Professional Development for Elementary and Middle School Teachers: Enhancing Teacher Implementation of 21st Century Skills Through the Engineering Design Process

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1.0 Overview

In today's changing economy and global workforce, several published policy documents advocate an increase in science, technology, engineering, and mathematics in K-12 education (Committee on Prospering in the Global Economy of the 21st Century, 2007; National Academy of Engineering, 2009; National Research Council, 2010). Science and engineering education are seen as promising vehicles to promote 21st century skills in the classroom because they are not only a body of accepted knowledge, but they also involve processes that lead to knowledge (Casner- Lotto & Barrington, 2006; NAE, 2009). For instance, in the engineering design process (EDP), students are able to ask questions, propose possible solutions, construct and test prototypes, and present final products that can potentially promote creativity, innovation, critical thinking, problem solving, communication, and collaboration (Macalalag et al., 2010)(see Appendix A). In the US, employers demand skill sets from recently hired workers, such as the ability to effectively communicate, collaborate, problem solve, and think critically. However, these work-related skills were found to be lacking in many high school and college graduates (Casner- Lotto & Barrington, 2006). Little is known about effective teacher professional development (PD) models to cultivate 21st century skills in K-12 science and engineering content and classroom activities (Bybee & Fuchs, 2006). Most research studies and teacher PD that promotes the use of EDP focused on increasing teachers' and students' knowledge in science and engineering. However, only few programs examine the contribution of EDP to enhance students' skills (Boettcher et al., 2005; Dyehouse, Diefes-Dux, and Capobianco, 2011; Macalalag et al., 2010; NAE, 2009). Moreover, it is not clear what teachers know about these skills or if they know how to foster them, particularly in elementary classrooms (Macalalag et al., 2010; NRC, 2010).

To address some of these challenges, 46 Grade 3-8 science teachers from eight school districts throughout N.J. are taking part in a professional development program that uses science inquiry and EDP to foster 21st century skills in their classrooms. These teachers are currently participating in 15-credit hours of graduate content courses in physical and earth sciences, four professional development workshops, and monthly classroom support visits in the 2010-2012 school years. *We employed qualitative methodology to describe the extent in which teachers' description of skills that are important for their students to learn, as well as instructional methods and assessments to enhance these skills, changed over time as a result of the program. These were based on the pre- and post-clinical interviews conducted in 2010-2011 school year.*

Our analysis of interviews revealed several shifts in certain skills sets described by teachers: critical thinking and problem solving, communication and collaboration, and creativity and innovation, which are the same skill sets identified by the Partnerships for the 21st Century Skills. Given the program's focus on EDP, there was a significant increase in teachers' descriptions of implementing the engineering design process in their classrooms. Teachers mentioned engineering lessons such as designing roller coasters and windmills to teach the concepts of motion, forces, energy, and work; and in turn enhance skills like critical thinking and problem solving. Moreover, our analysis seems to suggest that teachers' lessons were more student-led (students' active participation in the lesson) after engaging in one year of the program compared to the start of the program. However, we didn't see growth in the teachers' knowledge of certain skills such as computer/information technology, global awareness and civic literacy, and skills associated with core subjects in schools (reading, writing and arithmetic). Finally, it was challenging for our teachers to propose assessments to evaluate their students' skills. We discuss our methods and findings in the next section.

2.0 Literature Review

Alarming trends from the Rising Above the Gathering Storm and the America's Perfect Storm policy reports showed that: (1) there are not enough students in the STEM fields today to support the workforce of tomorrow, (2) the number of science and engineering degrees awarded in the U.S. had fallen by 20% compared to 1985, (3) the number of engineering graduates in the U.S. today is one-fifth the number of graduates in India and less than one ninth the number in China, and (4) there are not enough qualified K-12 STEM teachers to meet the needs of the changing population of students (Committee on Prospering in the Global Economy of the 21st Century, 2007; Educational Testing Service, 2007; NAE, 2009). Also of critical importance in the contemporary workforce are such technological literacy skills as designing, developing, and utilizing technological systems; working collaboratively on problem-based design activities; and applying technological knowledge and ability to real-world situations (Deloitte Development, LLC, and the Manufacturing Institute, 2005; International Society for Technology in Education, 2002). A survey conducted to over 400 employers across the U.S. described the skill sets that new entrants or recently hired graduates (high school and college) need to succeed the workplace. Results indicated that the majority of the employers are looking for workers with the following sets of skills: critical thinking/problem solving, information technology applications, teamwork/collaboration, creativity/innovation, oral communications (Casner-Lotto & Barrington, 2006).

Science and engineering education are seen as promising vehicles to promote 21st century skills in the classroom because they are not only a body of accepted knowledge, but also involve processes that lead to knowledge (NRC, 2010; NAE, 2009). For instance, the Science Teaching Standards encourage teachers to teach science through inquiry (NRC, 1996). This includes engaging students in modeling and representation, learning investigations, and argumentation, which can foster critical thinking, problem solving strategies, collaboration, and communication (Michaels, Shouse, & Schweingruber, 2008). Similarly, in the EDP, students are able to ask questions, propose possible solutions, construct and test prototypes, and present final products, which promote creativity, innovation, critical thinking, problem solving, communication, and collaboration (Macalalag et al., 2010). For instance, in a study conducted by Kolodner, et al. (2003) showed that students in classrooms that used problem-based learning lessons performed better than those in traditional settings with respect to collaboration, metacognitive, and science process skills.

