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Anticipating Change: An Exploratory Analysis of Teachers' Conceptions of Engineering in an Era of Science Education Reform

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Abstract

While integrating engineering into science education is not new in the United States, technology and engineering have not been well emphasized in the preparation and professional development of science teachers. Recent science education reforms integrate science and engineering throughout K–12 education, making it imperative to explore the conceptions teachers hold of engineering as a discipline, and as an approach to teaching. This analysis draws on focus group interviews with practicing secondary teachers ($n = 12$) conducted during a professional development seminar. The goals of the seminar were to present engineering as a heterogeneity of practices and inquiries organized to solve human problems; and, to model design-build-test pedagogy as a new approach to teaching. Outcomes show teachers' conceptions of engineering as a discipline are that it redefines failure as necessary for success, and that it can more directly link school learning to serving society. Teachers also anticipated that design-build-test pedagogy would disrupt procedural learning in science, and likely invert which students achieve and why. These outcomes are discussed in light of reform goals, particularly as regards issues of equity. Implications for science teacher educators are also discussed.

Keywords: pre-college engineering, teacher professional development, reform

While integrating engineering in science is not new in the United States (AAAS, 1989, 1993; National Research Council [NRC], 1996), engineering has not been well emphasized in the preparation and professional development of science teachers (Next Generation Science Standards [NGSS]: NGSS Lead States, 2013, Appendix A, p. 3). Current science education reforms integrate science and engineering throughout K–12 schooling. Engineering appears, for example, as practices to be used when introducing students to life, physical, earth and space science; engineering design is also articulated through separate standards in the K–12 curriculum (NGSS Lead States, 2013, Appendix I). The reforms distinguish scientific inquiry from engineering design within its integrated framework by differentiating the goals of these activities (NGSS Lead States, 2013, p. 49). If the goal of an activity is to answer a question, then students are engaged in science. If the goal is to define and solve a problem, they are engaged in engineering. Such simplistic descriptions run the risk of misrepresenting the nature and purpose of the disciplines—for example, implying that engineers do not ask questions or that scientists do not define and solve problems. As reforms take hold, therefore, understanding how teachers conceptualize where the disciplines converge and diverge is important (Honey, Pearson, & Scheweingruber, 2014). In particular, exploring how teachers conceptualize engineering as a discipline, and as a teaching approach (i.e., design-build-test pedagogy), may prove consequential to the long-term sustainability of integrating pre-college engineering in school science.

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This analysis draws on data collected during a professional development seminar for secondary school teachers that was organized by faculty in the Schools of Engineering and Education at a large public university. The seminar was designed to familiarize secondary school teachers with engineering as systematic design to solve human problems, and design-build-test as a pedagogical approach (Dym, Agogino, Eris, Frey, & Leifer, 2005). Drawing on focus group interviews with participants, we ask: *What are teachers anticipating about engineering in school science?* As a result, this analysis explores teachers' anticipations of engineering, which we have organized in relation to two categories of conceptions: (1) conceptions of engineering as a discipline; and (2) conceptions of engineering as a pedagogical approach. This exploratory analysis marks an important foray into future research on the preparation of science teachers for pre-college engineering education in K–12 science classrooms. As important, our results speak to the equity-minded reform goal of science and engineering for all (NGSS Lead States, 2013, Appendix D).

Prior Research

The Significance of Teachers' Conceptions of the Discipline

In the broadest sense, teacher beliefs are defined as the implicit, sometimes unconscious, assumptions about students, classrooms, and the academic material being taught (Kagan, 1992; Pajares, 1992). Teachers' conceptions of science, for example, have been the subject of study for over thirty years (e.g., Abd-El-Khalick & Lederman, 2000; Aguirre, Haggerty, & Linder, 1990; Akerson & Hanucscin, 2007; Irez, 2006; Lederman, 1992; Lederman & Abell, 2014; Liu & Lederman, 2007). Such studies have led to a clearer articulation of the discipline as a body of knowledge, a way of doing, and a way of thinking (NRC, 1996; NGSS Lead States, 2013; Sagan, 1990); conceptions that directly impact practice (Bryan & Abell, 1999; Loucks-Horsley, Stiles, Mundry, Love, & Hewson, 2009; Sang, Valcke, Tondeur, Zhu, & van Braak, 2012). This line of research has also shown that teachers readily mobilize their understandings of science in their teaching (e.g., Capps & Crawford, 2013; Duschl & Grandy, 2013; Waters-Adams, 2006) because ultimately, an implemented curriculum is beliefs put in action (Short & Burke, 1996). Thus, in the early stages of reform, when teachers are designing new learning opportunities for students, it becomes critical to consider what conceptions of the discipline govern their pedagogical work.

Teachers' Conceptions of the Discipline and the Success of Reforms

As reforms integrate engineering with science, conceptions about how the disciplines converge and diverge may inform the pedagogical choices teachers make (Honey et al., 2014). Science is a method of inquiry into the natural world that continually extends and refines knowledge (Rudolph, 2014; Schweingruber, Duschl, & Shouse, 2007). Engineering is the systematic process of design to solve human problems (Katehi, Pearson, & Feder, 2009; NRC, 2012, pp. 11–12). As learning endeavors, there are similarities between engineering and science. For example, conceptual understanding, problem solving, and the need for active learning are among the key commonalities that advance success in both (Singer, Nielsen, & Schweingruber, 2012). Then again, while scientific inquiry and engineering design are conceptually comparable approaches to problem solving, they also differ in ways that have direct implications for teaching (Lewis, 2006). Engineering design takes students through several phases of deliberate inquiry: specifying a problem, researching the problem, making, testing, refining, and optimizing a solution (Jones, Rasmussen, & Moffitt, 1997; Moursund, 1999; NGSS Lead States, 2013). The differing nature of scientific inquiry and engineering design can introduce challenges in teaching students to work between the disciplines (e.g., Schauble, Klopfer, & Raghavan, 1991; Silk, Schunn, & Cary, 2009). Understanding how teachers conceptualize the relationship between science and engineering may prove instrumental in the success of reforms (Katehi et al., 2009; Honey et al., 2014; Stohlmann, Moore, & Roehrig, 2012) and in particular, in realizing the equity-minded goal of science education for all (NGSS Lead States, 2013, Appendix D).

