

# **AC 2009-2016: TOWARD A TECHNOLOGICALLY LITERATE SOCIETY: ELEMENTARY-SCHOOL TEACHERS' VIEWS OF THE NATURE OF ENGINEERING**

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# **Toward a Technologically Literate Society: Elementary School Teachers' Views of the Nature of Engineering**

## **Abstract**

Generating a technologically literate society is considered to be one of the main goals of primary and secondary education. At the heart of technological literacy would be a knowledge of the nature of engineering (NOE) upon which content knowledge in engineering/technology could be built. Technological literacy of this nature cannot be developed among elementary school students, however, without dedicated and well-informed teachers. That raises the question: What should teachers know to promote technological literacy and spread it in their students' hearts and minds? We believe that an appropriate view of the NOE can play a role in the development of engineering and technology literacy that is similar to the role that an appropriate view of the nature of science (NOS) plays in the development of scientific literacy. We therefore studied elementary-school teachers' views of the NOE to obtain information that could guide both researchers and curriculum developers understand the current status of elementary-school education.

A naturalistic research approach was applied to design of this study. Data were collected by employing individual interviews with ten K-5 teachers. Content analysis was applied to the interview data to find general themes and patterns in teachers' views of the NOE. Results showed that teachers have positive attitudes towards engineering, but their knowledge of NOE is mostly limited to what they have experienced through popular culture. We noted that teachers' views of the NOE were influenced by personal relationships they might have with engineers who were close relatives or friends. Another pattern that was found in teachers' views of the NOE involved their perception that engineering is a problem-solving activity, or involved problem solving within the process of inventing or creating innovative products. Although the teachers believed that engineers need to function in a holistic fashion, taking social and economical factors into account in their work, their perceptions of engineering were not sufficiently rich to allow them to explain how social and cultural factors affect engineering.

The results of this study of teachers' views of the NOE provide insight into the way professional development programs for elementary-school teachers should be designed to help these teachers bring engineering into the elementary-school classroom.

## **Background and research questions**

The literature on the nature of science (NOS) has suggested that students, teachers, and the vast majority of society, in general, believe certain common myths about science, including the myths that scientific facts are absolute and purely objective, that there is no role for human interpretation or imagination in science, and that scientists have certain rigid methods to generate scientific knowledge and/or solve problems.<sup>1-5</sup> Driver and her colleagues<sup>6</sup> have shown that students form ideas about science, its process, and its product — scientific knowledge — before any formal science instruction. The students' ideas are not nearly as sophisticated as those held by scientists and/or philosophers of science, but even elementary school students have ideas about how scientists work. It has been suggested that these ideas come from the students' exposure to the image of science and scientists from a variety of sources, including films, television programs, and from their parents and relatives.<sup>7</sup>

Research on students' misconceptions of science has suggested that teachers are a source of students' alternative frameworks.<sup>8-12</sup> The alternative frameworks held by the teachers can play a particularly important role in students' learning because formal instruction may either generate new alternative frameworks for the students or support the old ones. As a result, attempts to change students' conceptions of a particular phenomenon using conceptual change strategies may not be as fruitful as we would either hope or expect because, in the end, teachers deliver the instruction we design.<sup>10</sup> Teachers who have naïve or alternative frameworks or conceptions of a subject may not teach them well or they may produce ill-structured schema in students' minds.

Unlike the well-established field of the philosophy of science, no equivalent study of the philosophy of engineering exists.<sup>13</sup> However, inasmuch as engineering and engineering artifacts are part of our everyday life, elementary school students and their teachers have some elements of a developing epistemology of engineering and engineering thinking which may not be the desired one.<sup>14-16</sup>

It has historically been difficult for many people to separate achievements in science from those in engineering. When the Apollo 11 put Neil Armstrong on the surface of the moon, for instance, many people called it a victory of science. When a new type of material, such as lightweight, super-strong composites emerges on the market, newspapers and other media often report it as a scientific discovery. Genetic engineering of crops to resist insects is also usually attributed wholly to science. However, even though science is strongly tied with all of these advances, they are actually examples of technology that requires the application of unique skills, knowledge, and techniques.<sup>17</sup> Thus, there is reason to believe that teachers are likely to confuse science and engineering,<sup>15</sup> especially inasmuch as there is no direct exposure to engineering in pre-service teacher training programs.

