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Assessing High School Science Teachers' Nature of Engineering (NOE) Perceptions with an Open-ended NOE Instrument (Fundamental)

Dr. Erica J. Marti, University of Nevada, Las Vegas

Dr. Erica Marti is an Assistant Professor in Civil & Environmental Engineering at the University of Nevada, Las Vegas (UNLV). She holds a PhD and Master of Science in Engineering and Master of Education from UNLV and a Bachelor of Science in chemistry from the University of Illinois at Urbana-Champaign. Prior to graduate studies, Erica joined Teach for America and taught high school chemistry in Las Vegas. While her primary research involves water and wastewater, she has strong interests in engineering education research, teacher professional development, and secondary STEM education.

Mr. Erdogan Kaya, University of Nevada, Las Vegas

Kaya is a PhD student in science education at University of Nevada, Las Vegas. He is working as a research assistant and teaching science methods courses. Prior to beginning the PhD program, he received his MS degree in computer science and engineering and holds a BS degree in chemical engineering. He taught K-12 STEM+CS for seven years. Additionally, he coached robotics teams and was awarded several grants that promote Science, Technology, Engineering, and Mathematics (STEM) and Computer Science(CS) education. He is also interested in improving STEM+CS education for minorities. He has been volunteering in many education outreach programs including Science Fair and Robotics programs such as First Robotics competitions. Areas of research interest include engineering education, STEM+CS, and robotics in K-12 education. Kaya advocates his view that research, teaching and learning are best practiced as a unified enterprise that benefits students and society. He has received numerous teaching awards as well as grants for his research from several foundations. Kaya is an active member of AERA, ASEE, ASTE, NARST, and NSTA, has presented at over 15 conferences, published in ranked journals (e.g. Journal of College Science Teaching), reviewed conference proposals (e.g ASEE).

Dr. Hasan Deniz, University of Nevada, Las Vegas

Hasan Deniz is an Associate Professor of Science Education at University of Nevada Las Vegas. He teaches undergraduate, masters, and doctoral level courses in science education program at University of Nevada Las Vegas. His research agenda includes epistemological beliefs in science and evolution education. He is recently engaged in professional development activities supported by several grants targeting to increase elementary teachers' knowledge and skills to integrate science, language arts, and engineering education within the context of Next Generation Science Standards.

Miss Ezgi Yesilyurt, University of Nevada, Las Vegas

Ezgi Yesilyurt is a PhD student in curriculum and instruction/science education at University of Nevada, Las Vegas. She is working as a graduate assistant and teaching science methods courses. She received her MS degree and BS degree in elementary science education. She participated European Union Projects in which she conducted series of professional development programs for in-service science teachers. Areas of research interest are engineering education, inquiry learning and evolution education.

Johana Iglesias, University of Nevada, Las Vegas

Johana Iglesias is a third-year undergraduate student at the University of Nevada, Las Vegas. She helped to develop and manage NSF EPSCoR STEM high school outreach programs, including: a STEM career program (SISTEM) and the Summer Research Experience (REX) program for novice researchers.

Assessing Secondary Science Teachers' Nature of Engineering (NOE) perceptions with an open-ended NOE instrument

The recent adoption of the Next Generation Science Standards (NGSS) by some states provides an opportunity to integrate engineering education in the K-12 science curricula. While engineering education research in K-12 is emerging, there is an expanding literature that focuses on the epistemology, philosophy and history of engineering education, specifically the Nature of Engineering (NOE). Although NOE aspects are not explicitly stated in NGSS, they are implicitly woven into the standards, and can be extracted through analysis of the document. NOE aspects, although reported in less than a dozen papers, show consistency among researchers, and a few examples include engineering as a distinct body of knowledge, the use of creativity in engineering, and social- and cultural-embeddedness. Teachers and students have a naive understanding of NOE, which can be enhanced through exposure to engineering instruction and the engineering design process. We believe that an introduction to NOE will improve K-12 engineering education. Specifically, understanding NOE allows learners to make sense of engineering and technology in daily life, helps learners to make informed decisions, causes learners to appreciate the contribution of engineering in our culture, assists learners in recognizing the ethical and moral values that engineers need to demonstrate, and aids in the teaching and learning of engineering instruction. However, NOE teaching is not an easy task, and a lack of NOE understanding also raises many issues and obstacles for science teachers to incorporate NOE in science instruction. Science teachers need training to fulfill the requirements described in the NGSS and to inform teachers about NOE aspects. To meet this goal, we provided a professional development that focuses on NOE and the engineering design process during summer 2017 in a southwestern research institute. Using the cognitive apprenticeship model, secondary science teachers were exposed to an engineering design challenge, either by building solar thermal water heaters or water treatment systems. The teachers used the NGSS engineering design process and NOE aspects were explicitly taught at the beginning of the professional development. Four secondary science teachers' NOE understanding was assessed by using an open-ended NOE questionnaire coupled with semi-structured interviews before and after the engineering design intervention. The following research question guided our case study research: To what extent did secondary science teachers NOE views change after exposure to an engineering design challenge? Our results show that at the end of the professional development teachers either kept well-articulated understanding of NOE aspects or improved them.