Teachers' Conceptions of the Discipline and Equity

Teachers' conceptions of engineering as a discipline and as a teaching approach have implications for actualizing the decades-long goal of redressing the underrepresentation of female, African-American, Latino, Native, and Alaskan students in science and engineering (Duschl, Schweingruber, & Shouse, 2007; National Academy of Engineering [NAE], 2008; NGSS Lead States, 2013; Quinn, Schweingruber, & Keller, 2012). Stereotypes about engineering (e.g., as associated with the elite) or stereotypes about who are best suited to be engineers (e.g., white males) pose significant threats to achieving equity, and grow in part from the way teachers (and others) conceptualize the discipline and its teaching (Nosek et al., 2009; Pilotte, Ngambeki, Branch, & Evangelou, 2012; Yasar, Baker, Robinson-Kurpius, Kraus, & Roberts, 2006). Disrupting social biases in teachers' conceptions of engineering is not a guaranteed outcome of professional development. In a study of *Project Lead the Way (PLTW)*, for example, a nationally-recognized pre-college engineering curriculum (Committee on Prospering in the Global Economy of the 21st Century, 2007; Project Lead the Way [PLTW], 2009), researchers found teachers' social biases related to engineering remained largely unchanged even as they learned new ways to teach. Specifically, both before and after experiencing the *PLTW* curriculum, teachers endorsed engineering as best suited for high achieving and economically elite students (Nathan, Tran, Atwood, Prevost, & Phelps, 2010; Nathan, Atwood, Prevost, Phelps, & Tran, 2011). The interrelation of social bias and conceptions of the discipline, as reflected in such outcomes, means that attending to teachers' conceptions of the discipline and how it is taught also means grappling with the meaning of those conceptions for achieving equity.

Drawing from the broader field of teacher professional development, we recognize that the long-term feasibility of science reforms may rest in part on professional development treating teachers' conceptions as objects of analytic attention (Battey & Franke, 2015; Darling-Hammond & Baratz-Snowden, 2005; Fishman, Marx, Best, & Tal, 2003; Spencer, Santagata, & Park, 2010). In the context of "all standards, all students" in current science education reforms (NGSS Lead States, 2013, Appendix D), the pernicious class-based, gendered, and race-based associations with engineering must be supplanted by an understanding that engineering involves complex thinking, creativity, and an ethic of care toward society that *all* children are capable of accomplishing (Katehi et al., 2009; NAE, 2008; National Science Board [NSB], 2012). If, however, teachers' conceptions of engineering as best suited for particular "kinds of students" (based on race, gender, class) goes uninterrupted, they will reproduce a narrow vision of engineering and unduly exacerbate existing disparities in who pursues the discipline and why. Thus, exploring how teachers conceptualize engineering as a discipline, as a teaching approach, and the possible implications for such conceptions on achieving equity, becomes imperative in the early stages of reform.

Methods

Overview of the Seminar

The data in this analysis come from a 2013 initiative by a large public university's Schools of Engineering and Education. Recognizing the value of interdisciplinary professional development for teachers of engineering (Donna 2012; Reimers, Farmer, & Klein-Gardner, 2015) the seminar was advertised as an opportunity for any secondary STEM teacher to work collaboratively with engineering and education research faculty to learn about "design-build-test" pedagogy. As a result, the seminar included secondary science, mathematics, technology, and MESA (Math Engineering Science Achievement) teachers from local school districts who were interested in engineering and teaching engineering.

There were two main objectives in designing the professional development seminar that are relevant for this analysis: (1) to present engineering as a discipline that encompasses a heterogeneity of practices and inquiries that are organized to solve human problems; and (2) to demonstrate engineering design as an approach to teaching that could be taken up by mathematics, technology, and especially science teachers, as part of their existing practice. The following sections briefly describe features of the seminar's design meant to advance these objectives, respectively.

Engineering as a discipline. One seminar objective was to introduce teachers to the heterogeneity of practices and inquiries of engineering while also communicating the discipline as fundamentally motivated by solving human problems. To accomplish this, we organized the seminar to engage teachers in discussion with research engineering faculty from a variety of fields. Eight research engineers (the Dean, six faculty, and a graduate student) developed and presented 1.5 to 2-hour long engineering modules that represented multiple fields including civil, chemical, environmental, and biological engineering (see Table 1). Engineering research faculty typically began their modules with a presentation of the pressing social problems their research addresses (e.g., climate change, alternative energies, public health) and then transitioned into engineering activities that reflected some aspect of their work (with two exceptions, see Table 1). We conjectured this framing would communicate a view of engineering as a discipline organized to solve societal problems while also demonstrating that the knowledge, practices, and tools of engineers can vary widely.

The Microbial Fuel Cell, for example, was an activity that began with faculty discussing the importance of alternative energy sources. Then, through the multi-day investigation, teachers learned how to design a microbial fuel cell and (due to time) used prefabricated cells to compare differences in energy output from soils of differing nutrient content. Engineering faculty led teachers in a discussion about nutrient-rich soil, its relationship to energy production, and how population density relates to soil degradation. This conversation framed the microbial fuel cell investigation as an investigation of human activity and related it to the problem of natural resource depletion.

Engineering as an approach to teaching. In articulating standards for the preparation and professional development of teachers of engineering, Reimers and colleagues (2015) argue the need to direct professional development "toward engaging participants in active experimentation and problem solving, encouraging them to become more familiar with the methodology of engineering and the processes of engineering design" (p. 41). Wherever possible, the engineering faculty created modules that involved engineering problem solving or design-build-test pedaogy, the latter of which reflects the dominant paradigm of pre-college and college engineering education (Dym et al., 2005). For example, the Index Card Structure module, which was facilitated by the Dean of Engineering, led teachers through the design-build-test process in using

Table 1
Engineering modules designed by engineering research faculty.