### *Significance*

It has been argued that America's progress has been synonymous with engineering innovations, and that corporate growth and economic development, coupled with a higher standard of living, are inextricably tied to technological advancement.<sup>18</sup> As societies of the 21<sup>st</sup> century have become increasingly dependent on engineering and technology it is more important than ever that our citizens, as well as the technologically minded workforce, are scientifically and technologically literate.<sup>14,19,20</sup> There are many possible ways to develop technological literacy among public and recruit engineers. However, one of the most wide-reaching is through K-12 education.<sup>14, 16, 18</sup>

According to Lewin<sup>21</sup> engineering has become a banal academic subject with the unwanted perception of an anti-social nature in today's contemporary culture. Engineering is perceived to lack social and intellectual respectability, as indicated by recent public polls and the rate of enrollment in engineering programs.<sup>22, 23</sup> Lewin argued that the reason for this perception of engineering is either the absence of an understanding of what is engineering or a misperception of the field of engineering. In other words, the inadequacy of the socially shared meaning of the nature of engineering might make engineering unpopular. To overcome this

problem what we need to do is similar to what has been done in science and mathematics — cultivating a lasting love for engineering in students that starts among the very young.

The literature in science education strongly suggests that curriculum development should be derived from and shaped by students' conceptions and misconceptions.<sup>24, 25</sup> Our research designed to probe 6<sup>th</sup>-grade students' conceptions of the NOE suggests that students' views of engineers and nature of engineering are very naïve and include many misconceptions.<sup>26</sup> Many students, for example, mistakenly consider train conductors, factory workers, mechanics, technicians, individuals involved in artistic design, and architects as representations of an engineer. These findings overlap many findings of Knight and Cunningham<sup>16</sup> and the recent report of the National Academy of Engineering prepared by Baranowski and Delorey.<sup>27</sup> When we asked students where they obtained their knowledge of engineering, they noted that an important source was their teachers. This is not surprising when one looks at the research literature about students' views of the nature of science, which suggests that teachers' conceptions were a major constraint on students' attempts to learn about NOS.<sup>1, 28</sup> This literature has also noted that teachers represent one of the important sources of student misconceptions of the NOS.<sup>29</sup> As the research literature on VNOS evolved, it is not surprising that researchers shifted their focus from probing students' views of the NOS to their teachers' views of the NOS.

Cunningham et al.<sup>15</sup> noted that “knowledge of teachers' background knowledge, conceptions, attitudes, and comfort related to engineering and technology is important information that should shape engineering curriculum development, teacher resources and materials, and teacher professional development.” However, relatively few studies have probed teachers' conceptions of engineering and technology.<sup>15</sup> Therefore, the goal of this study is to probe elementary school teachers' views of the nature of engineering (NOE). Guiding research questions for this study include:

- What are the elementary school teachers' views of engineering?
  - What are elementary school teachers' views of engineering process?
- How do elementary school teachers distinguish engineering from science?

## **Methods**

To address the guiding research questions, a qualitative research approach was pursued.

### *Pilot Study*

A pilot study was carried out with a total of 14 elementary and middle school teachers by employing informal-conversational group and individual interviews in order to generate the questions that were used in the main study and to identify other factors that may affect data collection. The questions used in the pilot study were based on the work that has recently been done by examining elementary and middle-school students' views of the nature of engineering.<sup>26</sup> All interviews were audio-recorded, but not transcribed.

### *Setting and participants*

Two school districts and 5 elementary schools from a Mid-Western county were selected to conduct the study. Ten teachers from first- to fifth grade were chosen on a voluntarily basis. As seen in Table 1, all but one of the participants were women. Grades 3, 4, and 5 were chosen as the target of this study because more science, technology, and engineering topics are covered in these levels than in grades 1 and 2. Years of experience was another criterion used to identify the participants because we want to compare teachers who had taught various grades and grew up in pre-computer era with teachers who had less experience, but grew up with computers.