***Keywords**: NOE, engineering design process, nature of engineering, secondary science teachers, NGSS, engineering design challenge, professional development, cognitive apprenticeship*

Introduction

To meet the demand of an increasing science and engineering workforce, teachers must be prepared to integrate engineering in their instruction. There are some attempts at policies and educational reforms aimed at changing science and engineering education to improve students' understanding of engineering and to influence more students to study those degrees [1], [2]. Teacher training programs in the US do not adequately prepare secondary science teachers to integrate engineering in their curriculum and, in turn, to increase the awareness and interest of secondary school students in careers in engineering fields [2], [3]. Exposure to engineering is important because when students learn about the field and experience engineering activities they will become more interested in engineering careers [4]. Wagner et al. [5] emphasized that teachers need to create relevant content to improve students' learning and, at the same time, inspire them in engineering careers. Cohoon, Cohoon and Soffa [6] also underlined the importance of teacher professional development to encourage students in engineering courses. Therefore, teacher training for the successful integration of engineering in K-12 education is crucial, as we have documented in our past research [7], [8], [9], [10].

Nature of engineering (NOE) is an analog to nature of science (NOS), and consists of aspects that describe the work of engineers, as well as their behaviors and mindset. While some past studies have focused on solely on describing the role of engineers and the products they create [11], we agree with other studies that NOE is broader and comprises several aspects [7], [8]. Examples of aspects include an empirical nature, tentativeness, and creativity. Unlike NOS, where K-12 educators and agencies have agreed upon which aspects students should learn [12], [13], NOE is not yet well-defined. Due to the push to increase engineering literacy, researchers are attempting to reach a consensus about which NOE aspects should be included in K-12 engineering education.

The body of knowledge for K-12 engineering education is growing, but there is little research on secondary science teachers' NOE views. In addition, it is reasonable to assume that secondary science teachers are under prepared to teach the engineering design process because there are very few professional developments available [3]. Training is critical; therefore, we designed a professional development for secondary science teachers to improve their knowledge of engineering design and to enhance their understanding of NOE.

The goal of our research is to examine the perceptions of in-service secondary science teachers' NOE views as they learned engineering design. The cognitive apprenticeship model is often used in higher education engineering courses or the engineering workplace to train students or novice engineers [14]; however, it is not commonly used for teacher professional development in K-12 engineering education. We designed our professional development using the cognitive apprenticeship model and engaged teachers in an engineering design challenge (i.e., the intervention). With this approach, we were able to assess the change in their NOE views before and after the engineering design intervention.

Literature Review

Research on students' and teachers' views about engineering

Researchers have put effort into understanding students' views of engineering [9], [11], [15]. Studies illustrate that students hold misconceptions about engineering and the work of engineers.

Newley et al. [9], for instance, studied fifth grade students to investigate their understanding of engineering. The students' drawings of engineers informed researchers that the students have a limited view of NOE. In particular, most students did not know how engineering is different from science, and students did not view the engineering design process as dynamic but rather a step-by-step method. In addition, students did not have adequate understanding of the influence of engineering on society. However, students' NOE views improved after explicit-reflective engineering instruction. Similarly, Knight and Cunningham [15] investigated 135 high school students with a draw-an-engineer test, and they found that some students relate engineering to fixing. Understanding students' misconceptions about engineering is an important first step in improving K-12 engineering education.

The above mentioned studies address students' misconceptions about engineering; however, teachers also have low engineering literacy, which influences their engineering instruction. Research has indicated that K-12 science teachers do not have sufficient understanding of engineering or NOE [10], [16], and, in turn, do not adequately integrate engineering into their instruction [17]. For instance, Robinson et al. [17] attempted to examine how high school science and mathematics teachers cover engineering in their instruction. Results revealed that most teachers did not even know what engineers do. It is not surprising, therefore, that they did not integrate engineering in their science and math lessons. In another study, Deniz et al. [8] found that elementary teachers did not differentiate between science and engineering properly. They described engineers as laborers who mostly construct buildings. Nearly half of the elementary teachers did not include problem solving, human imagination and creativity, teamwork, and science and math integration as aspects of engineering. However, at the end of the professional development, teachers held informed views of NOE. In a related vein, Nathan et al. [18] examined how teachers' beliefs and expectations about engineering influence their instruction. Results showed that teachers generally hold the view that high academic performance is a prerequisite for entry into pre-engineering courses. However, teachers who participated in the summer engineering training program were less likely to have this view. Therefore, professional development may influence engineering teaching culture, which in turn affects the inclusion of a diverse group of students in engineering.

Research on Engineering Professional Development

Previous studies underscored the importance of teacher guidance for students in improving students' views of engineering and choosing STEM fields for their future career path [6], [19]. Bearing in mind that teachers lack knowledge about engineering and how to integrate it into their lessons, several researchers have attempted to develop professional development (PD) programs to improve teachers' knowledge. For example, Cunningham et al. [20] prepared a two-week Pre-College Engineering for Teachers PD in which they emphasized engineering concepts and activities for secondary school levels. They evaluated the effect of the program on science, mathematics, and technology teachers' views about the integration of engineering. They found that their confidence about teaching engineering increased after the two-week program. Also, results demonstrated that teachers' skills in engineering instruction were positively affected through understanding the engineering design process and learning how to modify a lesson to integrate engineering. In a similar manner, Singer, Ross and Jackson-Lee [21] examined the impact of a PD program on secondary school STEM teachers' pedagogical knowledge about engineering and application of their pedagogical knowledge. In the scope of this program, teachers implemented STEM activities with students by using curriculum materials from the PD program, and they were asked to provide reflective critiques on their pedagogical practices. Analysis was based on video-recorded lessons, and teachers' reflective critiques indicated that teachers' pedagogical content knowledge and practices improved; however, they mostly adhered to the curriculum without modifying it for their classroom. This result suggests that the teachers were able to apply what they had learned in the PD, but were unable to synthesize new curriculum.