In the same manner, engineering robotics activity has shown to increase science literacy and systems understanding skills of 26 middle school students (Sullivan, 2008). Specifically, academically advanced eleven and twelve year old students participated in an intensive robotics summer camp to foster thinking skills and science process skills. Results showed that students used and enhanced their thinking skills of observation, manipulation, and estimation as well as science process skills of hypothesis generation and testing, control of variables, and evaluation of solution skills while solving robotics challenges. In another robotics project, 36 middle and high school students participated on a week of designing and building robots, made of LEGO™, that must operate underwater in a three dimensional space (McGrath et al., 2008). Analysis of data revealed that students not only used the engineering design process, but also learn the underlying science concepts (e.g. buoyancy, gear ratios, and mechanics) that impact the performance of their robot. Furthermore, the underwater robotics design helped students to learn to work in groups, communicate their challenges and successes to other groups, iterative problem solving, and reinforced their math skills.

In previous studies that we conducted in elementary classrooms, 47 grade 3-5 teachers in N.J. improved their notions of model-based science inquiry after attending a two-week summer workshop (Macalalag et al.,2009). Moreover, twenty nine 3rd grade students were able to improve their content knowledge in science such as understanding of the reasons for different seasons on Earth after engaging them in model-based science inquiry. In the process of modeling, students were able to communicate their understanding, work with each other in conducting experiments, and critically think as they revise their initial models. In our follow-up study (Macalalag et al., 2010) with 43 experimental teachers, 35 comparison teachers, and their students, our research findings based on the pre- and post-tests showed that experimental teachers and their students significantly increased their content knowledge in earth science and the EDP concepts compared to the comparison group. Moreover, experimental teachers mentioned in their survey that the EDP helped their students' structure their problem solving and ability to work in groups.

The *Partnership for 21st Century Skills* together with the *National Science Teachers' Association* identified skill sets that are important for students to learn in schools. They provided information, in their 21st century skills map document, of how teachers can foster these skills through science inquiry and EDP. For instance, by asking student teams to design plans for a device (e.g. a mechanical hand extension) that will assist people with disabilities or by asking students to think of ways to solve a problem, then teachers can potentially increase students' creativity and innovation skills (see Figure 1). We provided and used this document along with the skill sets and definitions identified by the Partnership for 21st Century Skills to our teachers (see Appendix B).

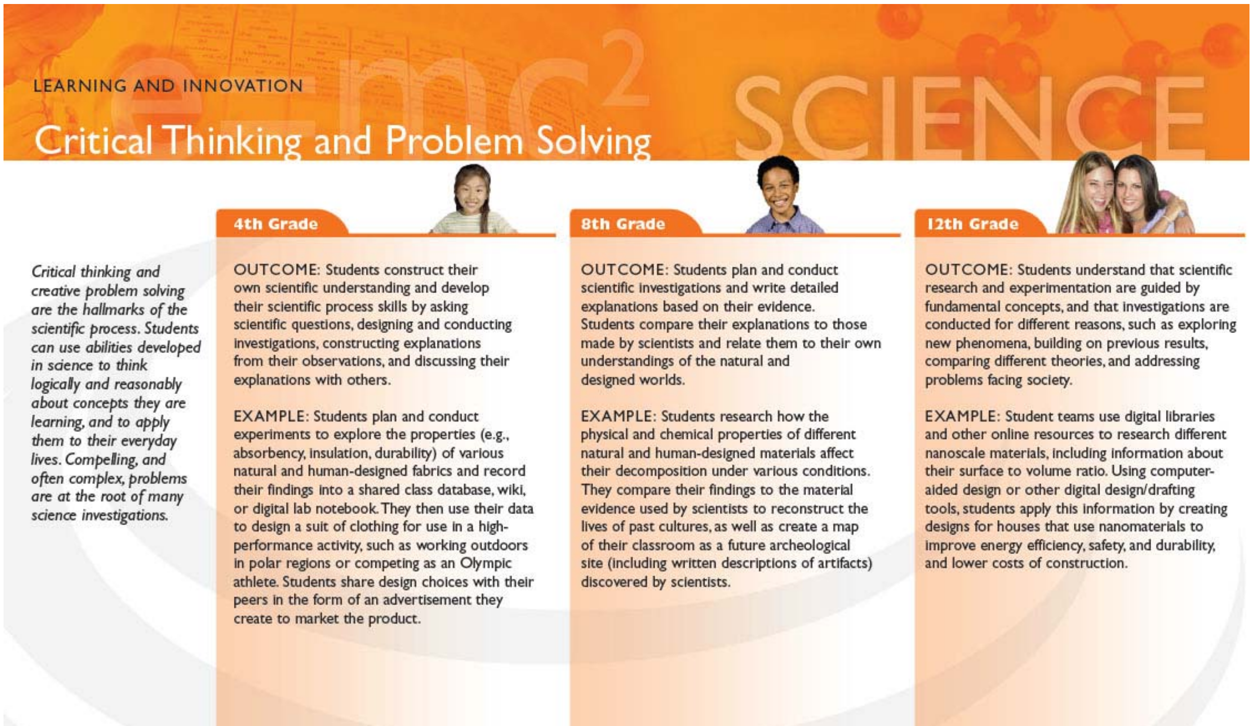


Figure 1. 21st Century Skills Map.