Module	Field of Engineering	Description
Index Card Structure	Civil	Keynote address and presentation on the significant contributions of engineers to the advancement of humankind. Teachers then built a structure out of index cards and staples that could bear the weight of a brick eight inches from the table top.
Microbial Fuel Cell	Chemical & Environmental	Framed in relation to a need for alternative energy sources, teachers collected and used soil samples to learn about fuel cells, and to investigate what it takes to generate enough current to power an LED.
Climate Change	Environmental	Framed in relation to global drought and famine, teachers used online climate science resources to investigate patterns of weather, climate, and water availability around the globe based on historical data, satellite observations, and modeled simulations.
Microfluidics of the Heart	Biomedical	Framed in relation to heart disease, the teachers learned about the physiology of the heart and ways of modeling cellular flow. Teachers worked with microfluidic channel devices and explored what optimizes flow through ports.
LED City	Electrical	Framed in relation to advances in modern computing, teachers learned about microprocessors and pin design. Teachers then designed and built a "city" using a battery, breadboard, and LEDs that optimized energy output to all sectors.
Molecular Detection of Diseases	Biomedical engineering	Framed in relation to targeted therapies for cancer treatment, teachers learned about molecular profiling, cell analysis, and targeted delivery of therapeutic agents to sites of disease in the human body. This module did not have an associated activity.
Robot Programming	Computer	Framed in relation to the risks and rewards of artificial intelligence (AI) as the capacity of machines to imitate intelligent human behavior. Teachers learned to produce binary-based commands and "programmed" one another (teacher as machine) to walk a maximally efficient path to retrieve candy from a bowl.
Shrinky Dink Microfluidics	Materials Science	Framed in relation to the importance of advancing nanoscale investigations, engineers demonstrated a novel method of microfluidic channel network printing. Based on commercially available children's art materials (Shrinky Dinks), teachers discussed the idea of technological advances arising from the everyday. This module did not have an associated activity.

index cards to support the weight of a brick at least eight inches above a surface. Teachers discussed design-build-test as a pedagogical approach that could be mobilized in science, mathematics, technology and MESA classes. In another module (Microfluidics of the Heart), teachers learned about laminar flow and heart disease; were led through a design-build-test activity in which they tested flow in channels of differing diameters; and then related the design-build-test process to their disciplines where, for example, mathematics teachers discussed how the Reynolds number animates the concept of ratios.

In other instances, teachers were engaged in inquiries that applied science and engineering practice standards. For example, in the Climate Change module, teachers were introduced to online satellite data that could be used to investigate and model the historic and contemporary nature of flooding, drought, and landslides around the globe. This module reflected many of the science and engineering practices articulated in reforms, including how engineers define a problem, how they pursue that problem through mathematics and computational thinking, and how that pursuit leads to the development and refinement of models to approximate social (or natural) phenomena.

To further support teachers, the seminar was designed to incorporate collaborative lesson planning. These collaborative sessions addressed the pragmatic and reasonable desire of teachers to gain knowledge that "directly relates to the day-to-day operation of their classrooms" (Guskey, 2002, p. 382) while also deepening opportunities for teacher learning (Burghardt & Hacker, 2007; Donna, 2012). As regards engineering education, supporting teachers' development of engineering pedagogical skills involves teachers working together in a community (Reimers et al., 2015). Thus, eight of the nine days ended with two unstructured hours for participants to collaborate on lesson plans based on the engineering module presented that day.

In summary, Table 2 presents the seminar's goals as aligned to features of the seminar's design.

Participants

The teachers. The Director of Outreach in Engineering recruited participants through local county education administrators and the MESA program. MESA is a national program that promotes engineering design, particularly among female and underrepresented racial minority (URM) students (Atwood & Doherty, 1984). With funding for 10–12 teachers, we suggested the following selection criteria based on research that argues for recruiting teaching teams with administrative support (see Garet, Porter, Desimone, Birman, & Yoon, 2001), and from a variety of STEM disciplines (Donna, 2012; Reimers et al., 2015). Thus, we had four criteria for participant selection: (1) secondary teachers from the same school; (2); teachers whose administrators provide a written endorsement for their participation in the seminar; (3) secondary teachers of

Table 2
Seminar design features in relation to seminar goals.

Seminar Goal	Design Feature
To present engineering as a heterogeneous discipline that involves systematic design to solve human problems.	• Engaging engineering faculty from a range of disciplines • Discussions of engineering design and inquiry as motivated by human problems
To model engineering as a new approach to teaching that may be incorporated into teachers' current professional practice	• Engaging in design-build-test modules or inquiries that reflect the application of engineering practices • Unstructured time for teachers to collaborate in translating engineering modules into classroom lessons

Table 3
Teacher participant profiles.

Teacher	Level	Subject Area(s)	School Context
Efraim	High School	Biology & Physics	Private Religious
Scott	High School	Physics	Public Traditional
Heather	High School	Physics	Public Traditional
Graham	Middle School	Science	Private
Sarah	Middle School	Science	Private Religious
Brad	Middle School	Science & Technology	Public Fundamental
Rosa	High School	Biology, Chemistry & MESA	Public Traditional
Abigail	Middle School	MESA	Public Math & Science Magnet
Ellison	Middle School	MESA & Mathematics	Public Traditional
Abraham	High School	Mathematics	Public Fundamental
Ray	High School	Mathematics	Public Traditional
Minh	High School	Mathematics	Public Traditional

any STEM subject with preference to teachers of URM students; and (4) teachers with experience or interest in project-based teaching (what we perceived as a point of entry into design-build-test pedagogy).

After reviewing online applications and administrator endorsements, 12 of 63 applicants were selected. While the majority of our desired criteria were met, the Director was unable to recruit more than one teacher from a given school. Table 3 presents an overview of the participants, their subject areas, and schools.

All of the teachers in Table 3 had administrative support and prior experience with project-based learning. Four of the 12 teachers identified as female; eight teachers identified as male. Nine of the 12 teachers taught a majority of URM students, all of whom were also in public schools. Teachers received $500 for participating in the seminar.

Data: Focus Group Interviews

Videotaped focus group interviews (45–90 minutes) were held at the end of each week. Teachers participated in one of two groups (A or B) resulting in four interviews total (i.e., A1 and B1 and later, A2 and B2). In the first interview, we asked 23 questions regarding: (1) prior support and expectations for engineering standards, (2) the week's activities, and (3) development of lesson plans. In the second interview, we asked 13 questions regarding: (1) the week's activities; (2) expectations for implementing their lessons; and (3) the seminar structure overall.

Data Analysis

In preparation for qualitative coding, all four focus group interviews were transcribed. Our approach to coding followed what Miles, Huberman, and Saldaña (2013) describe as two cycles of qualitative coding. In the first cycle, we created data chunks, which were single or multiple turns of talk that were topically related. Using qualitative analysis software (Dedoose) we then assigned descriptive codes (Miles et al., 2013, p. 74) that reflected the general idea under discussion (e.g., *Resources*, *Anticipations for Students*, *Nature of Engineering*, *Administrative Support*). The first cycle of coding resulted in 17 unique descriptive codes. For this analysis, we focused on three in particular: *Nature of Engineering, Anticipations for Students,* and *Anticipations for Teaching*, which were most relevant to answering the research question. The codes are illustrated with example excerpts in Table 4.