Teacher PDs where authentic engineering design challenges have been shown to have positive effects on teachers' understanding of engineering. Deniz et al. [10] conducted a weeklong summer professional development where participants were exposed to real world engineering design challenges. In the workshop, participants were involved in design challenges in the role of engineers. They collaborated with professional engineers and engineering faculty, STEM education professors, and graduate students. At the end of the PD, their self-efficacy in teaching engineering increased and their NOE perceptions improved. Rynearson, Douglas and Diefes-Dux [22] conducted a qualitative study with 27 elementary teachers who attended summer professional development programs and learned how to teach the Engineering is Elementary curriculum. Teachers were interviewed to reveal what students learned after the engineering lessons. According to teachers' responses, it was found that students learned collaboration, teamwork, critical thinking, and revision of their solutions after mistakes. Carr and Diefes-Dux [23] also organized a PD for teachers during summer of 2009. They analyzed the effectiveness of the workshop through students' draw-an-engineer test results before and after teachers participated in the PD. They showed that their teacher PD was successful in helping teachers to change students' perceptions about engineering and misconceptions about engineering, as well as to improve teachers' engineering understanding.

It is not surprising that science teachers have not obtained the education or support to teach engineering. Most of the teachers are not familiar with engineering principles that they are expected to teach [24]. Even though there is national encouragement towards engineering curriculum development, training is not available to all teachers [24]. To summarize, secondary science teachers are not supported enough to teach engineering efficiently. Although there is a momentum towards K-12 engineering education, there is much more to do to support secondary school science teachers in improving their understanding of engineering.

Cognitive Apprenticeship Model

The cognitive apprenticeship model emphasizes that learning can be practiced with scaffolding and participation in authentic experiences, and this results in the gradual enculturation and information transfer by the experts in the field [25], [26]. As a result, apprentices improve their skills and become experts. In the cognitive apprenticeship model, the experience is a social endeavor and it improves with exposure to that community's culture.

Most professional developments lack the component "learning by doing in situated learning" and follow a traditional approach where ideas are presented without direct experience. This type of professional developments has its own problems by transferring limited understanding to accomplish the task [26]. However, if learners participate in trainings that are designed around an apprenticeship model, they receive a first-hand learning experience from experts, including beneficial components of cognitive apprenticeship (e.g., coaching and modelling) that will transfer their knowledge from lower levels to higher competencies.

The cognitive apprenticeship model is beneficial in teaching engineering to in-service science teachers. Firstly, teachers are accepted as novices in the context of teaching engineering, and they need scaffolding and support to teach in that new discipline. For instance, a science teacher who studied physics may feel confident and be considered an expert physics teacher, but he/she may not feel proficient enough to teach engineering due to lack of training. When faced with an obstacle in the course of apprenticeship training, they can get necessary scaffolding and coaching from the experts and move forward. Secondly, the cognitive apprenticeship model allows teachers to learn by exposure to the authentic engineering design challenges in collaboration [26]. This exposure results in enculturation of teachers into the engineering design process through teamwork. Lastly, the cognitive apprenticeship model increases science teachers' self-efficacy in engineering teaching. For example, it gives teachers the opportunity to see how experts and their peers approach the engineering design process. It provides teachers with an environment to brainstorm and discuss about the methods to solve complex problems, which simulates the way engineers actually work. Thus, it may help teachers to increase their engineering self-efficacy beliefs [8].

We designed our engineering professional development based on the cognitive apprenticeship model. Novices, in our case, were secondary science teachers who observed, worked together, interacted with, and learned from experts while taking part in a cognitive process. The professional development was embedded with situated learning where teachers learned via an authentic engineering design challenge. Teachers worked under the guidance of engineering faculty and expert K-12 engineering educators, in addition to support from undergraduate engineering students.

Research Question

The main purpose of our article is to describe the intervention (i.e., engineering design challenge) and compare participants' NOE understanding before and after the intervention. The following research question guided our research: To what extent did secondary science teachers NOE views change after exposure to an engineering design challenge?

Methods

We used a comparative case study for our research. Participants were four secondary science teachers who teach in the southwestern US. They participated in a forty-hour professional development in 2017 as part of a National Science Foundation grant. We collected nature of engineering data through an open-ended NOE questionnaire (pre- and post-test; Appendix C) and semi-structured interviews. Examples of teacher responses are shown in Appendix D. The pre-test questionnaire also included demographics and prior engineering design experience (Table 1).

The professional development was designed for in-service secondary science teachers who want to integrate engineering design into their science courses. The goal was to provide teachers with the necessary tools and first-hand experience in using the engineering design process so that they can incorporate engineering practices in their classroom. We aimed to introduce secondary teachers to the engineering design practices within NGSS, familiarize secondary teachers with the three main components of the engineering design process suggested by NGSS, and build confidence in performing engineering design and prototype construction.

The format of the course was mainly discussion-based and project-based learning. While the first sessions had lengthy explicit instruction, most sessions involved brief directions, one-on-one discussions with the instructor to determine the next steps, and unstructured time for their design challenge. Explicit NOE instruction occurred once at the beginning of the professional development.