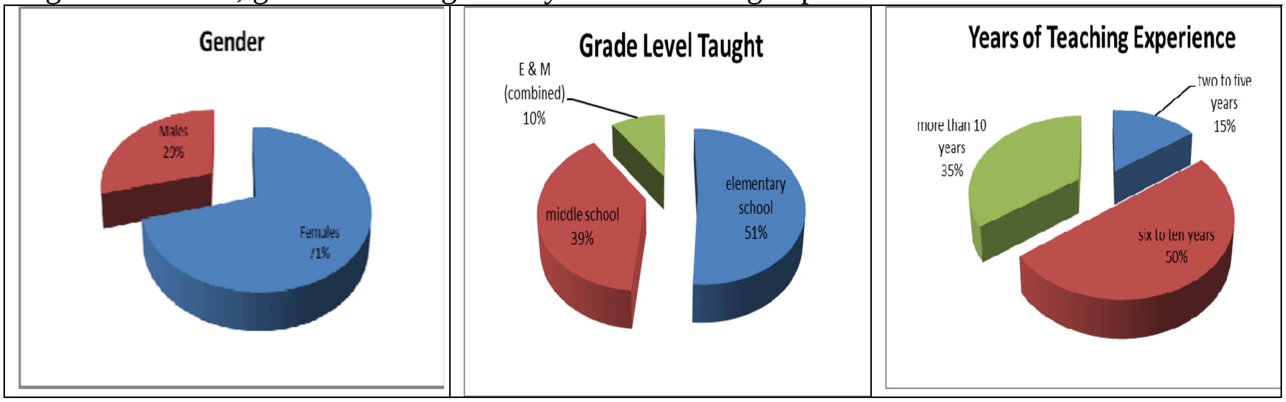
In this brief review, we described how science and engineering education can be used as context to promote 21st century skills in elementary and middle school classrooms. Our PISA[2] program will provide science content courses, workshops, and classroom support visits to support teachers implement science inquiry, EDP, and 21st century in the classrooms. Our hypothesis is that by using science inquiry and EDP, students' 21st skills will increase similar to what Kolodner, et al. (2003), Sullivan (2008), and McGrath et al. (2008) found in their studies. Given the findings of Macalalag et al. (2009) and Macalalag et al. (2010), teachers' conceptions and implementation of 21st century skills in the classroom will be basic at first, but will be comprehensive over time. We adapted the set of 21st skills, its definitions, and guidelines published by the Partnership for 21st Century Skills (2009) and the National Science Teachers Association. We will discuss our methods and data analysis procedures in the next section.

3.0 Methods

3.1 Participants

Forty six teachers from seven school districts throughout N.J. participated in our interviews. However, only 41 interviews have matched pre and post. Among the 41 teachers, 29 are females, 12 are males, 21 are teaching in elementary schools, 16 are teaching in middle schools, and 4 are teaching in both elementary and middle school levels. Moreover, 34 teachers have at least six or more years of teaching experience.

Figure 2. Gender, grade level taught and years of teaching experience.



3.2 Interview Protocol

We developed three questions to capture teachers' conceptions regarding 21st century skills and the different teaching approaches they described to develop these skills in their classrooms. The pre-interviews were conducted in June 2010 to provide us with baseline information, while the post-interviews were conducted after a year of teachers' participation in the PISA[2] program. The interview lasted for about 10-15min per teacher, and we asked teachers the following questions:

Question 1: Educators often consider both knowledge and skills that are important for their students to learn. Focusing on skills, what skills do you think your students need to prepare them to become productive citizens in the 21st century?

Question 2: How do you promote these skills in your classroom or in your lessons?

Question 3: How can students demonstrate these skills in the classroom, so that you can measure them?

3.3 Methods and Data Analysis

We employed qualitative procedures to analyze the pre and post interviews that we audio-recorded and transcribed. Before conducting our analysis, we blinded (removed names) and rearranged the transcripts to minimize bias. The development of our coding schemes proceeded through an iterative process of application to the data set and refinement of codes to capture relevant emerging themes in our data (Corbin & Strauss, 2008; Merriam, 1988). We double coded our data in instances when a statement fit into two different categories.

3.3.1 Analysis of the first interview question- skill sets identified by teachers.

Our analysis started by coding the teachers' answers on the first question – important 21st century skills. We used the framework developed by the *Partnership for 21st Century Skills* and *the National Science Teachers Association* to guide our coding process (see Figure 1 and Appendix B). A number of categories and subcategories emerged in our analysis of teachers' responses to identify skills they think are important for their students to become productive citizens in the 21st century. These categories included: (a) creativity and innovation, (b) critical thinking and problem solving, (c) communication and collaboration, (d) computer technology skills, (e) life and career skills, (f) global awareness and civic literacy, and (g) skills from core subjects in schools (reading, writing, and arithmetic). Appendix C lists the categories, sub-categories and examples that we used in our analysis.

3.3.2 Analysis of the second interview question- implementation of 21st century skills.

With regards to the second question, our coding process focused on the different pedagogical approaches teachers mentioned promoting skills that they described in the first question. The following categories emerged in our analysis: (a) different pedagogical approaches (science investigations, EDP, and use of computer technology) and (b) the degree in which teachers considered their students while designing their lessons (teacher-centered instruction and student-led investigations). Appendix D lists the categories, sub-categories and examples that we used in our analysis.

3.3.3 Analysis of the third interview question- assessing 21st century skills.

Finally, our analysis of the third question gave us the different forms of assessments that teachers mentioned assessing students' 21st century skills in the classroom. Teachers mentioned using rubrics, teacher observations, tests, reports, science products, and engineering products as ways to assess students' skills. We present the list of categories and examples in Appendix E.