Table 1. Participants

Pseudonym	Age	Exp.	Grades	Education	Engineers in relatives
Amy	60	23	1	EE (BS, MS)	N/A
Sam	26	4	2	EE (BS)	Father (E)
Lily	48	22	2-3 Gifted	EE (BS), CD (MS)	N/A
Rick	46	10	3	GM (BS), EE (MS)	N/A
Lisa	36	14	4	EE (BS)	N/A
Jamie	58	35	4	EE (BS, MS)	Brother-in-law (E)
Carol	49	12	4	EE (BS)	Bother-in-law, nephew
Debra	61	26	4-5 Gifted	ED, ES (BS); R (MS)	Daughter-in-law (E)
Mary	35	35	5	EE (BS)	Brother
Kim	30	6	5	EE, SE (BS, MS)	N/A

Exp: Experience in the field; BS: Bachelor Degree; MS: Masters Degree; CD: Curriculum Development; ED: Education; EE: Elementary Education; ES: Earth Science; GM: General Management; R: Reading; SP: Special Education; E: Engineer

### *Data collection and analysis*

Teachers' views of the NOE were investigated by conducting individual semi-structured interviews (see Appendix for the interview protocol).<sup>30</sup> The interviews took 20 to 40 minutes to complete. All interviews were audio-recorded and transcribed verbatim. The data from the interviews were analyzed by employing content analysis in order to find repeating themes and patterns. The analysis process began with open coding because there are no pre-determined categories, a technique known as inductive data analysis.<sup>30</sup> Interview transcripts were examined by looking for similarities and differences among them. The hermeneutic circle that underlies research methodologies such as phenomenology presumes that this first stage of analysis leads to initial categories that describe participants' views of engineering. The data were then subjected to a second, deeper analysis that helped us develop more general categories and themes. In category development process, internal consistency of each category was one of the important goals.

## **Results**

We found five main categories into which we could classify teachers' view of engineering: the purpose of engineering, the process of engineering, the scope of engineering, the impact of engineering and the factors that influence engineering (See Table 2).

### *Purpose of engineering*

As can be seen in Table 2, almost all of the teachers stated that the main purpose of engineering was to improve the efficiency of products or productivity in general.

*Mary: Basically, that is kind of what I see as the role is... they (engineers) are trying to do something better, faster, more efficiently, more cost effectively. They are trying to improve things so you...*

Almost half of the teachers pointed out that engineering is a field that works constantly to make our lives better and easier.

*Researcher: OK. What do you think the main purpose of engineering?*

*Rick: To make things easier. I say to make things easier for people, to make things safer for people... to make things more efficient, umm... to make things... to give better accessibility to different things. Like if you think a lot of designs in transportation that allows people to go to different places to... see different things, to... have different experiences.*

Solving problems that arise was cited by four teachers as another aspect of engineering.

*Researcher: I asked you "is engineering important?" You said "yes." Why is it important?*

*Lily: Well, I think that as we progress for the future, new and different problems arise. And I think there is a need for more immediate communication, more immediate transportation. Umm... and I think technology and engineering kind of go hand-in-hand to help those things happen to make our lives more efficient.*

As can be seen in Table 2, the aspects of engineering that were mentioned by teachers less frequently were: meeting a need, making life safer, helping civilizations progress and understanding how things work. In general, teachers perceived engineering as a tool or a vehicle for progress in almost every aspect of life.

### *Processes of engineering*

Another category that was created on the basis of the interview data involved statements that referred to the processes of engineering. In this category we summarized methods and techniques that teachers thought engineering work involved: Problem solving and designing were mentioned by eight teachers, six of whom referred to both.