Intervention

The five-hour schedule for the eight days of professional development was flexible but consisted of several key components. On the first day, teachers completed the questionnaire and some teachers were selected for interviews. Then all participants received explicit instruction on NOE (Appendix B) and the three phases of the NGSS engineering design process (i.e., Define the Problem, Develop Solutions, Optimize). Participants learned about problem definition, criteria and constraints, and then practiced their understanding through a simple exercise about designing an office chair. Next, participants learned about developing alternative solutions and they practiced their understanding with the same office chair example. After this, optimization was discussed but not practiced. Finally, participants were shown an example of a solar thermal water heater and an example of a water treatment device. Their task was to select one option (solar heater or water treatment) and design a system for their own classroom. They had time to collaboratively start on phase one of their design challenge by defining the problem and identifying criteria and constraints. On the second day, teachers received explicit instruction on the later stages of phase one: creating design goals and generating an evaluation matrix. During the remaining time, teachers continued to work on phase one of their design challenge. Over the course of the next couple of days, participants finished phase one and began developing alternative solutions for phase two. After evaluating their solutions with the matrix they created in phase one, participants then started optimization or phase three. Participants searched for appropriate materials to build their system and revised their winning design based on a maximum budget and availability of materials. Other revisions occurred during the construction process. Undergraduate engineering students assisted participants as they learned specialized techniques (e.g., soldering and power tools) since many teachers had no prior experience with these tools. By the end of the eighth day, participants had completed the construction of their solar heater or water treatment system. They developed lesson plans, prepared pre- and post-assessments for student learning, wrote a report on the process they used to design their system and how the system works, and reflected on their own engineering design learning experience. Throughout the professional development, participants worked either collaboratively, independently, or a mix of both as they completed the design challenge. While participants received the same explicit instruction and had the same requirements (i.e., consistent activities and assignments), their experience differed in the amount of interaction they had with other teachers and the undergraduate student assistants.

Table 1. Teacher's Profile

Pseudonym	**Rachel**	**Tony**	**Natasha**	**Kayla**
Category	Senior Teacher	Senior Teacher	Senior Teacher	Senior Teacher
Gender	Female	Male	Female	Female
Experience	25 years	17 years	15 years	34 years
College courses	25	30	15	0
Grades	High School	High School	High School	High School
Incorporate engineering (pre-test)	More than once a month	Never	More than once a month	More than once a month
Prior EDP experience	Some engineering design experience	No engineering design experience	Some engineering design experience	Some engineering design experience
Disciplines	Physics / Chemistry	Chemistry Teacher	General Science / Chemistry / Physics / Earth Science / Life Science	Life Science
Desire (pre-test)	Definitely yes	Probably yes	Definitely yes	Definitely no
Preference	More engineering challenge-based	More engineering challenge-based	More engineering challenge-based	More engineering challenge-based
Efficacy	Above average	Above average	Above average	Above average

Questions
Experience - How many years of teaching experience do you have?
College Courses - How many college science or engineering courses have you taken?
Grades - What grade levels do you teach?
Incorporate engineering - How often do you incorporate engineering activities in your science classroom? (never, once a year, twice a year, once a month, more than once a month)
Disciplines - What science disciplines do you teach?
Desire - If you had a choice, would you choose to teach engineering to your middle or high school students? (definitely no, probably no, not sure, probably yes, definitely yes)
Preference - The major portion of my time in engineering instruction should be spent in: (textbook-based presentation only, more textbook-based presentation than anything else, an equal amount of textbook-based instruction and engineering challenge-based instruction, more engineering challenge-based instruction than textbook-based presentation, engineering challenge-based instruction only)
Efficacy - Please rate how you view your own efficacy as a science teacher (superior-one of the most outstanding teachers of science/engineering in the building or a master teacher; above average; average-a typical teacher of secondary school science; below average; low-one of the least effective teachers of secondary school science, in need of professional development in this area)

Data Analysis Methodology

Survey responses and interview transcripts comprise the data sources. In our study, secondary in-service science teachers were asked to complete the open-ended, written Views of Nature of Engineering (VNOE) survey [7] at the beginning and at the end of the course. Additionally, we conducted semi-structured interviews to probe and elaborate on teachers' NOE understanding beyond their written responses. Another purpose of conducting the interviews was to avoid misinterpretations of the written responses and explicate teachers' views. We interviewed two of the secondary science teachers at the beginning and one of the teachers at the end of the professional development. Interview sessions lasted 30 minutes on average.

We adopted the open-ended VNOE questionnaire (Appendix C) and analyzed the collected data on the NOE aspects (Appendix B). Deniz et al. (7) defined the NOE aspects based on the extensive review of the NOS research and related science policy documents (K-12 Science Framework, NGSS, SFAA, and Benchmarks for Scientific Literacy). Additionally, the same researchers created the open-ended VNOE questionnaire based on the defined NOE aspects and VNOS instrument. Finally, the instrument and the NOE aspects were validated by an expert panel consisting of engineering professors and science education faculty. The instrument was used in prior research studies such as Newley et al. [9], and Deniz, Kaya and Yesilyurt [10].

Data were analyzed by following a specific procedure, which matches previous studies using the VNOE questionnaire. We analyzed the written responses and interview transcripts separately. We used a 4-point scale to score teachers NOE responses (Table 2) by comparing teachers' responses to the NOE descriptions in the scoring rubric (Appendix A). Authors scored the responses individually and then discussed the scores until consensus was reached.

Analysis of the teachers' responses was not one-to-one between the instrument and the NOE aspects, as recommended on the analysis method of VNOS instrument [27]. We explicated teachers' perceptions of NOE aspects not only from the targeted aspect questions but from the responses to the different items on the instrument. This holistic approach brought several advantages to the data analysis. First, it allowed us to understand the teachers' views in a wide context instead of a narrow view. Second, it allowed us to check for consistency of each NOE view across the questionnaire [27].