To assure consistency of descriptive code application, the authors first discussed the content and coding of approximately 10% of the data chunks before working independently. Upon completion, the authors compared coding results and reached over 85% interrater-reliability, and discrepancies were resolved through discussion. Though time and discourse intensive, this approach bolstered the trustworthiness of interpretations before findings and claims were articulated (Hatch, 2002). Once the descriptive codes and their associated data chunks had been agreed upon, we moved into the second cycle of coding, known as pattern coding.

Table 4
Selected descriptive codes from the first round of qualitative coding.

Descriptive Code	Definition/Description	Example
Nature of Engineering	References to what engineering "is" or "should be" in schools	It's intertwined between all the disciplines, and we are looking at the engineering during the designing process, it taps on every single discipline that there are. And so, in a sense when we develop an engineering project based lesson plan, it can be very tiring in terms of planning it, but can, the end result can be quite interesting to see what the kids can actually gain from it.
Anticipations for Students	References to the impact of engineering in science, or a particular lesson developed in the seminar, on students	I think for the index card structure…the challenge is getting it to work; [students] are gonna get stressed out because they are not sure if it's gonna work, and some of [the structures] won't work and they [the students] are going to freak out about their grade!
Anticipations for Teaching	References to how teaching may change with greater integration of engineering in science	I think for my part, in terms of [what is] challenging is now the ball is back onto my field. For me personally, I'm more scared of how I'm gonna manage it…Because with engineering project-based learning the student will tend to dive in, get their hands dirty and how am I gonna be?

Table 5
Four thematic codes emerging from pattern coding in the second cycle of coding.

Code	Description	Example Excerpt
• Failure	References to what defines failure or success in engineering	Students [get] immediate feedback whether or not their engineering designs have come to a great design or [if]…they didn't get the result they wanted to, it also gives us a chance to have a discussion within the classroom and say, 'Okay, so you predicted this was going to happen but yet this happened. What went wrong? Why?'…
• Procedural Learning	References to teaching engineering as more than cookbook science	When you throw in the design element, that really throws them for a loop because they're just not used to doing that. Well, they have done labs in the past, well, here's your procedure.
• Serving Society	References to engineering as serving society	I am familiar with, let's say aerospace, electrical, civil, mechanical…[an] engineering career, research…solves problems, human needs.
• Achievement Inversion	References to how student achievement may change with greater integration of engineering in science	I've seen a lot of times, kids who aren't as active…aren't as academic and they can succeed in some of these [engineering] activities whereas, some of your more academic kids get frustrated.

Pattern coding involves looking for patterns within and across the descriptive codes in an effort to condense the data into smaller analytic units (Miles et al., 2013, p. 86). As will be discussed in the results, the emergent patterns (or themes) reflect the teachers grappling with points of convergence and divergence between engineering and science. The themes included, specifically, descriptions of how engineering rewrites the notion of failure in science (*Failure*), how engineering can disrupt procedural learning associated with science (*Procedural Learning*), how engineering serves society (*Serving Society*), and the potential for engineering in science classes to invert who has historically achieved (*Achievement Inversion*). Examples of all four themes are presented in Table 5.

As previously described, we independently coded ~10% of the data before engaging in the same discourse and interaction intensive approach to achieving consistency of code ascription throughout.

Limitations

There are several limitations to this study, which render it exploratory. First, while this analysis offers insights on some of what secondary teachers may think of engineering as a discipline and approach to teaching, the focus group interviews were not explicitly designed to elicit this reasoning exhaustively. Second, without direct evidence of teachers' practice, the results cannot be interpreted as assuredly leading to particular changes in teaching, especially since research linking beliefs to practice often yield mixed results (e.g., Boz & Uzunitryaki, 2006; Mansour, 2009; Roehrig & Kruse, 2005; Savasci & Berlin, 2012). Third, the study involves a relatively small sample of teachers working across disciplines and school contexts. Therefore, we rely on reader generalizability wherein readers assess the transferability of findings to their respective settings in the absence of statistical generalizability (Creswell, 2007;

Hatch, 2002). Fourth and finally, research on the positive impact of comprehensive and sustained professional development (e.g., Johnson, 2007; Supovitz & Turner, 2000) contrasts with the nine-day seminar described here. Despite these limitations, understanding how a teacher may conceptualize engineering as a discipline and teaching approach is both generative and important for the long-term feasibility and sustainability of reforms.

Results and Analysis

The goal of this analysis was to understand, against the backdrop of sweeping reforms in science, teachers' conceptions of engineering as a discipline and approach to teaching. What follows are the results presented in two sections, each of which describes the emergent themes resulting from pattern coding. The first section describes teachers' conceptions of engineering as a discipline that redefines failure, and makes visible how school learning connects to society. The second section describes teachers' conceptions of engineering as a teaching approach that disrupts procedural learning in science and inverts who achieves and why. Taken together, these themes speak to the research question: *What are teachers anticipating about engineering in school science?* A summary of the analytic findings is presented in Table 6.

Teachers' Conceptions of Engineering as a Discipline

This section presents two themes that emerged in teachers' conceptions of engineering as a discipline, which were most often shared by identifying points of convergence or divergence between engineering and science: (1) engineering redefines failure as necessary and productive; and (2) engineering directly serves society.

Redefining failure. Some teachers saw connections between science and engineering in that both rely on an exploratory process that involves learning from failure:

> I just like the "thinking like a scientist" idea that engineering activities lend itself to…because we want kids to know…what it's like to be a scientist, to be curious, to explore, to try this, to see what works, to test hypotheses, and to know if you fail, that's not really failing in science. (Graham, A1).

Although Graham is explaining what he likes about engineering activities, his response connects engineering to science through the idea of learning from trying and failing. Like Graham, Efraim explained that engineering shows students that "great inventions are based on failure at some point, and it was reacting to that failure that caused the greatest advances" (A1). Graham and Efraim's responses associate engineering as a discipline that turns the typical dynamic of success versus failure into one of success *through* failure.

