research questions, we developed *EDP Content Codes* and *EDP Teaching Codes*, as shown below in Table 1. These codes were developed by first looking for themes throughout the data set, and then grouping them based on their abundancy. The *EDP Content Codes* were designed to align with teachers' observed conceptions of the steps involved in the EDP as measured by the pre- and post-test questions 25A and 25B-A. The *EDP Teaching Codes* were designed to capture teachers' stated pedagogical moves and instructional strategies relating to teaching the EDP as measured by the pre- and post-test questions 25B-B and 25C.

The *EDP Content Codes* consisted of the following: *Research*, *Interview*, *Brainstorm*, *Plan*, *Prototype*, and *Mathematics*. *Research* in this context refers to looking things up (online or offline), reading articles or watching videos to look for information. *Interview* refers to communicating with experts in order to obtain their opinion. *Brainstorm* refers to coming up with a list of ideas, either individually or with a group, and can be a written or verbal list. *Plan* refers to the mention of developing/outlining steps or a specific process for solving a problem. *Prototype* can refer to going through an iterative process of design/redesign, creating models, revising initial ideas, and/or a process of trial and error. The final *EDP Content Code*, *Mathematics*, refers to the mention of any formulae or necessary/potential calculations or creation of tables/charts/graphs.

All but the final *EDP Content Code* align with the five stages of the EDP as developed by the Boston Museum of Science [25]. The *Research* and *Interview* codes both correspond to the first step, *Ask*, in the EDP. The *Brainstorm* code corresponds to the *Imagine* step of the EDP. The *Plan* code corresponds to the *Plan* step of the EDP. The *Prototype* code corresponds to the *Create* and *Improve* steps in the EDP. The last *EDP Content Code*, *Mathematics*, does not correspond to any of the EDP steps in [25].

The *EDP Teaching Codes* consisted of the following: *Slow Down*, *Analogies*, *Argument from Evidence*, *Data Analysis*, *Discussion*, *Redirection by Teacher*, and *Research Other Groups*.

Slow Down refers to this phrase being used as a direct quote or idea. *Analogies* refers to the use of analogies as an explanatory teaching tool. *Argument from Evidence* refers to participants' mention of persuading others based on scientific observations or other evidence, including the creation of a pros/cons list. *Data Analysis* refers to the mention of analyzing various data in order to reach a conclusion. *Discussion* refers to students talking with others about ideas without explicit mention of specifically involving evidence. *Redirection by Teacher* refers to treating ideological conflict between students as a misbehavior requiring teacher intervention that does not encourage debate or discourse, but instead seeks to resolve the conflict as quickly as possible by ignoring the root of the conflict, and can include the teacher leading the students to choose an approach at random. The final *EDP Teaching Code*, *Research Other Groups*, refers to the mention of observing/interacting with other groups to uncover other solutions or examine/explore other ideas.

In order to discuss the magnitude of the differences in the frequency of codes from pre- to post-tests observed in our data, we used the following labels to describe our results: *negligible*, *slight*, *moderate*, and *substantial*. A *negligible* change was determined to be less than a 10% change in code frequency from pre- to post-tests. A *slight* change was determined to be greater than or equal to a 10% change, but less than a 20% change in code frequency from pre- to post-tests. A *moderate* change was determined to be greater than or equal to a 20% change, but less than a 30% change in code frequency from pre- to post-tests. A *substantial* change was determined to be greater than or equal to a 30% change in code frequency from pre- to post-tests.

Table 1: Coding Manual

Question 25A: List and describe the steps you are going to take to design and create a type of coat for your team members	
Question 25B-A: You provided this challenge to your students to solve. One group started to create the coat as soon as they receive the materials. What steps did they skip?	
Question 25B-B: What advice would you give them?	
Question 25C: A different group of students is having some trouble because they could not agree on the color and materials to use for the coat. What advice would you give them to resolve this issue?	
EDP Content Codes	**Examples**
Research: looking things up (online or offline), reading articles or watching videos to look for information	"Research: What is the weather like in the mountains aside from cold, is it wet? Dry?" -- Stephanie
Interview: communicating with experts in order to obtain their opinion	"Call NASA for ideas for insalation [sic]" -- Micaela; "interview hikers from various parts of the world with varying degrees of experience" -- Jaheim; "survey actual hikers" -- Aiyanah
Brainstorm: coming up with a list of ideas, either individually or with a group; can be written or verbal	"Brainstorm a list of possible ideas -- anything goes" -- Dymiere; "I would think of all materials available that might lend themselves to this