Table 2: *Teachers Pre and Post NOE Scores*

Teacher Names	**Rachel**			**Tony**			**Natasha**			**Kayla**		
NOE Aspects	Pre	Post	Δ	Pre	Post	Δ	Pre	Post	Δ	Pre	Post	Δ
Demarcation	2	4	↑	2	4	↑	1	4	↑	2	4	↑
EDP	2	3	↑	2	4	↑	2	4	↑	3	4	↑
Tentativeness	3	3	-	4	4	-	2	4	↑	4	4	-
Creativity	3	4	↑	3	4	↑	2	2	-	4	3	↓
Subjectivity	4	4	-	4	4	-	2	4	↑	4	4	-
Social and Cultural Embeddedness	2	3	↑	2	4	↑	1	4	↑	2	4	↑

Results and Discussion

In our 4-person case study, we examined secondary science teachers' nature of engineering views before and after an intervention involving an engineering design challenge. Findings from the study are presented in this paper.

Results of NOE Pre-Assessment

The NOE aspect of demarcation refers to what engineering is and how it differs from other disciplines. All four teachers gave responses that showed only partial alignment to the description or showed a misconception. Rachel, Tony, and Natasha all mentioned that engineering involves problem solving and solutions; however, none described engineering as systematic. Natasha stated that "engineering is a science," which goes against the view that engineering is different from other disciplines such as science.

In alignment with NGSS, the engineering design process is considered to have three main components: define, develop solutions, and optimize. Two teachers correctly identified two stages (i.e., defining the problem and coming up with solutions), but they did not include optimization or redesign. A third teacher identified developing solutions and optimizing the design as part of the process; however, the teacher stated that the first step is "find out what exactly the product is," which is a narrow view of the way that engineering design is used. Kayla was the only teacher whose response was fully aligned with the description of engineering design process.

Tentativeness is the NOE aspect that deals with the changing nature of engineering design. For example, the steps of the engineering design process are not linear, and engineers frequently make changes to the problem definition or propose new solutions even after they have moved ahead in the design process. Rachel and Tony provided fully aligned responses that designs change over time. Rachel did not give an example to clarify her response, while Tony's interview included a relevant example. Kayla also gave a fully aligned response with specific examples for cell phones, surgical techniques, and transportation methods. On the other hand, Natasha's response was partially aligned to the description for tentativeness. She mentioned that tests should be performed with several trials, but she did not indicate that designs or solutions change.

Engineers use creativity in all stages of the engineering design process. Prior to the intervention, three of the four teachers indicated they believed that creativity is present in all phases of engineering design. Only Natasha held a partially aligned view that creativity plays a role in developing solutions and creating prototypes, but it is not part of the initial problem definition stage.

Another NOE aspect is subjectivity or the idea that many solutions exist for engineering design problems. There is no unique, single solution. From the pre-intervention survey responses, two teachers, Rachel and Natasha, indicated that more than one solution was possible, but no explanation was given as to why multiple solutions were valid; thus, they were rated as having partially aligned views. Tony stated multiple solutions are possible based on meeting budget or cultural constraints; however, he did not clarify his view with an example. Kayla was the only teacher who clearly justified her view that multiple solutions are possible. She gave an example of how various transportation systems exist in different countries and each system works well for that particular location. After analyzing interview responses, Tony and Rachel were rated as having fully aligned views because they gave specific examples of how multiple solutions can work. Overall three of the teachers had fully informed views on subjectivity and provided concrete examples; however, it was necessary to analyze interview transcripts for two of the teachers. One teacher held a partially informed view on subjectivity and an interview response could have helped to dig deeper into her understanding.

Social and cultural values influence engineering design because engineering is a human activity. Teachers were asked if they believed that engineering is universal or if it includes social and cultural values. Overall, three teachers had mixed views that the engineering design process is both universal and sociocultural. They seemed unwilling to select one or the other. The fourth teacher, Natasha, selected universal, and she appeared to regard “universal” as a greater goal to achieve than conforming to sociocultural values.

The final NOE aspect studied is that engineering design is a social process rather than a solitary process. This social dimension enhances the quality of engineering design solutions. The social nature of engineering design was not a specific question on the pre-test. Instead, all surveys and interview responses were analyzed. Natasha and Rachel mentioned collaboration and working in teams, whereas Kayla and Tony did not mention collaboration or working in a group in their survey responses. However, when Tony was directly asked in the interview about engineers working alone or in groups, he stated that “engineering in itself has to be a communal project.” Rachel reiterated in her interview that engineers collaborate because people have different strengths and weaknesses, and those who work alone miss the opportunity to build on individual's strengths. Overall not all teachers expressed that engineering design is a group process; however, they were not asked directly about this NOE aspect in the survey.

Results of NOE Post Assessment

After the intervention, all four teachers received the maximum score on demarcation. They indicated that engineering uses a systematic process to solve problems. For example, Tony stated that, "Engineering is the solving of problems through systematic approach using the engineering design process. With engineering, problems are solved then refined and optimized." Responses also mentioned the use of science and math within engineering to solve human problems and create new technologies.

In explaining the engineering design process, three teachers gave responses that were fully aligned with the NGSS engineering design process. Only one teacher, Rachel, was rated as having a partially aligned view because she mentioned aspects of problem definition (i.e., criteria and constraints) and developing solutions, but she did not describe optimization or redesign.

For tentativeness, all teachers gave responses that were fully aligned with this NOE aspect. They all mentioned that designs change after initial development. This may occur during the optimization stage or it could be the result of society's needs changing, which is reflected in the criteria and constraints of the problem. Three teachers gave specific examples on how the design may change. Rachel did not provide a clear example; therefore, her response was rated as three instead of four.

Most teachers indicated that creativity is present in all stages of the engineering design process. Rachel and Tony provided specific examples while Kayla did not. Natasha stated, “I believe that engineers use their creativity and imagination in every step after identifying the problem.” Thus, her response was rated as partially aligned to the description of creativity.

Teachers’ responses about the NOE aspect of subjectivity were consistent. All teachers indicated that engineering design does not result in a single best solution. The reasons provided by Rachel were that, “that criteria and constraints may be different for different projects. Another reason is engineers are creative people looking at the solution in different way.”