4.0 Findings

4.1 Changes in teachers' notion of 21st century skills.

Our analysis suggests several shifts in teachers' notion of 21st century skills. These included improvements in teachers' notion about critical thinking and problem solving, communication and collaboration, and creativity and innovation. As an example, Chantal mentioned problem solving as essential skill for her students to learn. This included ability to determine the problem, find possible ways to solve the problem, evaluate information, and make decisions based on data:

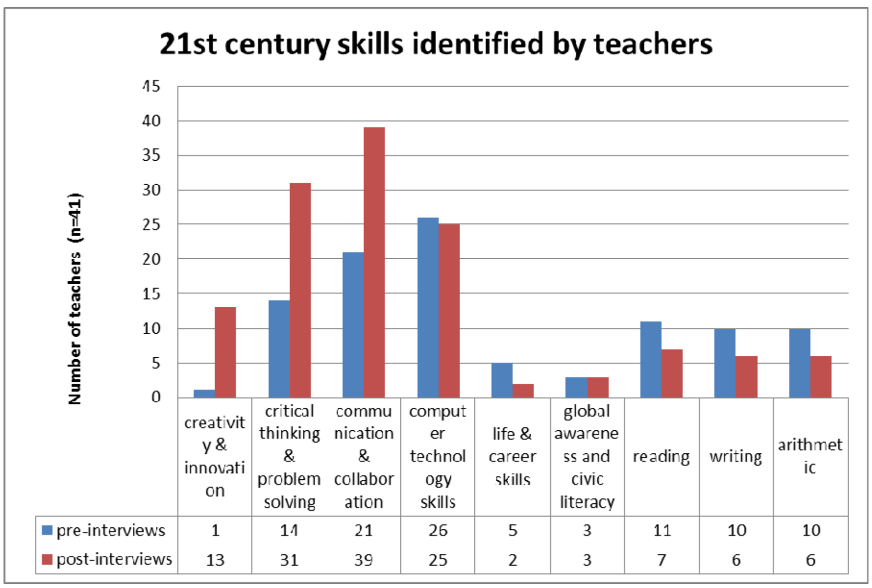
> *They need problem solving skills. With problem solving skills they have to be able to figure out how to determine a problem and steps to solve it and if that doesn't work revaluate situations, look at different sites, gather information that maybe pertinent and discard information that is irrelevant to the situation, differentiate between good information and bad information and incorporate that into their problem solving skills*"
> Chantal

In addition to problem solving, teachers also identified communication and collaboration skills. For instance, Amanda mentioned ability to communicate through speaking and writing as important skills for her students to learn:

> *Obviously being able to work in teams, communication: speaking and writing, being able to communicate their thoughts and your thought process as well as any conclusions. Being able to accept others' ideas and finding a way to working things out*" Amanda

However, we found no changes in the teachers' ideas about computer technology, life and career skills, global awareness, and skills associated with the core subjects in schools (reading, writing, and arithmetic). These findings were not surprising because we focused on certain skills (e.g. critical thinking and problem solving) and not on others (e.g. computer technology skills, life and career skills) in our courses and workshops. Specifically, critical thinking and problem solving as well as communication and collaboration are skill sets associated with the engineering design process and science investigations, which are the core practices that we promoted in our program. Figure 1 shows the shifts in the teachers' ideas of 21st century skills.

Figure 3. 21st century skills identified by teachers.



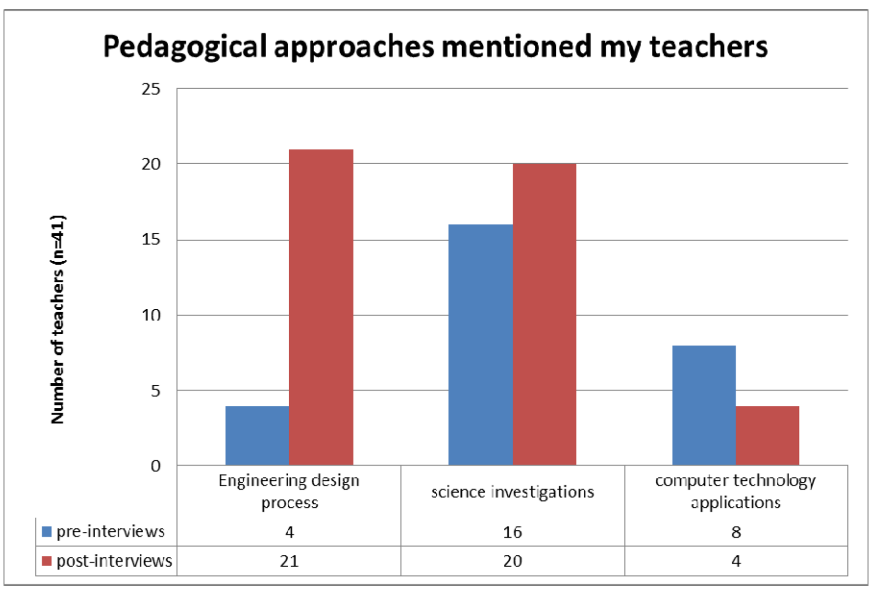
4.2 Changes in teachers' pedagogical approaches to promote 21st century skills

Our analysis suggested two main shifts in the teachers' descriptions of the pedagogical approaches they used to enhance students' 21st century skills. These included implementing the engineering design process and science investigations as part of their science instructions. For instance, Alison described asking her students to design roller coaster rides in order to teach the concepts of force and motion while engaging them in the engineering design process:

"Recently we did a lesson about force and motion and the students had to design a roller coaster, using foam pipe wrapping and marbles and only masking tape. They used different objects from the classroom to help stabilize their roller coaster but they couldn't tape it down to anything else. They worked in cooperative groups and they were told that they had to use I think it was four feet of track and they had to have one loop and they had to make the marble go through the entire track of roller coaster and they didn't get any other restriction or any other information and they really had to go through a trial and error process to see how different things work, what wasn't working and share different ideas when they thought something was working or wasn't working to get to that goal." Alison

In addition, Alison suggested enhancing the skills of her students by allowing them to collaborate and communicate with each other, as well as by engaging in a trial and error process in solving their problem. However, similar to the first question, we did not see any growth in the teachers' responses with regards to computer technology skills. Figure 2 shows the shifts in the teachers' pedagogical approaches to promote 21st century skills.

Figure 4. Pedagogical approaches.