	challenge” -- Solomon
Plan: mention of developing/outlining steps or a specific process for solving a problem	"discuss plan [and] what features the coat should have" -- Jaylin; “plan how to do it by using prior knowledge and experience” -- Kahree
Prototype: going through an iterative process of design/redesign, creating models, revising initial ideas, and/or a process of trial and error	"Revise prototype based on data findings and communicate for feedback. Repeat until data communicates effectiveness" -- Xiomara; "Based on these tests any problems would be adressed [sic], the prototype would be redesigned and re-tested." -- Manuela
Mathematics: mention of any formulae or necessary/potential calculations or creation of tables/charts/graphs	"Gather mathematical data of how the models succeeded (or failed) in meeting the criteria" -- Francis
EDP Teaching Codes	**Examples**
Slow Down: as a direct quote or idea	"stop and think about the design process" -- Dymiere; "slow down -- get to know who you are designing for" -- Jameel
Analogies: use of analogies as an explanatory teaching tool	"Think about insulation. Why do many people in a room keep it warmer? Why does a thermos keep liquid cool or warm?" -- Daneyah
Argument from Evidence: mention of persuading others based on scientific observations or other evidence; includes creation of pros/cons list	"use the available data to explain/defend the materials they would like to use" -- Xiomara; "I would invite the students to come up with data driven arguments to defend their ideas." -- Eva
Data Analysis: mention of analyzing various data in order to reach a conclusion	"run some tests to collect data on the attributes they are debating" -- Aiyanah; "they should make a decision based on the evidence. They need to use the information they have to make an informed decision" -- Manuela
Discussion: talking with others about ideas without explicit mention of specifically involving evidence	"Discuss what the most important features should be" -- Sitsofe
Redirection by Teacher: treating ideological conflict between students as a misbehavior requiring teacher intervention that does not encourage debate or discourse, but instead seeks to resolve the conflict as quickly as possible by ignoring the root of the conflict; can include choosing approach at random	"This is not relevant to the design" -- Kevin; "I would tell them to each put their ideas on a piece of paper and place in a hat. Then do a random drawing of the ideas and begin" -- Solomon

Research Other Groups: mention of observing/interacting with other groups to uncover other solutions or examine/explore other ideas	"An additional option would be for them to gather information from other groups to see how that info might affect the outcome" -- Stephanie

In order to establish intercoder reliability [26] 100% of the pre- and post- tests were double coded by the first and third author. As shown in Table 2 below, for each question, the percent agreement before discussion was above 90%. Specifically, percent agreement before discussion was 91% for question 25A, 92% for question 25B-A, 94% for question 25B-B, and 92% for question 25C. This percent agreement is evidence of the reliability of the codes, and therefore demonstrates the degree of trustworthiness we may have in our results [26] After coding, the percent difference in occurrence of each theme between the pre- and post- tests was computed to analyze the change in participants perceptions and conceptions of the EDP and its implementation in elementary classrooms throughout the graduate course.

Table 2: Double Coding Agreement per Question

	Question			
	25A	25B-A	25B-B	25C
Agreement Before Discussion	91%	92%	94%	92%
Agreement After Discussion	99%	99%	100%	100%
Disagreement	1%	1%	0%	0%

Findings

Our data suggests ways in which participants' PCK has evolved throughout the duration of the EDP teaching methods course. In particular, our data reflect the ways in which teachers' understanding of the EDP has changed, as well as how to support students through the EDP. Over the course of our analysis, three findings emerged: First, teachers mentioned *brainstorming, planning,* and *prototyping* more frequently from pre- to post-tests when describing steps necessary to a design challenge and providing feedback to students. Second, teachers' instructional strategies with regard to teaching EDP suggest that they recognize the need for explicitly teaching *planning* and *prototyping* skills to students. Third, at the conclusion of the course, teachers' focus had shifted to *data analysis* as a means for resolving disagreements among students engaged in the EDP.