Teachers’ responses about social and cultural values within engineering design were all fully aligned with the rubric. Kayla and Natasha provided specific examples; thus, their responses were rated as four. Rachel and Tony did not include examples in their post-survey responses; however, Tony shared an example about cultural influences on architectural design in his final interview, which resulted in a score of four.

Again, the social component of engineering design was not directly asked in the survey, but most teachers gave implicit or explicit responses that engineers work together. Both Kayla and Tony consistently used the title engineer in plural form, which suggests that engineers work together rather than alone. Rachel and Natasha specifically stated that engineers collaborate. In addition, Tony acknowledged that engineers bring unique ideas and perspectives to a group.

Changes in NOE Understanding

Teachers' increased their understanding of engineering and how it differs from other disciplines. Prior to the intervention, three of the four teachers had some engineering design experience and one teacher had no experience with engineering design (Table 1). Despite having experience with engineering design, all four teachers gave initial responses that showed only partial alignment to the description or showed a misconception. After the intervention, all teachers had the maximum score, and teachers did not indicate that engineering is a form of science. In looking at Kayla's original response, she described engineering as having, "a lot of number analysis involved...in engineering one has to use the mathematical computations to build something." When asked about her choice to teach engineering, she revealed that she had no desire to teach it, which could reflect a disinterest in math. After the intervention, Kayla responded that "engineering involves defining problems and finding solutions to the problems. In engineering, tangible materials or products are constructed in most cases to make life easier and more comfortable to humans." She no longer focused on mathematics as a major theme of engineering; instead, she focused on the design process. Interestingly, her post-survey showed a dramatic change in desire to teach her students engineering; she switched from *definitely no* to *definitely yes* as a response. The intervention clearly altered her view of engineering. The three other teachers maintained the same level of desire (*probably yes* or *definitely yes*) to teach their engineering students.

Teachers increased their knowledge of the NGSS stages of the engineering design process. Prior to the intervention, only one teacher scored three or higher, whereas three teachers scored three or higher after the intervention. Rachel's response did not include the redesign or optimization stage, resulting in a score of two. This could be due to the limited time that teachers had to optimize their design. Some teachers spent longer on the problem definition and developing solution stages, which means they had less time to make changes as they constructed their water treatment system or solar water heater. However, Rachel does show an understanding of the redesign stage as demonstrated in a response for a different survey question, “From developing the design conceptually to refining the design, engineers need to think broadly and consider novel or unorthodox approaches.” When taking this into consideration, all teachers increased their score for this NOE aspect.

Scores for tentativeness did not change much after the intervention. Most teachers scored three or higher on the pre-test survey. Natasha, the only teacher to receive a score of two initially, increased her score to three. Her post-test survey response clearly demonstrated a view that designs do change. For example, she stated that, “...engineering design will change based on whether it is meeting the criteria for success and constraints or limits,” and, “Success comes with optimizing the design solution by systematic testing and refining.” Overall, teachers’ views for this NOE aspect did not change substantially, but this is likely due to high pre-test scores.

Varying changes occurred for teachers’ views on creativity within the engineering design process. Scores for Rachel and Tony increased from three to four by the inclusion of concrete examples, whereas Kayla’s score dropped from four to three since she did not provide a specific example. However, all three teachers started and ended with fully aligned views for this NOE aspect. On the other hand, Natasha’s score remained at two. She maintained her view that creativity is present during the solutions and redesign phases, but it is not part of the process where engineers define the problem. Overall, the intervention had little impact on teachers' views about creativity in engineering design. Beliefs were essentially maintained.

Subjectivity is another NOE aspect where most teachers' views were not altered. Three of the four teachers received a score of four prior to the intervention, and they maintained that score in the post-test survey. Natasha's score increased from two to four. After the intervention, she justified her view that there is no single best design by stating that, "Engineers... come with different levels of creativity and skills." While the intervention appeared to influence Natasha's view on subjectivity within engineering design, an overall impact on this NOE aspect is difficult to assess due to high initial scores.

Across the board, teachers' scores for social and cultural embeddedness increased after the intervention. Initially, many teachers expressed mixed views that engineering design is both universal and socio-cultural. In the post-test survey, all teachers received scores of three or four, and their responses emphasize the importance of social and cultural values in engineering design. Natasha responded that, "Engineering is very much a human activity, meaning that society and engineering have constant interaction." Similarly, Tony commented in his response that, "The individual engineers have developed socially through their cultural environment and this will be reflected in their approach to the engineering design process." In general, the intervention successfully increased teachers' understanding that social and cultural values are embedded in the engineering design process.

Lastly, there was minimal change in teachers' responses about the social component of engineering design. The question did not appear directly in the survey; nonetheless, Rachel and Natasha commented in the pre- and post-test surveys that engineers collaborate and work together. Kayla and Tony did not explicitly describe engineering as a collaborative or social process, except when Tony was directly asked in the interview about engineers working together. On the whole, there was no change in teachers' perceptions about the social aspect of engineering design. In future research, this NOE aspect should be assessed with a straightforward question in the pre- and post-test surveys.

Conclusions and Recommendations

Our results show that at the end of the professional development teachers either kept well-articulated understanding of NOE aspects or improved them. The greatest increases were in demarcation, the stages of the engineering design process, and socio-cultural embeddedness. For tentativeness, creativity, and subjectivity, the initial scores were quite high; thus, minimal improvement was possible.