Abigail, a MESA instructor, similarly focused on engineering as a way to evidence learning through trying and failing, something she felt children today rarely experience. Reflecting on a conversation with an engineer who assists her in MESA, she explained:

> [We agreed that] kids nowadays don't know how to tinker or play with things…but when you're doing [an] engineering project, it's testing and trying something and then saying "No, that's not working" and so redesigning, rethinking. And so, to get them involved in that process is what we really need.

Here, Abigail is not explicitly comparing engineering with science but with what she perceives about children's lives today (i.e., not knowing how to tinker or play). She therefore suggests that children can, should, and need to be involved in systematic design ("redesigning, rethinking"), an experience she fundamentally associates with engineering.

These responses represent how teachers were grappling with what engineering as a discipline could represent for students, in and beyond the classroom. For Graham and Efraim, both classroom science teachers, they saw engineering as converging with science in requiring experts to be inquisitive, perseverant, and systematic in learning from their failures. For Abigail, a MESA instructor, the focus was on how divergent engineering is from the everyday, and how the discipline normalizes a kind of learning that is missing (and needed) in children's lives.

The second theme that emerged in teachers' conceptions of engineering as a discipline focused primarily on how engineering creates explicit links between learning and society, in ways that current classroom teaching does not.

Serving society. Teachers saw engineering as directly serving society in a way they did not associate with science.

Table 6
Summary of analysis.

Research Question	Categories of Conceptions	Themes
What are teachers anticipating about engineering in school science?	Teachers' perceptions of engineering as a discipline Teachers' perceptions of engineering as a teaching approach	• Engineering redefines failure as productive in science • Engineering links learning to societal needs directly • Engineering disrupts procedural learning in science • Engineering will invert who achieves in science and why

In discussing the microbial fuel cell lab, for example, Brad and Heather had an exchange that represented this distinction:

1	Brad	We could have learned to make the fuel cell from a chemist. A chemist could have taken us through all those steps but [the] engineer said there's a growth that happens in [the] population and in ten years, there's going to be X number of people, and if I gave, I remember he said, if I gave every one of them [a] light bulb, and he gave an example of why we need to do this.
2	Heather	The engineers come from a more practical –
3	Brad	Engineering is more for the human need…the chemist, you know, okay, cool, the dirt. But the engineer goes, 'we need energy' and you go, 'oh yeah, we do' [*teachers nod in agreement*]

These teachers saw engineering as deliberate inquiry to develop solutions that serve society in "practical" ways (Lines 1-3). Brad contrasts this view of engineers and engineering with science and scientists (Lines 1, 3), where he associates the latter with broader inquiries into natural phenomena ("okay, cool, the dirt"). Thus, while not suggesting scientists are ambivalent to issues of human need, the teachers saw engineering as more deliberate in addressing societal problems. This is perhaps unsurprising because, as Brad describes of the module above, the engineering modules were presented as directly related to human problems.

For Ray, a mathematics teacher, engineering was a way to connect learning to real life, and in that sense, antithetical to superficial or shallow learning that he associates with more typical activities. Reflecting on the climate change module, he explained how asking students to do online research rarely involves deep thinking or authentic inquiry. In contrast, the online climate change resources offered something different:

> There are so many ways teachers can create kids to go and look for information and come back and do it as an activity [about] what they learned. But then that's not addressing the need like the Dean of Engineering said: Engineers do hands on and I think these activities cannot be done in any other way than giving them the conceptual understanding [and] what are the implications of real life and how this is useful in real life… (B1)

Ray's perspective on engineering reflected in his lesson plan for the climate change module. As he explained, the lesson drew on "economics, business, not just science and math, so as a teacher I can [discuss] what the food prices is going to affect, what does it have to do with climate, everything to do with it" (B1). For Ray, this engineering inquiry project represented an interdisciplinary possibility he did not otherwise associate with teaching.

Like Ray, Abraham (also a mathematics teacher) explained his interest in the microbial fuel cell project because of its potential to connect students to environmental issues:

> So again, the typical renewable energy, let's say, wind or sun, and here we are with the soil. So, it just fascinated me to tell the kids…we can find the source of new energy somewhere…just keep exploring and keep finding new ways, to just tell the new generation science engineers, to the students, "Look! There's more to be found!" (B1)

In his response, Abraham cast engineering as inquiry at the frontier of new possibilities; of finding answers to society's great energy-related dilemmas. And notably, even as a mathematics teacher, he recognizes this as the comingling of science and engineering in imagining the "new generation [of] science engineers."

These conceptions that relate engineering to societal need were explicitly tied to teachers' experiences of the professional development seminar and in particular, the engineering faculty's presentations. What teachers drew out as the nature of engineering from the modules mirrored what reforms suggest as a key difference: "'science' is generally taken to mean the traditional natural sciences… [and reforms] use the term 'engineering' in a very broad sense to mean any engagement in a systematic practice of design *to achieve solutions to particular human problems*" (NGSS Lead States, 2013, Appendix I, p.103, our emphasis). Thus, while this is perhaps an unfair distinction as regards the goals of science, the distinction between science as inquiry into natural phenomena and engineering as the deliberate design of solutions to human problems, was significant in how teachers conceptualized engineering as a discipline.

Teachers' Conceptions of Engineering as a Teaching Approach

In their conceptions of design-build-test pedagogy, teachers repeatedly compared their current practices with the possibilities of what a new teaching approach might mean for student learning. This section presents two themes that emerged in teachers' conceptions of engineering as a new pedagogical approach: (1) design-build-test pedagogy carries the promise of disrupting procedural learning associated with science; and (2) this new teaching approach will likely result in an inversion of which students achieve in science and why.

Disrupting procedural learning. Many of the teachers expressed dismay that school science rewards procedural learning and rote memorization. In contrast, engineering design was conceived of as a disinctly *different* experience that would challenge students anew:

> [W]hen you throw in the design element, that really throws [students] for a loop because they're just not used to doing that…They have done labs in the past…"Okay, here's what you're supposed to do, here's what you're supposed to look for." Whereas [with engineering] it's "Okay, design something that does this," and [students] go, "Well, what are the instructions?" and there are none. The fact that they have to be able to push themselves to this higher level…is going to be a challenge until they get used to doing that. (Efraim, A1).

Efraim makes two central claims that suggest he sees engineering and science in school as importantly different. First, he argues that while science labs are often scripted, engineering design is not. He sees the lack of explicitness as pushing students to a "higher level" of learning. Second, he anticipates that students will eventually adapt to the challenge of engineering design.