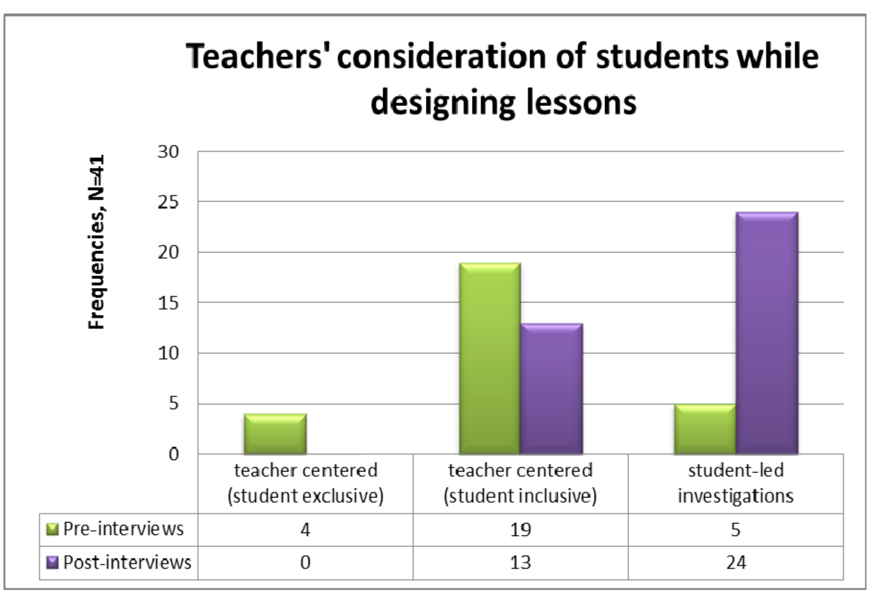
Further analysis of lessons described by teachers to implement 21st century skills in their classrooms gave us insight about the teachers' considerations of students while designing their lessons. The majority of lessons described by teachers in pre-interviews were mostly teacher-centered, student inclusive (level 1) in which teachers provided the questions to students while students engage in cook-book type activities or confirmatory labs. For instance, Haydee asked her students to conduct a web quest to answer the questions that she gave them, and later on engage in an activity to confirm what they learned from their research.

> *"…I did an oil spill with my sixth graders, but before they came to my lab I had them doing research in the computer lab, I gave them four websites that were geared toward children and gave them several questions I needed answers and I made them do the research, when they came to the lab, then they took the information that they had learned and answered my lab questions with that information and then I think they were better able to do the hands on lab because they knew what an oil spill was, they knew how oil reacted with water"* Haydee

On the other hand, the majority of instructions described by teachers as part of their post-interviews were mostly student-led investigations (level 2) in which students were engaged in asking questions, solving problems, and engaging in guided inquiry or engineering design. For instance, Amanda gave her students light bulb, battery and wire to investigate how they can make the light bulb work. Students worked in teams, discussed their ideas with each other, and think critically to solve their problem.

> *"I gave my students … a little light bulb, battery and wire and I said 'make this light bulb light up' … it took them about 20 minutes before the first group actually put a little apparatus together. They were working in teams, they were working in pairs and they worked very well together and so on…you know…they learned from each other, they watched what each other were doing and they were very respectful of each other's ideas and, you know, some kids were more agreeable but every child in the classroom was on task and involved…so they got the job done, and they used their critical thinking skills to put things together*" Amanda

Figure 5 shows the shifts in the degree of teachers' considerations of students in their instructions.



4.3 Assessments described by teachers to assess students' 21st century skills

Our analysis of assessments described by teachers gave us ideas of how they assess or what they use to assess their students' 21st century skills. There were shifts in teachers' identification of using rubrics and conducting observations to assess skills. For instance, Diane mentioned using a rubric to evaluate students' engineering project as well as their communication skills as they engage in the engineering design process:

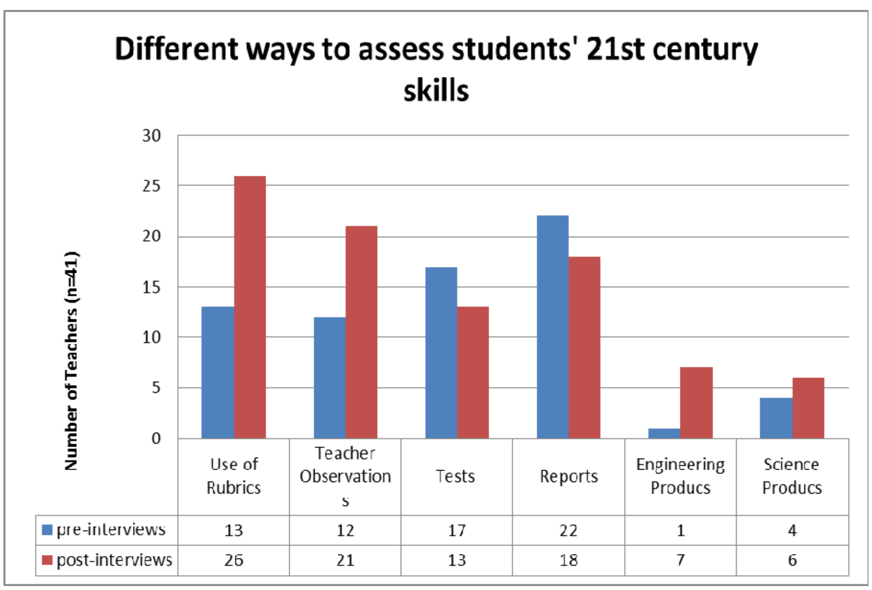
> "*Yes, there's a rubric in every design project, and within that rubric there's communication, because that's important. Engineers have to work with other people and need to communicate with one another, so engineering process is part of the rubric with communication*" Diane

However, in most cases, teachers' proposed assessments were vague. Specifically, it was unclear what the rubric will measure or how it can be used to assess skills. One possible explanation was that our instrument (interview) was not able to capture details or nuances of the teachers' assessments. It was also unclear if the assessments were meant to evaluate students' skills or knowledge. For instance, Chantal's assessments consisted of short constructed response items:

> "*As it is right now…I do these assessments, I start with vocabulary recognition after we have gone through it…and short constructive responses, I'm generating it myself…they don't have science textbook in grade 5*" Chantal

Chantal's descriptions hinted on assessing students' knowledge, such as vocabulary words, and not skills.