*Researcher: What images come to your mind when you think of engineering?*

*Lisa: Lots of math, working on complex problems and equations that related to an actually practical problem you're trying to solve that is what I think of...*

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*Researcher: So, when you think about... if you think... another bridge is going to be built over the Wabash River, what do you think engineers do in the process of building that bridge?*

*Mary: They would first start with computers and paper, getting some data they would have to know the load strength and all of that. So they would be using some science involved. They would get it all planned out most likely with a computer program. Umm... they would... you know would they have to check their specifications, make sure everything and then they would pass the plans on to the people who would build it.*

*Researcher: OK. In your view what does design mean in the context of engineering?*

*Mary: Design is coming up with the idea and putting it down into a form that some can read like either it be on paper pencil or be with a computer aided program. Design would be thinking... either taking somebody else's idea and improving on it or coming with the idea using the science behind it. Putting it all together into a form that can be used by somebody whether it'd be a line in a factory or a bridge or something else.*

Mathematical calculations were described as part of the engineering process by more than half of the participants.

*Researcher: So, why do you think a good engineer should have a good mathematical mind?*

*Lisa: Well, to calculate so that things work though right way. I mean you know you have to be able to calculate what is gonna go together to make it work right or if you are chemical, you have got to be able to understand measurement in a different sense.*

*Researcher: So, engineering deal with mathematics a lot?*

*Lisa: Well, I think... Yes, uhum... I mean I think of that when I think of engineering.*

Experiments and testing were acknowledged by half of the participants as a process of engineering. Mostly teachers referred to experimenting and testing as ways of checking whether the developed or designed artifact or the system is working, but one participant used “testing” to obtain the public opinion as well.

*Researcher: OK. So, what do they do to make it better?*

*Sam: They again, I just think they have to do experiment just like a scientist, they have to test things. Umm... I think a lot of times they test on the public in order to get response back, this is great then they might put it in more cars, but if they get back “oh my gosh this is horrible” then they might take it out from cars and try something else.*

As can be seen in Table 2, other processes that some teachers believed that engineering work involved are collaborative or co-operative team work, trial-error, trouble shooting, construction, observation, brainstorming, and reading others' work.

*Scope of engineering*

Teachers' responses to the questions revealed that engineering was believed to deal with developing, creating, or designing machines and consumer products (N=9), infrastructures and buildings (N=7), agriculture for better yield (N=4), pharmaceutical and chemical (N=4), industry and manufacturing (N=3), commerce and business (N=1), and services (N=1)

*Researcher: What image or images come to your mind when you think of engineering?*

*Carol: Probably more the civil type like buildings, bridges, and infra structures of cities those things that need to be created. I know engineering not just the (fused) building, but the internal strength and everything engineering. I also have... you know the engineering part of... with the chemical engineering of food products and different items it can be eaten and different that also come to in mind.*

Table 2. Teachers' views of engineering

Purpose	Improve productivity/ efficiency / things (N=8)	Making life better and easier (N=4)	Solving arising practical problems (N=4)	Meeting a need (N=3)
	Keeping things safer (N=3)	Figuring out how things work (N=1)	Helping civilizations progress (N=1)	
Process	Problem solving (n=8)	Designing (N=8)	Mathematics (N=6)	Experiment, testing (N=5)
	Team work, co-operation or collaboration (N=3)	Building, construction (N=2)	Trial and error (N=2)	Trouble shooting (N=1)
	Observation (N=1)	Reading others' work (N=1)	Brainstorming (N=1)	
Scope	Products (N=9)	(Infra) Structures (N=7)	Agriculture (N=4)	Pharmaceutical or chemicals (N=4)
	Industry (N=3)	Commerce and business (N=1)	Services (N=1)	
Impact	Advancement in technology (N=10)	A better enriched world (N=6)	Weapons (N=3)	Economy (N=2)
	Social and Cultural effects (consumption society) (N=2)	Globalization (N=2)	Making life complicated (N=1)	Dependence on machines and medicine (N=1)
	Pollution (N=1)	Global warming (N=1)	Political conflict (N=1)	
Influenced	What consumer/client wants, needs and their opinions (N=6)	Available resources - materials and/or technology (N=6)	Characteristics and skills of engineers (N=5)	Safety concerns (N=2)
	Political climate (N=2)	Cost (N=2)	Money: Profit/income (N=1)	Post effects (society and the world) (N=1)
	Natural constraints (N=1)	Scientific knowledge (N=1)		