Like Efraim, Abigail described engineering projects as an opportunity to break her students of past experiences in which being told what to do was equated with learning:

> We're trying to make [our middle schoolers] independent thinkers, some for the very first time. They very much want directions or, "What do you expect me to do?" or "Where should I put my name?" and so…one of the key things in MESA and with these projects that I'm looking for is that [the students] get a chance to be creative, think out of the box, be able to work and collaborate with a couple of other people. (A2)

Abigail perceives MESA students as having been conditioned to scripted science learning. She therefore expects engineering to be creative, collaborative and innovative in ways that cultivate independent thinking. Like Efraim, Abigail's expectations of engineering suggest a more general sense that this domain could mitigate the pervasiveness of procedural learning.

For some teachers, the pervasiveness of procedural learning was tied to standardized testing, which they perceived as rewarding rote memorization of vocabulary and definitions or facts. To integrate engineering into this reductive approach to learning was, as Graham explained, "like an oasis I see to help kids to have that experience of wrestling with problems and not knowing the answer." This literal (and literary) reference conveys a sense that wrestling with problems and the unknown in engineering provides much-needed fertile ground for learning in a desert of science vocabulary and definitions. Graham's response reflects the anticipation that engineering will offer a more sophisticated, complex and rewarding learning opportunity than science alone.

Overall, the teachers saw design-build-test pedagogy as cultivating independent and critical thinkers who wrestle with ideas that have unknown outcomes. Interestingly, teachers are casting engineering as a welcomed change from what they associate with science in schools—scripted activity, rote memorization, and standardized testing.

An inversion of who achieves and why. The second theme to emerge in relation to teachers' conceptions of engineering as a teaching approach, relates to what they saw as the impact of engineering on student achievement. Current reforms encourage teachers to engage students at the nexus of science and engineering practices, core disciplinary ideas, and cross-cutting concepts (NGSS Lead States, 2013, Appendix A, D). This more integrated casting of science learning is anticipated to advance equity. During the seminar, the Dean of Engineering reiterated the importance of equity and similarly described teachers as being on the front lines of that effort. However, a subset of the teachers conceptualized the teaching of engineering in science as likely to *invert* (rather than broaden) student outcomes.

Returning to the idea that engineering is different to procedural learning, the teachers reasoned engineering would reward students who struggle in science, while challenging those who typically succeed:

> [Engineering] is good for both [kinds of students], because the high-ended kids are expecting one answer only and you can see them when they say, "Oh, there isn't an answer." But the lower-ended, I had that with MESA with the competition, some of the kids [you] wouldn't even expect, 'cause they weren't engaged or motivated, but you give 'em a problem and they want to win, so they're the ones explaining to the group how this whole thing works…they're the ones that are actually willing to take that risk and go out and try. They have nothing to lose. And, they're excited by it. (Abigail, A1)

Abigail's explanation of why high achieving students will struggle with engineering is linked to the non-algorithmic thinking it requires. She anticipates that "lower-ended kids," those who demonstrate a lack of motivation in school subjects (elsewhere, she describes them as academically struggling) may take risks and attempt the unknown in an engineering project. Abigail went on to explain that this means low achieving children can become high achieving through engineering because: "it's actually the kids that struggle more and have to work through why and how and all of that, that might be better able to explain" (A1).

There are three important ideas to notice in Abigail's logic in relation to equity. First, the impact of engineering on science achievement is tied to conceptions of engineering as a domain that disrupts procedural learning, as previously discussed. Second, the inclusion of engineering will invert achievement such that students who achieved in science will struggle with engineering, and those who struggled in science will now achieve with engineering. Third and finally, Abigail concludes that the inversion of achievement is "good for both" low and high achieving science students. While grounded in conceptions of the discipline and how it is taught, Abigail's anticipation that engineering will still result in stratified outcomes is strikingly unlike the message of "all standards, all students" reflected in reforms (NGSS Lead States, 2013, Appendix D).

Abigail was not alone in how she anticipated engineering would impact science achievement. In what follows, Graham and Efraim have an exchange in which they imply that success in science involves mastering known information, while engineering rewards intuitiveness and comfort with the unknown:

1	Graham	I've seen a lot of times, kids who aren't as active, like you're saying, aren't as academic, and they can succeed in some of these [engineering] activities whereas some of your more academic kids get frustrated. They aren't used to –
2	Efraim	Exactly.
3	Graham	– having to come at a problem like this, and it's actually quite refreshing to me as a teacher to have some kid who consistently gets poor grades and he can intuitively know what to do and all of a sudden, he is the star of the class. And some of these other kids who are, you know, straight A kids, and they're practically in tears because they've never gotten a B in their life and now they think, they can't figure out how to get this thing to work…And they've never had to deal with solving a problem that has a practical solution and I think, Oh, this is so healthy for these little perfectionists to see, to not know how to solve the problem.
4	Efraim	They are so used to being good at algorithms and picking them –

Graham and Efraim also seem to anticipate that engineering will invert science achievement (Lines 1, 2) and they draw on the differences between the disciplines to level their argument. From what Graham says, it seems he sees science learning as involving solving problems but not problems with practical ends, as one finds with engineering (Line 3). Later, Graham goes on to imply engineering involves learning with unknown ends ("healthy…to not know how to solve the problem"), which Efraim contrasts with science learning as reflecting "being good at algorithms" (Line 4).

In their exchange, Efraim and Graham ascribe a particular disposition to high achieving science students. Graham explains such students are vigilant about their grades because they are "perfectionists" who have never had to create a "practical solution" (Line 3). Like Abigail, Efraim and Graham see the inversion of science achievement as good for both kinds of learners (Lines 3, 6) where engineering will be a "healthy" check on high-achievers who "can't deal with it" while the struggling student becomes a "star" because they will "intuitively know what to do" (Line 3).

The notion that some students will understand engineering *intuitively* can be interpreted in multiple ways. Graham could have meant what Abigail argued, that struggling students want to know how things work and are therefore predisposed to an engineer's mentality. Graham could also have meant students who struggle in science have engineering-like, non-algorithmic learning interests or experiences that are not rewarded in traditional science instruction. A third, and more pernicious possibility, is that Graham meant science achievement took book smarts (memorization, algorithms) while engineering is knowledge gleaned without reason (i.e., intuitive). Framing science as book smart and engineering as a version of street smart threatens to misrepresent the disciplines, what it means to achieve in them, and who is best suited to pursue them. In short, it creates a new rhetoric for differentiating and stratifying learners.