Finding 1: Teachers' Knowledge of the EDP Steps. Our analysis of teachers' answers from questions 25A and 25B-A provided evidence to support our first finding. These questions focused on uncovering participants' conceptions of the various steps involved in EDP by providing a concrete example, but without using the term EDP. In both questions, we see an increase in teachers' understanding of *brainstorming*, *planning*, and *prototyping*. Our data suggest that participants had a deeper understanding of EDP at the conclusion of the course.

Our analysis of question 25A, which asked our teachers to list and describe the steps they are going to take to design and create type of coat for their team members, suggests that, at the conclusion of the course, teachers better understood that *brainstorming*, *planning*, and *prototyping* were necessary steps in a design challenge. Table 3 shows the raw data for this question, which describes the number of participants (N = 17) who expressed the *EDP Content Codes* as measured by the pre- and post-test, as well as the difference from pre- to post-test, as both counted numbers and percentages. *Research* was mentioned by 71% (n = 12) of participants before the course, and by 65% (n = 11) after the course, resulting in a decrease of 6% (n = 1). *Interview* was mentioned by 24% (n = 4) of participants before the course, and by 29% (n = 5) after the course, resulting in an increase of 6% (n = 1). *Brainstorm* was mentioned by 12% (n = 2) of participants before the course, and by 47% (n = 8) after the course, resulting in an increase of 35% (n = 6). *Plan* was mentioned by 9% (n = 1.5) of participants before the course, and by 35% (n = 6) after the course, resulting in an increase of 26% (n = 4.5). *Prototype* was mentioned by 62% (n = 10.5) of participants before the course, and by 94% (n = 16) after the course, resulting in an increase of 32% (n = 5.5). *Mathematics* was mentioned by 0% (n = 0) of participants before the course, and by 12% (n = 2) after the course, resulting in an increase of 12% (n = 2).

Figure 1 shows the number of participants who mentioned these codes in the pre- and post-tests, and figure 2 shows the percent difference across pre- and post-tests. Through this side by side comparison, we can easily see how both the amount of participants who mentioned each code and the degree to which that changed in relation to the rest of the codes. For instance, while figure 2 shows a *negligible* change in *research* from pre- to post-tests, figure 1 shows that *research* was still the second most mentioned code from pre- to post-tests. This suggests to us that teachers' knowledge of the importance of *research* in the EDP was well-developed from the beginning.Additionally, figure 1 shows that while *brainstorm* was the third most mentioned code from after the post-test, figure 2 reveals that it had the greatest increase from pre- to post-test. As question 25A was designed to measure the extent to which teacher knowledge of EDP changes throughout the course, this data suggests that, by the end of the course, teachers' knowledge of EDP changed to reflect a greater understanding of the importance of the ability to *brainstorm*, *plan*, and *prototype* to the EDP.

Table 3: Question 25A: Teachers' Steps of the Engineering Design Process

Q25A	**Before (N = 17)**		**After (N = 17)**		**Difference**	
Codes	**n**	**%**	**n**	**%**	**n**	**%**
Research (Ask)	12	71%	11	65%	-1	-6%
Interview (Ask)	4	24%	5	29%	+1	6%
Brainstorm (Imagine)	2	12%	8	47%	6	35%

Plan	1.5	9%	6	35%	4.5	26%
Prototype (Create and Improve)	10.5	62%	16	94%	5.5	32%
Mathematics	0	0%	2	12%	2	12%

Figure 1: *Teachers' Steps of the Engineering Design Process*

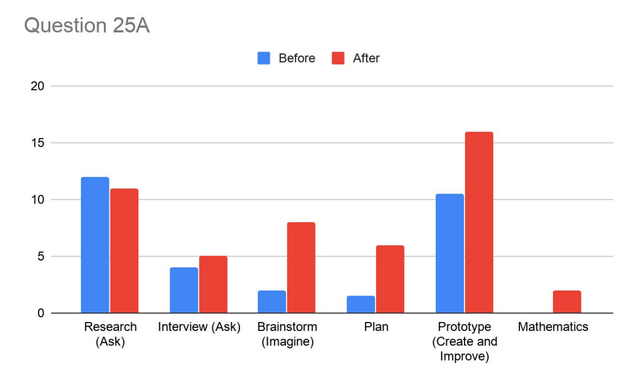
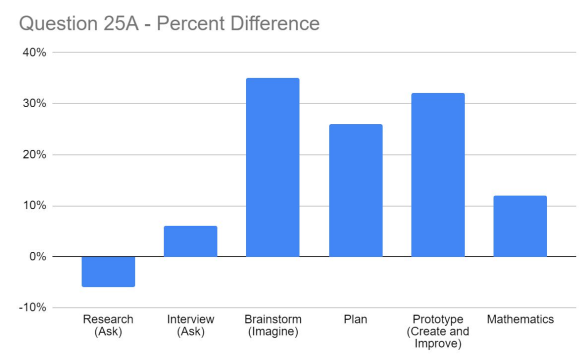