Figure 6. Assessments mentioned by teachers.



5.0 Conclusions and Discussion

The goal of our study was to describe the extent in which teachers' notions of 21st century skills (skills that are important for their students to learn) as well as their instructional methods and assessments changed over one year as a result of our program. Based on our analysis of pre- and post-interviews, our findings showed several shifts in teachers' notion of 21st century skills. Specifically, similar to the findings of McGrath et al. (2008) who found that the EDP of underwater robots promoted their students' communication, collaboration, and problem solving skills; we found that our teachers implemented EDP and science inquiry to enhance critical thinking and problem solving, communication and collaboration, and creativity and innovation in their classrooms (see Figure 1). In response to the NAE (2009) who advocated for an increase in implementing EDP in K-12 classrooms, we believe that our teachers made a significant progress in identifying and describing crucial skills for their students to learn because these skills were associated with the two pedagogical approaches that we used in our program- the EDP and science inquiry (see Appendix A). In fact about half of our teachers in post-interviews described using the EDP to enhance skills (see Figure 4).

Further analysis of lessons identified by teachers to implement 21st skills hinted growth in their considerations of students' participation in their lessons. Lessons in post-interviews appear to be mostly student-led investigations in which students were asked to solve problems and engage in guided inquiry or engineering design (see Figure 4). However, we did not find any growth in other skill sets, such as computer technology and civic literacy skills. This was not surprising considering that we did not focus on these skills in our program. Moreover, we found that it was challenging for our teachers to develop ways to assess their students' 21st century skills. Their proposed assessments were vague and it was unclear if assessments were meant to evaluate students' knowledge or skills (see Figure 4).

We believe that our research can potentially contribute to the ways in which PD programs can improve teachers' conceptions of 21st century skills through EDP and science inquiry. Our next steps are to: (a) conduct studies that will describe teachers' conceptions of skills as they implement a science or engineering lesson in their classrooms (e.g. classroom observations or video-analysis), and (b) design assessments that will evaluate students' skills (critical thinking and problem solving, creativity and innovation).

6.0 References

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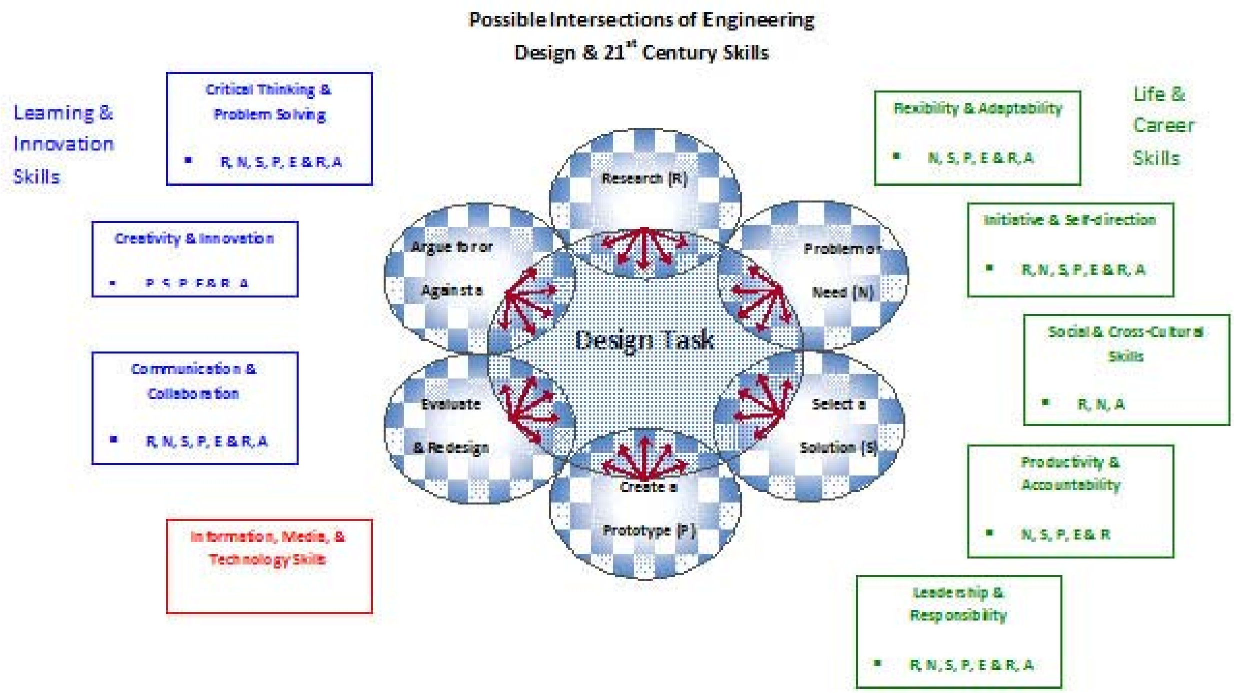
7.0 Appendix A: Possible intersections between the engineering design process and 21st century skills.