Elsewhere in the interview Efraim argued the implications of pre-college engineering on equity in a way more consistent with reforms. In the following response, Efraim does not offer the inversion of a hierarchy as the outcome of introducing engineering but rather, the possibility of more equitable collaborations among diverse learners:

> …sometimes it's the kids who are academically stronger [that] get stuck because, all of a sudden, you're forcing them out of their comfort zone. They're used to being very formulaic because the algorithm they know how to do, but also when it's free form, they're all, "Oh my God, what do I do?" Whereas another kid who's strong in terms of theory goes, "Oh, we just do this," whether it's because of life experiences, or more creative or whatever, and so I think the engineering approach, in a lot of ways, actually increases the chance of collaboration…In observational projects, there's always one or two of the kids who are going to dominate [and] my fear of the past has always been how do I make sure that this one kid doesn't do the work for everyone and everyone else just kind of tags along. And that's one of the big advantages. (A1)

There are three important and interrelated ideas in Efraim' comment that delineate what he perceives as the implications of engineering for equity. First, like his previously cited conversation with Graham, Efraim maintains the view that "academically stronger" students are likely to find discomfort with engineering design because it is not formulaic. Second, unlike Graham, Efraim does *not* cast low-achieving science students as the ones who will excel at engineering by intuition. Rather, he refers to such students as having a greater understanding of "theory"—ideas that explain something—based on life experiences or heightened creativity. It is significant that Efraim is not equating excellence at engineering with failure in science as others (and he) have done elsewhere—he is equating engineering success with creativity and (different) life experiences. Third and finally, Efraim is concerned with cultivating equitable interactions in group-based learning contexts and sees engineering (as taught through design-build-test pedagogy) as important to that goal. As Efraim describes it, the "big advantage" to an "engineering approach" is that it positions students to collaborate more equitably, perhaps because no individual student is predictably strongest in the group, as may be the case with more conventional science projects.

Discussion

Set against the backdrop of U.S. K–12 science education reforms (NGSS Lead States, 2013), this analysis asked, *what are teachers anticipating about engineering in school science?* As we seek sustainability and stability in the teaching of engineering in science, attending to what teachers are anticipating is important. In our analyses of focus group interviews we present two general categories into which their anticipations fell: (1) conceptions of engineering as a discipline; and (2) conceptions of engineering as a teaching approach. Within each of these categories, two themes emerged in teachers' discussions (see Table 6). As an exploratory analysis, we see these findings as warranting further research on teacher education and professional development vis-à-vis engineering in science and equity.

In our analysis, teachers were explicitly and implicitly grappling with points of convergence and divergence between engineering and science. Attending to how teachers conceptualize the relationship between STEM disciplines is important as reforms encourage them to engage in interdisciplinary teaching (Honey et al., 2014). In this section, we discuss these results and what they suggest about the implications of integrating engineering and science in schools.

Conceptions of engineering that unfairly position it in opposition to science should be viewed skeptically and interrogated further with teachers. This emerged when, for example, teachers implied that scientists do not learn through failure as engineers do, or that science rewards procedural learning. Such views inadvertently resurrect well-established concerns in studies of science education. Take, for example, the idea of science as procedural learning (especially labs). For decades, the scientific method, a backbone of science labs, has shaped how teachers and students think about scientific inquiry (Abell & Smith, 1994; Bencze & Bowen, 2001; Palmquist & Finley, 1997). National and international studies of science classrooms attest to the regular displacement of deep conceptual understanding with superficial activity, a critique that centers on the use of the scientific method (Banilower, Smith, Weiss, & Pasley, 2006; Roth & Garnier, 2006). Such implementations of the scientific method degrades inquiry to a series of cookbook steps that confirm or negate students' predictions. As Windschitl, Thompson, and Braaten (2008) demonstrate, a cookbook representation of the scientific method leads to students developing problematic understandings of what it means to do science. Thus, when teachers juxtapose engineering as creative and non-algorithmic thinking with science as procedural and certain, it creates an opportunity to address views of engineering while also *redressing* reductive views of science.

Another conception of engineering that teachers shared, which was more implicit in its contrasting of the disciplines, was the idea that engineering directly serves societal needs. This distinction is similar to the way reforms describe science as the natural sciences, and engineering as solving problems of human need (NGSS Lead States, 2013). And yet, no one would suggest science does *not* address issues of human need: the impact of advances in cancer treatment, space exploration, and hydrology inextricably link science, engineering and society. Like the previous discussion of science as procedural learning, the notion of science as inquiry in to the natural world (Rudolph, 2014; Schweingruber et al., 2007) requires complementary attention to how such inquiries relate to society. In fact, the call for greater social relevance in science education is decades long (e.g., Aikenhead, 1997; Calabrese Barton, 2002; Fusco, 2001; Lee, 2003), and thus we return to the idea that addressing teachers' conceptions of engineering provides a commensurate opportunity to remedy misconceptions of science.

There is great potential in teachers viewing engineering as a link between learning and social life, particularly as studies of women and URM students in STEM repeatedly stress a need for this link (Calabrese Barton, 2003; Eccles, 2007; Rodríguez & Kitchen, 2004). Understanding how engineering can serve the goal of making school learning *relevant* is important; teachers should design engineering learning opportunities that are complex, non-algorithmic, and socially relevant. While we do not see engineer–teacher partnerships as a viable relationship to design for at scale, research engineer–teacher partnerships in professional development may offer something unique in this regard. Unlike studies on scientist–teacher partnerships (e.g., Nelson, 2005; Wormstead, Becker, & Congalton, 2002) where the latter are often trained in the disciplines of the former, we see research engineers as offering expertise that *complement* teachers' disciplinary strengths while focusing on the relevance of learning; after all, research is often at the frontlines of addressing societal need.