Figure 2: *Teachers' Steps of the Engineering Design Process*



We also asked our teachers to review a scenario in which students had begun creating the coat immediately upon receiving the materials in the design challenge. Our analysis of their responses also suggest that they mentioned *brainstorming*, *planning* and *prototyping* more from pre- to post-tests when describing the steps that this group had skipped, as illustrated in our results from Question 25B-A below.

Our analysis of question 25B-A, which asked our teachers to consider the steps that a group of students skipped, suggests that, at the conclusion of the course, teachers better understood that *brainstorming*, *planning*, and *prototyping* were necessary areas to provide feedback and clarity to students engaged in a design challenge. Table 4 shows the raw data for this question, which describes the number of participants (N = 17) who expressed the *EDP Content Codes* as measured by the pre- and post-test, as well as the difference from pre- to post-test, as both counted numbers and percentages. *Research* was mentioned by 59% (n = 10) of participants before the course, and by 50% (n = 8.5) after the course, resulting in a decrease of 9% (n = 1.5). *Interview* was mentioned by 12% (n = 2) of participants before the course, and by 6% (n = 1) after the course, resulting in a decrease of 6% (n = 1). *Brainstorm* was mentioned by 12% (n = 2) of participants before the course, and by 32% (n = 5.5) after the course, resulting in an increase of 21% (n = 3.5). *Plan* was mentioned by 24% (n = 4) of participants before the course, and by 47% (n = 8) after the course, resulting in an increase of 24% (n = 4). *Prototype* was mentioned by 18% (n = 3) of participants before the course, and by 26% (n = 4.5) after the course, resulting in an increase of 9% (n = 1.5).

Figure 3 shows the number of participants who mentioned these codes in the pre- and post-tests, and figure 4 shows the percent difference across pre- and post-tests. Through this side by side comparison, we can easily see how both the amount of participants who mentioned each code and the degree to which that changed in relation to the rest of the codes. For instance, while figure 4 shows a *negligible* change in *research* from pre- to post-tests, figure 3 shows that *research* was still the most mentioned code from pre- to post-tests. This further suggests to us that teachers' knowledge of the importance of *research* in the EDP was well-developed from the beginning. Additionally, figure 4 shows that while *brainstorm* and *plan* had near identical gains from pre- to post-test, figure 3 reveals that *plan* was easily more prolifically mentioned than *brainstorm*. As question 25B-A was designed to measure the extent to which teacher knowledge of EDP changes throughout the course, particularly in terms of analyzing student behaviors to provide feedback, this data suggests that, by the end of the course, teachers' knowledge of EDP changed to reflect a greater understanding of the importance of the ability to *brainstorm*, *plan*, and *prototype* to the EDP.

Table 4: Pre/Post Codes for Question 25B-A

Q25B-A	**Before (N = 17)**		**After (N = 17)**		**Difference**	
Codes	**n**	**%**	**n**	**%**	**n**	**%**
Research (Ask)	10	59%	8.5	50%	-1.5	-9%
Interview (Ask)	2	12%	1	6%	-1	-6%
Brainstorm (Imagine)	2	12%	5.5	32%	3.5	21%
Plan	4	24%	8	47%	4	24%
Prototype (Create and Improve)	3	18%	4.5	26%	1.5	9%

Figure 3: What did students skip?