7.1 Appendix B: Skill Sets Identified by the Partnership for 21st Century Skills

LEARNING AND INNOVATION SKILLS	
Skill Sets	**Definitions**
Creativity and innovation	▪ Create new and worthwhile ideas (both incremental and radical concepts). ▪ Evaluate and refine ideas in order to make improvements.
Critical Thinking and Problem Solving	▪ Effectively analyze and evaluate evidence, arguments, claims and beliefs. ▪ Synthesize and make connections between information and arguments. ▪ Reflect critically on learning experiences and processes ▪ Identify and ask significant questions that clarify various points of view and lead to better solutions.
Communication	▪ Articulate thoughts and ideas effectively using oral, written and nonverbal communication skills in a variety of forms and contexts. ▪ Listen effectively to decipher meaning, including knowledge, values, attitudes and intentions.
Collaboration	▪ Demonstrate ability to work effectively and respectfully with diverse teams.
INFORMATION, MEDIA AND TECHNOLOGY SKILLS	
Skill Sets	**Definitions**
Information Literacy	▪ Access and evaluate information efficiently (time) and effectively (sources)
Media Literacy	▪ Understand both how and why media messages are constructed, and for what purposes. ▪ Examine how media can influence beliefs and behaviors. ▪ Understand and effectively utilize the most appropriate expressions and interpretations in diverse, multi-cultural environments.
Information, Communications, and Technology Literacy	▪ Use technology as a tool to research, organize, evaluate, and communicate information. ▪ Use digital technologies, communication/networking tools and social networks appropriately to access, manage, integrate, evaluate and create information to successfully function in a knowledge economy.
LIFE AND CAREER SKILLS	
Skill Sets	**Definitions**
Flexibility and Adaptability	▪ Adapt to varied roles, jobs responsibilities, schedules and contexts. ▪ Understand, negotiate and balance diverse views and beliefs to reach workable solutions, particularly in multi-cultural

	environments.
Initiative and self-direction	▪ Manage goals and time. ▪ Work independently. ▪ Go beyond basic mastery of skills and/or curriculum to explore and expand one's own learning and opportunities to gain expertise. ▪ Demonstrate commitment to learning as a lifelong process.
Social and Cross-cultural skills	▪ Know when it is appropriate to listen and when to speak. ▪ Conduct themselves in a respectable, professional manner. ▪ Respect cultural differences and work effectively with people from a range of social and cultural backgrounds.
Productivity and Accountability	▪ Manage projects. ▪ Produce results.
Leadership and Responsibility	▪ Use interpersonal and problem-solving skills to influence and guide others toward a goal. ▪ Inspire others to reach their very best via example and selflessness. ▪ Act responsibly with the interests of the larger community in mind.

7.2 Appendix C: Categories and examples of skill sets identified by teachers.

Category	Sub-categories	Level	Examples and Key Words
21st Century Skills Identified by Teachers	Learning and Innovation Skills	Creativity and/or Innovation	"*Students need to be creative…not to just look for the easy answer, not just to take the vocabulary word and find the definition in the book and here is my answer, but to actually either generate their own ideas, come up with their own…their own way to cast things their own way to maybe demonstrate what they have learned, you know, maybe they don't have to write it as a paragraph answer, maybe they can demonstrate it to the class, maybe they can you know, use technology and make some sort of a presentation, maybe they could construct something if they have artistic abilities, maybe they can do something like that; but to really allow them to work with whatever it is that they are learning*" Linda "*Thinking out of the box…let's say we did a unit on whales and the students would have multiple ideas on it and they got to choose their own projects and expand on it. Not necessarily telling them what they have to do but give them a topic and certain criteria within this topic giving them an opportunity to grow on their own and create their own ways to present their information*" Rosemary
		Critical Thinking and/or Problem Solving	"*They need problem solving skills. With problem solving skills they have to be able to figure out how to determine a problem and steps to solve it and if that doesn't work revaluate situations, look at different sites, gather information that maybe pertinent and discard information that is irrelevant to the situation, differentiate between good information and bad information and incorporate that into their problem solving skills*" Chantal

		Communication and Collaboration	"*I think they need communication skills, they need to know how to express their thoughts clearly, they need to be able to explain themselves to the best of their ability…*" Kirk "*They need to be able to talk about their findings with other people. They need to learn to work together in groups. They need to be able to discuss and come to a consensus with their peers*" Mercedes "*Obviously being able to work in teams, communication: speaking and writing, being able to communicate their thoughts and your thought process as well as any conclusions. Being able to accept others' ideas and finding a way to working things out*" Amanda
	Information, media and technology (computer technology skills)		"*Being able to use technology effectively, being able to handle spreadsheets, data that reflect research…being able to use different types of technology…using the internet…having the knowledge of how things work and how they can use them*" Diane "*Technology skills, they need to know how to use the internet, they to know how to use applications in computers. There's more technology out there now than there was several years ago…learning and sharing their ideas…all around the country*" Alan
	Core Subjects	The three Rs (reading, writing, and arithmetic)	"*I think other skills they definitely need are literacy skills, being able to read and write and understand what you're reading, what you're writing……probably the basic…like math skills, because math is involved pretty much in everything*" Gina "*with language arts, they need to know what nouns are, verbs are, everything that is related in language arts is related in every subject area and if they don't have the basic skills of reading*

			and writing, whatever they are going to do is not going to be their work, is going to be for some reason is going to be somebody else's work that they are handing in…" Rebecca
	Global awareness and civic literacy		"*…and be aware of global issues. Things that happen around the world that affect our country, our environment, you know, from tsunamis to bombings, anything that could affect our surroundings, whether in the fight ground or the political ground*" Denise "*Also global awareness, it's becoming a big thing making kids aware of what's going on in the world and how it impacts them and their learning…when the oil spill happened two years ago back then we discuss the impact on the environment*" Rosemary