This study used the cognitive apprenticeship as a model. The intervention, in which teachers designed and built water treatment systems or solar water heaters, was essentially apprenticeship training for the teachers. We think the increased understanding of NOE aspects is due to teachers' exposure to the engineering design process through first-hand experience. These developments and understanding of engineering may have a positive influence on teachers' confidence and interest in incorporating engineering design in their secondary science classrooms either as independent engineering design challenges or through integration of engineering and science to teach scientific content. We believe that other secondary science teachers could benefit from participating in a similar professional development.

As seen with other teacher professional development programs, this training successfully exposed teachers to the engineering design process and resulted in improved NOE understanding Our results are consistent with prior research such as Deniz er al. [8] and Newley et al. [9] where teacher training resulted in fully informed NOE views.

While the open-ended VNOE instrument has been used in the past [7], [8], [9], this is the first instance where it was used in a case study. In Deniz et al. [7], quantitative results derived from the VNOE instrument showed significant improvements in teachers' NOE understanding following the professional development. Here, we use a qualitative approach to look closer at changes in teachers' views for the NOE aspects. The value of this approach is to obtain a more detailed understanding of teachers' NOE views with in-depth analysis of the data.

We recommend some modifications for future research in this area. First, additional questions should be added to the VNOE survey in order to assess the social aspect of engineering and empirical nature of engineering design. Deniz et al. [7] makes the same recommendation for an additional questions. Second, we recommend including novice teachers, such as those with fewer than five years of teaching experience. This cohort may have lower self-efficacy and less exposure to engineering design, which would allow for better assessment of NOE growth. The senior teachers who participated in this study had high initial scores for some NOE aspects, which made it difficult to assess change. Third, we recommend using an explicit-reflective approach for NOE instruction, especially with teachers who have minimal exposure to engineering design. While we observed substantial increases in NOE understanding in this study in which explicit NOE instruction occurred only at the start of the professional development, we feel that frequent reflection will strengthen teachers' NOE understanding.

Limitations

We cannot generalize our findings due to the nature of qualitative research studies, specifically a case study design that is interpreted based on the researchers' background and prior experience [28]. Nevertheless, the purpose of this study is not to generalize findings but to explore the senior in-service science teachers' nature of engineering views in detail prior and at the end of the professional development designed with a cognitive apprenticeship model.

Additionally, participating teachers in this study were experienced science teachers and voluntarily enrolled in the professional development. In general, they were self-motivated and held high self-efficacy in teaching. Having teachers with above average motivation may have caused a deeper learning of engineering design, which resulted in high scores and holding informed NOE views.

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Appendices

Appendix A. NOE Aspects Scoring Rubric

Description	Point
No answer, incomprehensible or irrelevant answer, or an answer could not be categorized	0 points
An answer that is not aligned with the description of NOE aspect	1 point
An answer that is partially aligned with the description of NOE aspect	2 points
An answer that is fully aligned with the description of NOE aspect	3 points
An answer that is fully aligned with the description of NOE aspect. The view is well-articulated and/supported with relevant example(s)	4 points

Appendix B. Descriptions of Nature of Engineering (NOE) Aspects

NOE Aspect	Description
Demarcation criteria (What is engineering? What makes engineering different from other disciplines?)	Engineering is systematically engaging in the practice of design to achieve solutions for specific problems. Engineers apply their understanding of the natural world (scientific knowledge) to design solutions for real world problems. This endeavor results in new technologies. In the K-12 context, "science" is generally taken to mean the traditional natural sciences: physics, chemistry, biology, and (more recently) earth, space, and environmental sciences… We use the term "engineering" in a very broad sense to mean any engagement in a systematic practice of design achieve solutions to particular human problems. Likewise, we broadly use the term "technology to include all types of human-made systems and processes-not in the limited sense often in schools that equates technology with modern

	computational and communications devices. Technologies result when engineers apply their understanding of natural world and of human behavior to design ways to satisfy human needs and wants. (NRC, 2012, pp. 11-12)
Engineering design process	The core idea of engineering design includes three component ideas (NGSS Lead States, 2013): Define, Design, and Optimize A. Define: Defining and delimiting engineering problems involves stating the problem to be solved as clearly as possible in terms of criteria for success and constraints or limits. B. Develop Solutions: Developing solutions to engineering problems begin with generating a number of possible solutions. These potential solutions are then evaluated to assess which ones best meet the criteria and constraints of the problem. C. Optimize: Optimizing the design solution involves a process in which solutions are systematically tested and refined and the final design is improved by trading off less important features for those that are more important.
Empirical basis (Not part of this survey)	Engineers optimize their design solutions and compare alternative solutions based on evidence obtained from test data. They use assumptions to produce simplified models that does not contain the variables that the problem are insensitive to.
Tentativeness	Phases of engineering design process do not always follow in order, any more than do the "steps" of scientific inquiry. At any phase, a problem solver can redefine the problem or generate new solutions to replace an idea that is just not working out.
Creativity	Creativity and imagination of engineers play a major role during the engineering design process. The role of creativity and imagination is not limited to any specific phase of the engineering design process.

Subjectivity	There is no unique solution to an engineering design problem. While there can be many solutions to the same problem, some of these solutions may be more suited to meet the criteria and constraints of the problem.
Social aspects of engineering (Not part of this survey)	Engineering is not a solitary pursuit. Engineering design solutions are constructed through social negotiation. Despite their individual differences, members of an engineering community share common understandings, traditions, and values. This social dimension enhances the quality of engineering design solutions.
Social and cultural embeddedness	Engineering is a human activity. There is a continued interaction between engineering and society. Sociocultural factors influence the engineering design process, and in turn, engineering influences the society. These social and cultural factors include social composition, religion, worldview, political, and economic factors.