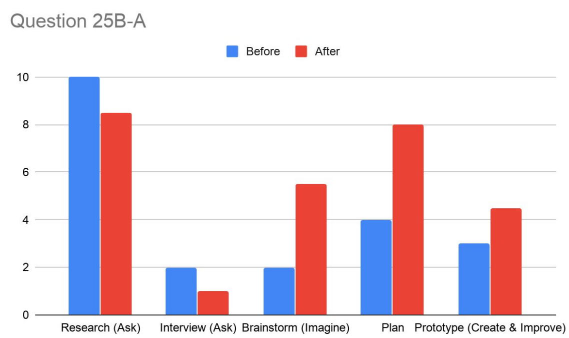
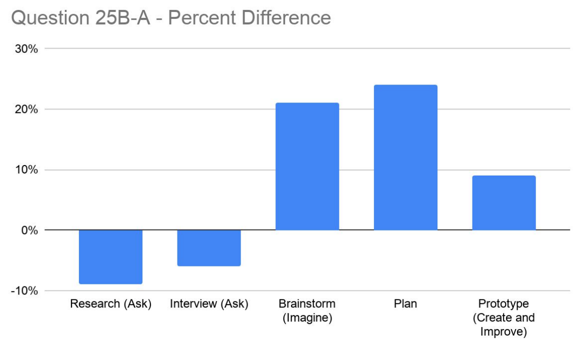


Figure 4: What did students skip?



Together, our analysis of the EDP Content Codes mentioned in Questions 25A and 25B-A, indicates that participants had a deeper understanding of EDP at the conclusion of the course, with particular emphasis on the elemental steps *brainstorm*, *plan*, and *prototype*.

Finding 2: Teachers' EDP Instructional Strategies. Our analysis of teachers' answers from question 25B-B provided evidence to support our second finding. This question asked participants to consider a scenario in which students had begun to create their coat as soon as they were given materials, and asked the participant, as the teacher, to give students advice. The advice participants describe shifts to show that, at the end of the course, the advice they give more frequently revolves around *planning*, and *prototyping*.

Our analysis of question 25B-B suggests that, at the conclusion of the course, teachers better understood that *planning* and *prototyping* were necessary areas to provide feedback and clarity to students engaged in a design challenge. Table 5 shows the raw data for this question, which describes the number of participants (N = 17) who expressed the *EDP Content Codes* and some of the *EDP Teaching Codes* as measured by the pre- and post-test, as well as the difference from pre- to post-test, as both counted numbers and percentages. *Research* was mentioned by 41% (n = 7) of participants before the course, and by 12% (n = 2) after the course, resulting in a decrease of 29% (n = 5). *Interview*, was mentioned by 6% (n = 1) of participants before the course, and by 0% (n = 0) after the course, resulting in a decrease of 6% (n = 1). *Brainstorm* was mentioned by 12% (n = 2) of participants before the course, and again by 12% (n = 2) after the course, resulting in a change of 0% (n = 0). *Plan* was mentioned by 29% (n = 5) of participants before the course, and by 35% (n = 6) after the course, resulting in an increase of 6% (n = 1). *Prototype* was mentioned by 0% (n = 0) of participants before the course, and by 30% (n = 5) after the course, resulting in an increase of 30% (n = 5). *Slow Down* was mentioned by 41% (n = 7) of participants before the course, and by 29% (n = 5) after the course, resulting in a decrease of 12% (n =2). *Analogies* were mentioned by 6% (n = 1) of participants before the course, and by 0% (n = 0) after the course, resulting in a decrease of 6% (n = 1).

Figure 5 shows the number of participants who mentioned these codes in the pre- and post-tests, and figure 6 shows the percent difference across pre- and post-tests. Through this side by side comparison, we can easily see both the number of participants who mentioned each code and the degree to which that changed in relation to the rest of the codes. For instance, figure 6 shows that *prototype* had a *substantial* increase while *plan* had a negligible change, however figure 5 reveals they are mentioned by similar numbers of participants at the end of the course. Additionally, while figure 6 shows a *substantial* decrease in *research* from pre- to post-tests and a *negligible* change in *interview*, figure 3 shows that *research* was one of the most mentioned codes at the beginning of the course, and was still mentioned more than *interviews* at the end of the course. Although there was a substantial drop in *research* from pre- to post-tests, this still suggests to us that teachers' knowledge of the importance of *research* in the EDP was well-developed from the beginning, and that teachers' focus was merely shifted to other codes such as *plan* and *prototype*. As question 25B-B was designed to measure the extent to which teacher knowledge of EDP changes throughout the course, particularly in terms of analyzing student behaviors to provide feedback, this data suggests that, by the end of the course, teachers' knowledge of EDP changed to reflect a greater understanding of the importance of the ability to *plan* and *prototype* to the EDP.