7.2 Appendix D: Categories and examples of pedagogical approaches described by teachers to implement skills.

Category	Subcategory	Level	Example
Pedagogical approaches	Engineering Design Process		"*Recently we did a lesson about force and motion and the students had to design a roller coaster, using foam pipe wrapping and marbles and only masking tape. They used different objects from the classroom to help stabilize their roller coaster but they couldn't tape it down to anything else. They worked in cooperative groups and they were told that they had to use I think it was four feet of track and they had to have one loop and they had to make the marble go through the entire track of roller coaster and they didn't get any other restriction or any other information and they really had to go through a trial and error process to see how different things work, what wasn't working and share different ideas when they thought something was working or wasn't working to get to that goal*." Alison
	Science Investigations (Hands-on experimentation, activities, etc.)		"*We did several lessons this year that have been very helpful for 21st century skills, I can tell you about our motion lessons…potential energy where I promote all of these skills, we used a pull-back car for acceleration, and we used a remote control car for constant speed, or rather than telling the kids what we were looking for, it was more of an inquiry based lesson where the kids sat along the floor to see the cars up close and they generated questions about the differences and similarities between the two types of cars and the speed that they were traveling, also the distances that they were traveling. While the kids were speaking they were listening to each other's questions and ideas and they were coming up with even more ideas going more deeply into the subject more than I had even planned, so that was one lesson in specific that we used to foster their inquiry based skills and their problem solving abilities and also communication*" Claire
	Teacher Centered (student exclusive)	Level 0	"*it's directly me just teaching or me just directly reading from a book*" Valerie "*In my classroom I give lectures or read something from the textbook*" Haydee

Consideration of students while designing lessons	Teacher Centered (student inclusive)	Level 1	*"I promote these skills by posing questions myself and asking a lot of questions of them, I usually set up a problem and we discuss it, and we discuss how are we going to find out the answer, what are the best ways to do that, whether it be a hands on activity or a research activity, we work together, they work with each other I usually try to have them rotate the groups on a regular basis*" Mercedes "*For instance we talked about motion and I showed them the pendulum moving back and forth. They had to write down words about all the things that might be involved in the project. And then I say "give me all the words" and I put them on the board, the same is done with each group. And then with all the words in the board we eliminate the words that really didn't fit and by the time the class in done they have the definition and concepts without me having to pull it out but figured out by the students themselves*" Brian
	Student-led investigations	Level 2	"*Engineering skills are promoted by presenting students with a problem or having them discover a problem on their own, research this problem using technology and resources, design, create and test a possible solution for the problem, and finally evaluate this solution and how to possibly make it better, for example, a roller coaster design project. All science lessons involve some sort of collaboration, whether it is small or large group. I allow students to investigate questions they have generated from their own curiosity*" Kirsten

7.3 Appendix E: Categories and examples of assessments.

Category	Subcategory	Level	Examples
Different Forms of Assessments	Use of Rubrics		"*I normally create some rubric before we begin so that I know…the rubric would definitely have points for the ability to work together with partners, the amount of communication that you had with your partners, the way your group thought things through, you know, when they first came they used too much tin foil, maybe they had to go back and put some lighter fabric on for example, so they had to think critically about they were doing and then go back and do that so I definitely would have a rubric for that*" Denise "*Yes, there's a rubric in every design project, and within that rubric there's communication, because that's important. Engineers have to work with other people and need to communicate with one another, so engineering process is part of the rubric with communication*" Diane
	Teacher Observations		"*Basically, I just walk around the room and listen to what they're talking about when we're doing a group activity…I take note of those who are not participating and then later I ask them why didn't they share something with their groups because sometimes certain students turn to be more dominant over the group than others and I try to make sure that all 4 or 5 members of the group are working together, participating. With problem solving everybody has some kind of idea and it should be express…so I keep track of how ideas are coming up in the conversation*" Diane
	Tests or quizzes		"*So my assessment consists of this called practicum, so maybe a question on a test would be multiple choice…or questions to be solved in groups*" Valerie "*We formally assess before and after. This is something new that I'm doing now. I really never gave a pretest of the material that I was going to cover in the past and I've been doing this for a dozen years now and it's a tool that really works well because the students actually understand what they*

			see on the pretest and what they will see on the posttest" Bruce
Student Products and reports		Reports, presentations, blogs	"*And towards technology...if they are successfully producing the required end result, whether they use a graph or PowerPoint presentation*" Glenda "…and then after the wiki was created each group designated a person to get up and communicate to the class the different type of bium that they did and present that information to the class" Rebecca
		Engineering products	"*They're usually in a group and get presented with a problem and they have to find the solution using different materials, so for example they have to create an object that withstand moist but not drown so they have to work together to do the design, choose the right materials, build it and actually test it out and if it doesn't work they need to improve their design and identify the area where they have the most difficulty with*" Gina "*There's a rubric in every design project, and within that rubric there's communication, because that's important. Engineers have to work with other people and need to communicate with one another, so engineering process is part of the rubric with communication*" Diane
		Science products	"*A lot of project based assessments. I actually teach a lab course so all I teach is lab. Just this year we started to use Vernier electronic data collection which was new for the kids because it's a new computer system for them, it's a new technology and it gives them the opportunity to do a lot of hands on with the probes, they do a lot of graphing, and let them actually develop a lot of their own experiments, like when we did an experiment I asked them how can we use this piece of equipment, you know, we were using something like just basic, like light probe, what else can we measure the light for? And actually letting them try through different things and experiment on their own, as far as critical reading I really have been trying to give them just the minimal basics and then kind of pulling out of them what they already know…really make them think*". Linda

			"*…they come to present their projects, basically they are taking the information from their paper and presenting that as they come up and do their whole presentation of their science fair experiment but they need to know their background information, so as they review their paper, they should know, they have to communicate that to me, so I know that they have an understanding of what their actual experiment is about*" Rebecca