### *Impact of engineering*

Another category that emerged from analysis of the interview data is the impact of engineering on the world. As can be seen in Table 2, eleven different sub-categories of the impact of engineering were cited by teachers. All teachers agreed that engineering promotes advancing in technology. More than half of the teachers also indicated that advancements in technology help our world and helps us live our lives in a better way. A few teachers, however, indicated that engineering is also responsible for weapons of mass destruction, pollution, global warming, and political conflicts (because of globalization). Amy, for example, indicated that even though she believed engineering offers a better future, it also makes us depended on machines and medicines in order to survive. Debra, similarly, pointed out how engineering helps advance technology and make our lives better. But, she also mentioned this has negative side effects on our social life and culture.

*Researcher: OK. So, how do you think engineering affect the world?*

*Debra: Umm... the new technology, the infrastructure of the country; building roads and building you need engineers so the economy is then of course affected by all that. The efficiency of farming for instance or manufacturing... good engineer helps out their problems so I think it is important.*

*Researcher: Your examples are very good. So, when you think about generally effect as global effects what do you think..?*

*Debra: Growth with different areas. I don't think it is always positive. I think that some of the things that we haven't, technology have not created necessarily a more humanlike person. I think it is taken away some of the humanity of... umm looking off the window kids have to play their video game in the car of enjoying nature. I mean technology to some kids is everything and what they don't have is reading, literature, talking about, I mean history, caring about it because it is so math and science oriented and those what make good engineer I think are math and science. So, I mean that is important and it is valuable, but I think we can get it's too wrapped up and that is the only thing.*

*Researcher: Good observations. Do you think any other effects?*

*Debra: No, I am just... I guess I just thinking in the terms of... our culture like we need to buy things all the time. We need to buy the newest technology and we have these huge lines overnight for the newest technology. But, you know do we spend that kind of money another things that maybe are important too. I just don't know, I just think you know it is wonderful that we have new things, but then it also creates problems that I don't know the people really think about how people are changing.*

### *Factors influencing engineering*

The last category that emerged from the data involved factors that affect the engineering work in general. As illustrated in Table 2, consumers'/clients' needs, wants, and/or their opinions were perceived the main influence engineering design. The teachers believed that marketing

success would be an indicator if the artifact was designed based on the customer's or buyer's needs and wants.

*Kim: Like if you buy a car certain cars easier to get into and certain cars you really have to like kind of fall into you know. Like, I drive a Pontiac 5 and I like it, cause you just kind of sit right into it and you don't fall into it and you don't have to step in to it. You know you just kind of sit and there it is. And it is a great car for like elderly people because of that. So that is good design and they're looking at a median and which that cars people use that car. Umm... Like a bad design would be something that people don't think about how someone would sit into something or I know they have people who study like "how to reach for the rear mirror, or how to like how comfortable it is to get the radio or changing your flipper shooter I call it, u-turn signal so things like that. Those are all design and how are you going to turn your turn signal? "Are you gunna pull it up? Are you gunna to pull it towards you? Or are you gunna just twist it? What is the best and why?" So things like that.*

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*Researcher: OK. The last question is how do you think good engineering work can be differentiated or distinguished from bad engineering work?*

*Rick: I think... the number one is the end result; does it meet the need you're looking for? If it doesn't that is bad engineering.*

### **Science versus engineering**

Another aspect we investigated involved teachers' views of the relationship between science and engineering. We found that many teachers could not recognize differences between science and engineering. Many teachers believed that engineering is another branch of science akin to chemistry or physics. A few teachers also indicated that they have never thought about this until we asked them:

*Researcher: OK. So, is science and engineering the same thing or different?*

*Jamie: I would say engineering is probably the manipulation of science isn't it? Never really thought about it (laughs). I know that is exactly what you always think about, but never really thought about that.*

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*Researcher: So, what do you think if there is any difference or similarities between engineering and science?*

*Debra: Ohh... I suppose that I thought of engineering is a subset of science and so. Science is more than engineering, but engineering is a part of science.*

*Researcher: Would you more elaborate that?*

*Debra: OK. I guess when I think of the science is as you know life sciences umm... earth sciences... umm... physical sciences things like that and I think of engineering as part of I guess the physical sciences and so umm... engineering... though I suppose you could have engineering that would be in the life sciences if you are talking about biomedical engineering.*

## **Conclusions**

Elementary teachers' views of engineering were collected under five main categories; purpose, process, scope, impacts, and factors that affect engineering work. Teachers' attitudes towards engineering were generally positive and most of the teachers believed that engineering improve productivity and efficiency as well as the life quality. In other words, many teachers associated engineering with progress. However, they could not perceive the deep impact of engineering on civilization and culture.