Table 5: Pre/Post Codes for Question 25B-B

Q25B-B	**Before (N = 17)**		**After (N = 17)**		**Difference**	
Codes	**n**	**%**	**n**	**%**	**n**	**%**
Research (Ask)	7	41%	2	12%	-5	-29%
Interview (Ask)	1	6%	0	0%	-1	-6%
Brainstorm (Imagine)	2	12%	2	12%	0	0%
Plan	5	29%	6	35%	1	6%
Prototype (Create and Improve)	0	0%	5	30%	5	30%
Slow Down	7	41%	5	29%	-2	-12%
Analogies	1	6%	0	0%	-1	-6%

Figure 5: Advice for struggling learners

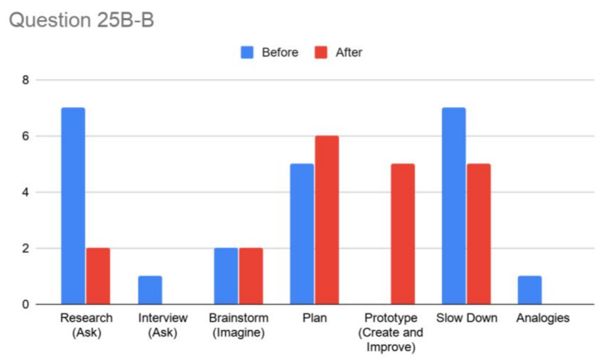
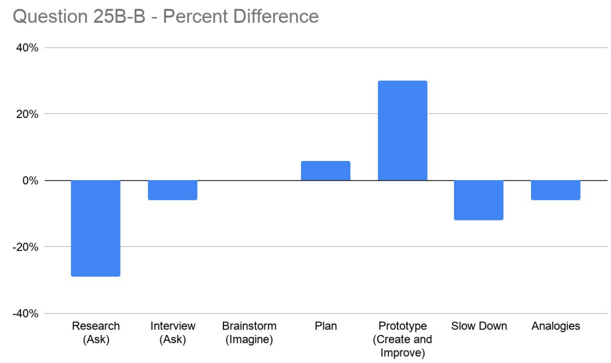


Figure 6: Advice for struggling learners



Finding 3: Resolving Disagreements Through *Data Analysis*. Our analysis of teachers' answers from question 25C provided evidence to support our third finding. This question asked participants to consider a scenario in which a group of students working together cannot agree on the best course of action, and asks the participant, as their teacher, how they could help to resolve this disagreement. The advice participants describe suggests that, as teachers develop a more thorough understanding of EDP, they may be more inclined to suggest students analyze data in order to solve problems and resolve real-life disagreements.

Our analysis of question 25C suggests that, at the conclusion of the course, teachers better understood that *prototyping* and *data analysis* were important to resolve disagreements among students engaging in the EDP. Table 6 shows the raw data for this question, which describes the number of participants (N = 17) who expressed the *EDP Content Codes* and the *EDP Teaching Codes* as measured by the pre- and post-test, as well as the difference from pre- to post-test, as both counted numbers and percentages. *Research* was mentioned by 6% (n = 1) of participants before the course, and by 18% (n = 3) after the course, resulting in an increase of 12% (n = 2). *Brainstorm* was mentioned by 12% (n = 2) of participants before the course, and by 0% (n = 0) after the course, resulting in a decrease of 12% (n = 2). *Prototype* was mentioned by 12% (n = 2) of participants before the course, and by 41% (n = 7) after the course, resulting in an increase of 29% (n = 5). *Argument from evidence* was mentioned by 29% (n = 5) of participants before the course, and by 24% (n = 4) after the course, resulting in a decrease of 6% (n = 1). *Data analysis* was mentioned by 6% (n = 1) of participants before the course, and by 47% (n = 8) after the course, resulting in an increase of 41% (n = 7). *Discussion* was mentioned by 18% (n = 3) of participants before the course, and by 6% (n = 1) after the course, resulting in a decrease of 12% (n = 2). *Redirection by teacher* was mentioned by 24% (n = 4) of participants before the course, and by 12% (n = 2) after the course, resulting in a decrease of 12% (n = 2). *Research other groups* was mentioned by 0% (n = 0) of participants before the course, and by 12% (n = 2) after the course, resulting in an increase of 12% (n = 2).