Among teachers' conceptions, one stood out as a potential threat to the equity-minded goals of reform: an inversion of who achieves in science and why. There are two significant dimensions to this idea. First, reforms advocate engineering in all grades as an opportunity to *increase* student achievement in science for all (Katehi et al., 2009; NGSS Lead States, 2013, Appendix D; NSB, 2012). If teachers operate on the idea that engineering will only invert achievement, they miss the opportunity to mobilize their teaching toward broadening who pursues engineering (and science). Second, associating science achievement with being "perfectionists," "bright" and high achieving ("high-ended") while associating engineering with those who learn from struggle, are lower achieving, or who need a chance to be a "star," suggests engineers are not theoretical actors like scientists; engineers work hard but are not "book smart." We know the general public, and students in particular, misunderstand engineering as a masculine and mechanical endeavor of fixing and building that relies on physical effort and not intellect (Capobianco, Diefes-Dux, Mena, & Weller, 2011; Dym et al., 2005; Oware, Capobianco, & Diefes-Dux, 2007; Pilotte et al., 2012). Allowing teachers to reproduce such conceptions is potentially perilous in the greater scope of broadening and diversifying student achievement in science and engineering. Indeed, this particular outcome makes vivid the significance of studying teachers' conceptions of engineering. After all, under the rubric of reforms, science teachers are the ambassadors of engineering and thus what they think will matter to what their students will experience. Based on this outcome, working with teachers' conceptions of engineering in the early days of reform is crucial to establishing that all children are capable of engineering, which involves complex thinking, teamwork, and problem solving (Katehi et al., 2009; NAE, 2008; NSB, 2012).

As reforms take hold in schools today, it is troubling that the fields of pre-college engineering education and engineering teacher education are evolving without a clearly articulated epistemic foundation (Donna, 2012; Marshall & Berland, 2012). While there exists a much longer history of mathematics and science teaching (and research on teaching), studying pre-college engineering in *all* schools and *all* grades is a relatively novel idea in the U.S. In a review of five major pre-college engineering programs, for example, Daugherty (2009) reveals that what proliferates in engineering education are curriculum driven models that focus on active engagement and collaborative learning (e.g., MSTP Project, 2003; PLTW, 2008). Thus, preparing teachers to teach engineering often becomes a secondary extension of the programmatic imperative to provide curriculum (Daugherty & Custer, 2012, p. 58). This suggests a general lack of theory to drive implementation and build capacity for supporting teachers, without which the promise of engineering in science may not be fully realized.

Recommendations for Teacher Education and Professional Development

The results of this preliminary and exploratory study are deceptively simple—teachers think engineering is an iterative and generative learning opportunity that diverges from science in terms of its non-algorithmic nature, design of solutions to problems, and direct service to society. This echoes the focus on developing engineering content knowledge and pedagogical content knowledge in preparing teachers of engineering (Reimers et al., 2015, p. 41). The rub, however, is that science teachers are not readily prepared *as teachers of engineering* and thus, science teacher educators (and science teachers) may not regularly consult those standards. In the science education research community, there remain ongoing calls for substantive and systematic changes to professional development (e.g., Wilson, 2013; Strouop & Windschitl, 2017). Thus, as these efforts emerge, we offer three recommendations in light of our outcomes.

First, teacher educators should contend with the benefits and drawbacks in how they frame the disciplines of engineering and science as converging and diverging. As Reimers and colleagues (2015, p. 42) argue, it may be that science teachers should be encouraged to see engineering as a *context* for teaching science while also seeing it as involving *its own* content and pedagogical content knowledge. This framing—at once convergent and divergent—creates an opportunity to work with teachers' conceptions of engineering while also redressing reductive views of science.

Second, as engineering features more prominently in science, teacher educators have a chance to solidify engineering (and science) as learning that makes the social lives of learners relevant to disciplinary mastery. We know that linking school learning to lived experiences or society is especially beneficial to underrepresented minority and female students (Calabrese Barton, 2003; Eccles, 2007; Rodríguez & Kitchen, 2004) and thus, that the link represents an opportunity to advance equity (Aikenhead, 2006; Bouillion & Gomez, 2001; Lim & Calabrese Barton, 2006; Roth & Lee, 2004). Creating this link is not simple; connecting school learning to the diversity of children's lived experiences involves decentering the supremacy of western science or scientism (Nadeau & Desautels, 1984; Ogawa, 1998), as the only legitimate forms of knowing or doing (see Bang & Medin, 2010; Bang, Warren, Rosebery & Medin, 2012). Nonetheless, engineering in science could mitigate the distance between life and school when teachers teach the discipline as expressing an ethic of care toward society (Katehi et al., 2009; NAE, 2008; NSB, 2012). This idea is similarly argued in the reforms:

> The NGSS, by emphasizing engineering, recognize the contributions of other cultures historically. This (re) defines the epistemology of science or what counts as science… [and so] from a pedagogical perspective, engineering has the potential to be inclusive of students who have traditionally been marginalized in the science classroom and do not see science as being relative to their lives (NGSS Lead States, 2013, Appendix D, p. 29).

Thus, as teacher educators work to support the engineering content and pedagogical capacities of teachers, so too must they consider the cultural competencies and connections to community that reforms invite.

Third, which builds on the prior recommendation, is that teacher educators should actively counter stereotypes of engineering as a practice of the elite, and help teachers to interrogate how such beliefs permeate their practice. This idea is not yet central in the dialogue around engineering teacher preparation. For example, there is no standard for the preparation and professional development of teachers of engineering that explicitly speaks to teachers interrogating the pernicious social "-isms" (racism, classism, sexism) associated with engineering. This may also be said of the National Science Teachers Association's (2012) standards for science teacher preparation, which are similarly silent but for a nod to "equitable achievement" for all students (Standard 3). Our findings suggest that this silence could have direct implications for the promise of engineering in science as a path to equity.

Conclusion

While engineering increasingly populates state education frameworks in the U.S. (Moye, Dugger, & Starkweather, 2012) and now features prominently in NGSS, research on pre-college engineering professional development is still emerging (Daugherty & Custer, 2012; Wang, Moore, Roehrig, & Park, 2011) and these findings, however exploratory, contribute to that dialogue. Borrowing from one of our participants, if we understand teachers as on the forefront of cultivating the "new generation science engineers," and NGSS as guiding that cultivation, then we must take seriously what conceptions teachers have of engineering, and what conceptions they emerge with and carry into their classrooms. Engineering in science could play a transformative role in children's experiences; it could fundamentally rewrite how children see themselves, the purposes of engineering and science learning, and their futures. Thus, what is at stake is not just the sustainability of yet another milestone in national reforms of science education, but the very possibility that doing this well is the greatest investment in our children someday solving the most pressing social and scientific problems of their time.

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