We also found that the teachers generally talk about positive effects of engineering to the world unless we ask directly any "bad" or "side" effects of engineering. A few mentioned humanitarian side effects of engineering (e.g. weapons and atomic bomb), one mentioned ecological side effects (e.g. global warming), and another teacher pointed out increasing dependence on machines and medicines would be a bad effect of engineering.

Many teachers perceived engineering as a problem-solving activity or involved problem solving along with the process of inventing and creating things. To solve these practical problems, the majority of the teachers believed that creative thinking and a high intellectual ability are essential. On the other hand, a few teachers indicated that engineers design buildings, bridges, road, etc. before we asked them directly the meaning of design in engineering. However, as opposed to similar studies in the literature, only a couple teachers stated that construction work is part of engineers' job. Rather majority of the teachers anticipated engineering as a "behind the scene or back stage" occupation that requires mental tasks. However, teachers did not mention brain storming and team work as often as problem solving or part of problem solving mechanism. This indicates that the process of engineering might be the least understood aspect of engineering because of its "behind the scene" nature.

The teachers, on the other hand, cannot easily differentiate engineering from science. Even a few teachers thought that engineering is part of science akin to chemistry or physics. The teachers' knowledge about engineering and science was not justified, but rather tacit and out of their everyday life.

As might be expected, a qualitative comparison between teachers who have a family member who is an engineer showed that these individuals had lot more to say about engineering and provided more insightful views of engineering than the ones who did not have engineers in their family. Teachers who had family members or close friends who were engineers also tended to respond the questions by giving examples from what their engineer relatives and/or friends do in their jobs.

Based on the findings of this study we recommended that any professional development programs or teacher education curriculums that intent to enhance teachers' scientific and technological literacy should take into account followings:

- Teachers' knowledge about engineering is tacit, although they don't usually think or talk about it. Thus, a professional development program or teacher preparation program should be designed to allow teachers to reflect on their views of engineering to be aware of their knowledge of and about engineering. Having practicing engineers talk to teachers in a small group environment might lead teachers to have a better understanding of engineering as a field.
- All of the teachers in this study pointed out one or more positive effects of engineering to our world and everyday life. However, a few indicated potentially negative side effects of the engineering and technology. Teachers would benefit from being exposed to opportunities to think about the nature of engineering; that should include that it is impossible to predict all aspects of how a technology would affect the society and the world no matter how holistically engineers work. It is also necessary to explain to teachers that engineering has the responsibility to overcome some of the side effects of the previous technologies.
- Similarities, differences, and close relationship between science and engineering should be part of any professional development and teacher preparation programs in order for teachers to really understand nature of science and nature of engineering.

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## **Appendix:** Interview protocol

1. In your view, what is engineering and what is its purpose?
2. What image or images come to mind when you think of engineering?
  - a. Would you more elaborate how this image related to engineering/aspects of engineering?
3. How do you think engineering affects the world?
  - a. Do you think engineering is important? Why or why not?
4. What do you think about the characteristics that are needed to be a good engineer?
  - a. Explain why each?
5. Are there any similarities between engineering and science?
  - a. If yes, what are the similarities between science and engineering?
  - b. What are the differences between science and engineering?
  - c. What do you think is the difference between an (environmental-own example) engineer and an environmental scientist does?
6. Could you give me an example of something that engineers do? What do you think engineers do during the process of designing/making (use their example)?
7. What does design mean in the context of engineering?
8. What factors affect engineering design?
9. How do you think good engineering work can be differentiated from bad engineering work?