Figure 7 shows the number of participants who mentioned these codes in the pre- and post-tests, and figure 8 shows the percent difference across pre- and post-tests. Through this side by side comparison, we can easily see both the number of participants who mentioned each code and the degree to which that changed in relation to the rest of the codes. For instance, figure 8 shows that *prototype* had a *moderate* increase while *data analysis* had a *substantial* increase, however figure 7 reveals they are mentioned at nearly the same rate (difference of 1 participant) at the end of the course. Additionally, while figure 8 shows the same *slight* decrease in both *discussion* and *redirection by teacher* from pre- to post-tests, figure 7 shows that *redirection by teacher* is still mentioned twice as frequently as *discussion* at the end of the course. As question 25C was designed to capture the ways that teachers' pedagogical moves to scaffold students' learning experiences of the EDP change from pre- to post-test, this data suggests that, by the end of the course, the focus of teachers' pedagogical moves shifted toward *data analysis* as a means for resolving disagreements among students engaged in the EDP.

Table 6: Pre/Post Codes for Question 25C

Q25C	**Before (N = 17)**		**After (N = 17)**		**Difference**	
Codes	**n**	**%**	**n**	**%**	**n**	**%**
Research (Ask)	1	6%	3	18%	2	12%
Brainstorm (Imagine)	2	12%	0	0%	-2	-12%
Prototype (Create and Improve)	2	12%	7	41%	5	29%
Argument from Evidence	5	29%	4	24%	-1	-6%
Data Analysis	1	6%	8	47%	7	41%
Discussion	3	18%	1	6%	-2	-12%
Redirection by Teacher	4	24%	2	12%	-2	-12%
Research other Groups	0	0%	2	12%	2	12%

Figure 7: Resolving Disagreements

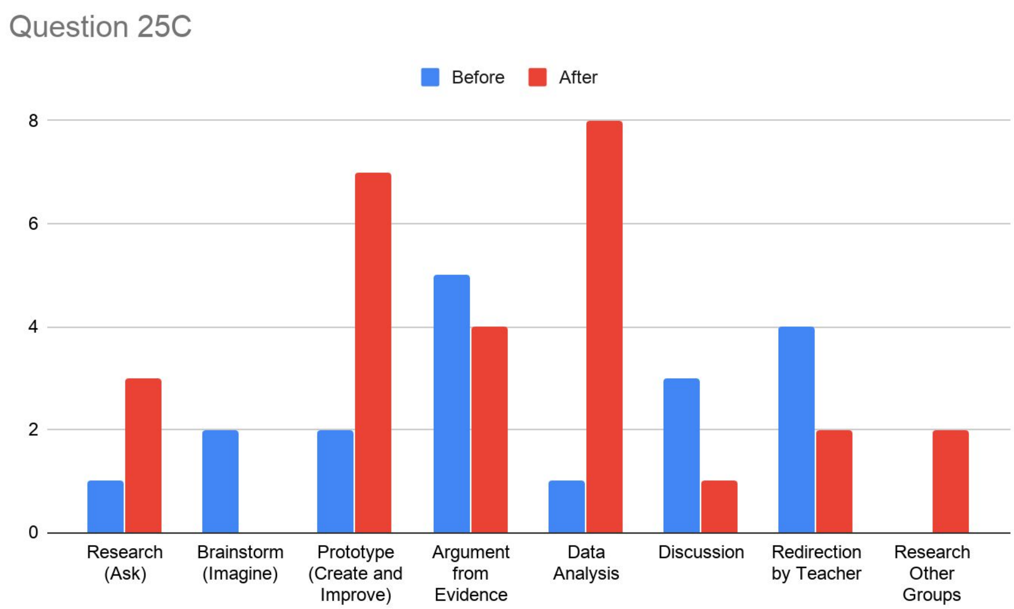
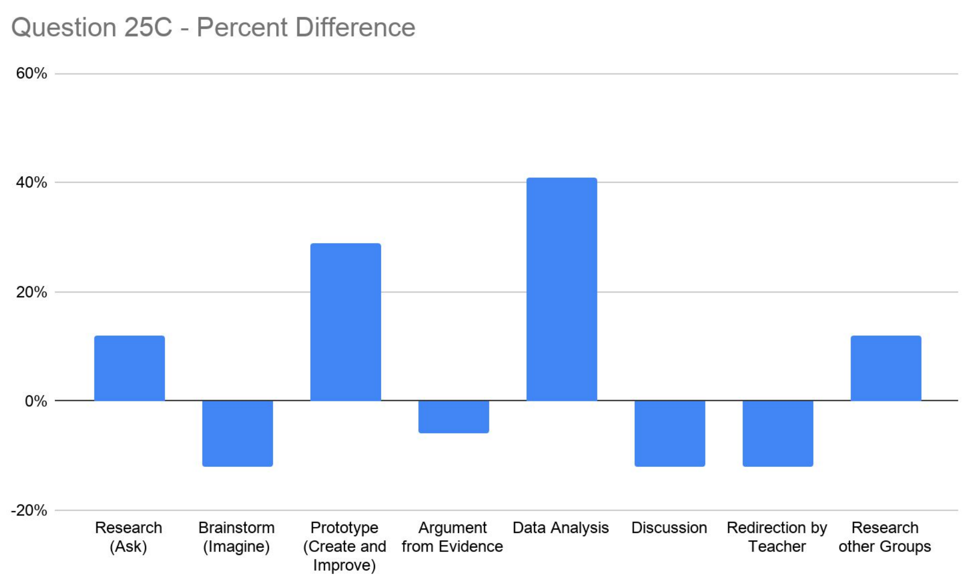