Appendix C. VNOE Questionnaire

1. What, in your view, is engineering? What makes engineering different from other disciplines (e.g., science, philosophy, religion)?
2. How do you define the work of an engineer? What do engineers do?
3. What is an engineering design process?
4. After engineers have developed an engineering design does the design ever change?
    •If you believe that engineering designs do not change, explain why. Defend your answer with examples.
    •If you believe that engineering designs do change, explain why.
5.Do engineers use their creativity and imagination during the engineering design process?
    • If yes, then at which stages of the engineering design process do you believe that engineers use their creativity and imagination: identifying the problem; developing the design conceptually; constructing the design, testing the design; refining the design? Please explain why engineers use creativity and imagination. Provide examples if appropriate.
    •If you believe that engineers do not use creativity and imagination, please explain why. Provide examples if appropriate.
6.Some claim that engineering is infused with social and cultural values. That is,

engineering reflects the social and political values, philosophical assumptions, and intellectual norms of the culture in which it is practiced. Others claim that engineering is universal. That is, engineering transcends national and cultural boundaries and is not affected by social, political, and philosophical values, and intellectual norms of the culture in which it is practiced.

•If you believe that engineering reflects social and cultural values, explain why and how. Defend your answer with examples.

•If you believe that engineering is universal, explain why and how. Defend your answer with examples.

7. Can there be a single best design for an engineering solution?

•If you believe that there is a single best design for a solution, please explain why.

•If you believe that there is not a single best design for a solution, please explain why.

Appendix D. Sample Teacher Responses from Pre- and Post-test for Each NOE Aspect

NOE Aspects	1	2	3	4
Demarcation	"Engineering is a science that focuses on solving problems in the real world through an integration of scientific inquiry and mathematics and the use of technology. Engineering is further a subject that focuses on the creation of several viable prototypes, then choosing the best possible solution."	"Engineering is developing a design to solve a problem." "The work of an engineer is to follow the engineering method to solve problems."	N/A	"It is the process of problem solving by creating designs and prototypes that solve human problems.This results in new technologies. Engineering is all encompassing; the creations of engineers are based on the social and cultural needs of society. There is no unique solution to a problem as would be in the case of many disciplines where there are levels of rigidity; in the case of engineering the optimal solution is the one best suited to meet the criteria and constraints of the problem."
Engineering Design Process	N/A	"1) Ask questions	"An engineering design process is a	"The engineering design process starts

		2) Identify issues/ problems 3) Devise a solution to the problem.”	series of steps followed to come up with a solution to the problem. It starts with the definition of the problem, designing the solution to the problem, making a prototype of the product, trying it out if it works, revising the design and finalizing the product for optimum use.”	with stating the problem that must be solved in terms of criteria for success and constraints or limits. The next step involves designing solutions to the engineering problem begin with generating a few possible solutions; and finally, the ones that best meet the criteria and constraints of the problem are selected.”
Tentativeness	N/A	“The design is about trying to get the best possible result ; so there should be several trials before a conclusion is reached.”	“Engineering designs do change after development. Designs change due to technology and needs of society.”	“I believe that in most cases the engineering design will change based on whether it is meeting the criteria for success and constraints or limits. The design and prototype would have to really be phenomenal to be accepted by all involved at the first trial. Success comes with optimizing the design solution by systematic testing and refining. In most cases the final design is improved by trading off less important features for those that are more important; and when there is consensus among team members.”
Creativity	N/A	“Yes. Creativity most likely is needed during the looking for solutions and during the	“Yes, creativity and imagination is important. Walt Disney was great at this!	“Engineers use their creativity and imagination during all of the steps of the engineering design

		designing of the prototypes."	I believe creativity and imagination is used in all the parts. You first need to dream about the idea and then test, design and refine using your creativity and imagination. It is important to surround yourself with others so communication and collaboration take place. Parts you are weak in maybe a strength for someone in your team."	process. When addressing a problem, engineers define the problem by using their prior experience or research. In the development of the design, each engineer will develop solutions based on their ingenuity and creativity bringing a unique perspective to the solution. The use of creativity and imagination by engineers allows them to develop unique solutions to a problem which in turn increases the possibilities for a successful solution."
Subjectivity	N/A	"There is generally not a single best design for a solution. Engineers need to focus on different aspects of the problem and there is no one solution fits all."	"No, every engineering problem can have multiple best solutions. Out of the best solutions, one might be more appropriate due to budget or cultural constraints."	"When a problem presents itself, the solution can be expressed many different ways. Each engineer brings a different background to the process which will influence a designed solution. For example, a bridge needs to connect two pieces of land, yet we have many different types of bridges in the world."
Social and Cultural Embeddedness	I believe that engineering is universal. The engineering design process supercedes social and cultural values because of the goal to be reached."	"I fall in the camp that believes engineering is actually social and universal. When constructing a building, an engineer might be required to model their design after	"In each society, the organization of that society reflects the values and norms governing that society. The use of engineering to solve the issues of a society do not escape the	"Engineering is very much a human activity; meaning that society and engineering have constant interaction. Social and cultural factors affect society and in turn engineering affects

		cultural architecture yet meet the international codes and requirements for the structure."	framework under which the society has built itself upon. The individual engineers have developed socially through their cultural environment and this will be reflected in their approach to the engineering design process. In addition, engineers work together, so through this social construct a solution will be influenced by the larger societal context."	society; generally, positively. Elements such as religion, politics and socio-economic factors makes society, culture and society intertwined. Example; the socio-economic factor is what determines the design and construction of low-income housing. The goal is to get as many units built as will be acceptable within the limited space available in the inner city, while at the same time considering the safe use of material and giving some level of comfort to the residents."