Figure 8: Resolving Disagreements



Discussion

In order to answer our research questions, we gathered data from identical pre- and post-tests administered at the beginning and end of the course to all 17 participants. The test was designed to measure participants' knowledge of the EDP and pedagogical moves to scaffold students' learning experiences of the EDP. Similar to the study of Hynes [10] that found their teachers showed mixed levels of subject matter knowledge of EDP, but were successful in constructing a prototype and redesign, the analysis of our findings indicate three points that bear further discussion. First, our analysis of data suggests that participants had a deeper understanding of EDP at the conclusion of the course, with particular emphasis on *brainstorming*, *planning*, and *prototyping* as steps of the EDP (see Figure 1). This was confirmed when we asked our teachers to review a scenario in which students had begun creating the coat immediately upon receiving the materials in the design challenge (see Figure 3). Our findings support the studies of McGrath et al. [12] in which teachers in their program who engaged in the Engineering is Elementary curriculum increased their knowledge of EDP and supported their implementation of EDP in the classroom.

Second, with regard to teachers' instructional strategies with regard to teaching EDP, our findings suggest that teachers recognize the need for explicitly teaching *planning* and *prototyping* skills to students. Although there was a substantial drop in *research* from pre- to post-tests, this still suggests to us that teachers' knowledge of the importance of *research* in the EDP was well-developed from the beginning, and that teachers' focus was merely shifted to other codes such as *plan* and *prototype*. This challenge was similar to those teachers who were learning how to implement model-based science inquiry for the first time. Teachers' focus tended to shift as they learned new concepts and pedagogical moves [27].

Third, contrary to the findings of Capobianco et al. [22], who saw their teachers gave priority to the first steps of EDP (identifying the problem and planning) and less time on the later steps (testing, communicating results and revising) during lesson planning, our teachers' focus had shifted to *data analysis* as a means for resolving disagreements among students engaged in the EDP. Our teachers' pedagogical moves toward *data analysis* suggest sophistication of their pedagogical knowledge of EDP that points to revision of prototypes based on evidence.

Limitations of Our Study

Our study has several limitations. First, written tests are only one of many ways of looking at teachers' knowledge and pedagogical moves. As such, it may not be the most accurate reflection of what teachers' instruction would look like in the classrooms. Second, this study did not include an assessment of teachers' content knowledge in the domain of science as they participated in the methods course. Domain-specific knowledge likely had an effect on the teachers' abilities to design EDP lessons, which was not described or accounted for in this study. Third, since we did not collect data (observation or video recordings) during classroom implementation, we are unable to describe how our teachers implemented their lessons in the classroom.

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