Building Youths' Socio-Technical Engineering Knowledge through Engagement in a Community Solar Energy Project (Evaluation)

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The 21st century has seen increased public and research attention to engineering as a socio-technical field, requiring knowledge not only related to technical systems being designed to address a human problem, but also knowledge of social systems in which the designed technology will be implemented and of the interdependencies between the technical and social systems¹. This recognition is reflected across the K-12 Next Generation Science Standards² under the cross-cutting concept “Influence of Science, Engineering, and Technology on Society and the Natural World”, and specifically in at least two middle (MS) and high school (HS) Engineering, Technology and the Application of Science Standards (ETS):

- The uses of technologies and any limitations on their use are driven by individual or societal needs, desires, and values; by the findings of scientific research; and by differences in such factors as climate, natural resources, and economic conditions. Thus, technology use varies from region to region and over time (MS-ETS1-1).
- New technologies can have deep impacts on society and the environment, including some that were not anticipated. Analysis of costs and benefits is a critical aspect of decisions about technology (HS-ETS1-1 and 1-3).

Yet, helping youth understand the complexities of sociotechnical issues in engineering is no small feat, and teachers and researchers alike struggle to support students' understanding of the multiple and multi-faceted factors involved in implementing engineered solutions to address a human need or desire. Nonetheless, failing to do so at best limits students' understanding of engineering as a possible career path and, at worst, fosters misconceptions about the nature of engineering. Furthermore, treating engineering as a solely technical field may be particularly detrimental to students from underrepresented communities and to women, groups for which social concerns and community relationships are often of importance.

Despite significant effort on the part of the engineering community, engaging future engineers in ways that support their trajectories into engineering careers remains a substantial challenge for engineering education programs³. In particular, recruitment and retention of women and students from underrepresented minority populations have proven difficult to increase¹.

Recently, several scholars have laid the blame for engineering education programs' lack of attention to effectively sustaining engagement in engineering at the doorstep of outdated approaches to preparing engineers, in essence, the over-emphasis of technical problem solving³. Scholars who challenge the narrow coverage of discipline-focused technical concepts and the peripheral place of design experiences relative to structured problem solving^{4, 5, 6} urge educators to adopt approaches that honor diverse aspects of engineering, such as technical, organizational, and personal⁷.

This report details the design, implementation, and evaluation of a summer engineering research experience for high school students aimed at increasing underrepresented youth's engineering competence and furthering their trajectories along engineering pathways by building their socio-technical engineering knowledge through a community energy project. The five participants (two women, three men) were selected from a Title I school district to participate in a five-week

summer research experience for Youth Scholars program in a solar energy research center in the US. Students were mentored by the members of our research team, all of whom had varying interests in supporting the project: two educational scholars (Authors 1 and 2), a local middle school teacher (Author 3), an engineer/social scientist (Author 4), and a social analyst of technology (Authors 5). All five team members brought diverse expertise to bear on two community solar energy engineering projects through which the Youth Scholars framed their learning about socio-technical issues. Our ultimate goal was to remove barriers to participation, preparedness, and identity development for students from populations underrepresented in engineering. In the current study, we focus on the extent to which participants gained socio-technical engineering knowledge as they engaged in program activities, and we consider the implications for future such learning programs.

These Youth Scholars learned about photovoltaics, engineering, community engagement, and college success; (b) collaboratively designed a community solar engineering research project that contributes to a larger program of research; and (c) communicated about energy policy with neighborhood, city, state, and national stakeholders while exploring ways to advance community engagement in promoting clean energy policy and fostering the design and development of solar energy innovations at the community level. Specifically, we asked:

- What knowledge did the Youth Scholars gain about socio-technical aspects of engineering?
- How and to what extent did the Youth Scholars use concepts from a socio-technical model of energy innovation to think about, explain, and move forward their community solar energy project?

Theoretical Frameworks

Taking an Activist Stance

In response to the overemphasis on technical problem solving and single way of knowing and doing, scholars argue for approaches to engineering education that take an activist stance.^{8, 9, 10, 11} An activist stance is being posited as useful for engineering education because of the possibilities to (1) focus on “humanistic” aspects of engineering; (2) increase knowledge through participatory action learning; and (3) allow students to engage meaningfully in the futures of their communities. “Humanistic” engineering integrates the humanities and social science disciplines with the technical aspects of engineering, to highlight impacts of engineering designs on people and systems.^{13, 14, 15} Just as importantly, it may draw students into engineering who may not be attracted to traditional engineering education through its focus on meaningfully addressing community needs.

Beyond just incorporating engineering’s social aspects, however, other scholars argue that engineering education should counter “the culture of inaction or passivity”⁸ (p. 2) traditionally found in teaching and learning science. Citizen science approaches are one means by which scholars and educators are attempting to meet this goal. However, many citizen science approaches position “citizens” as data collectors rather than investing them deeply in identifying and addressing problems alongside engineers in ways that have positive effects on their community^{8, 16}. Stetsenko’s¹¹ transformative activist stance (TAS), building on Vygotsky’s insights from his community-based projects, suggested that “the process of knowing is

understood to be contingent on activist involvements in, and contributions to, collaborative transformative practices” (p. 108). In other words, actively and collaboratively *doing* engineering projects and practices can result in deeper *knowing* than passively learning information and processes in decontextualized settings. Further, Stetsenko¹² argues that activism provides a pathway for learners making “authentic-authorial contributions” to community practices and knowledge (p. 33). This meaningful engagement moves “beyond the status quo” to “enacting the future through agentive contributions to collaborative practices”¹¹ (p. 103). It allows students to do something good in the world through their activist stance.

Engineering as a Socio-technical Field

To take such a stance one needs socio-technical, not just technical, knowledge. The 21st century has seen increasing understanding of engineering as a socio-technical field in which practitioners must develop expertise in not only technical aspects of engineering design, but also in practicing social competencies of engineering. Moreover, they must become skilled at recognizing and navigating the interdependencies among the technical and social challenges of engineering. Although the technical aspects of engineering have been long recognized, only in recent decades have social skills such as empathy, communication, and collaborative teamwork in interdisciplinary teams come to the forefront of research and practice concerns.^{17,18,19} Alongside the integrative turn toward socio-technical approaches to engaging students in engineering is increasing interest in social justice perspectives on engineering and community engineering orientations the practice of the profession. Applying engineering processes to sustainability or humanitarian projects offer students opportunities for engaging directly with community stakeholders and for gaining familiarity with specific social contexts that shape local problems that are reflective of broader social challenges.^{20, 21, 22, 23}

At the pre-college level, similar turns have occurred in STEM learning more widely, e.g., Gutierrez’s²⁴ cultures of participation, and Ito’s²⁵ connected learning through “self-directed, passion-based projects”, and Barab’s²⁶ consequential engagement. There is a social justice element, as well, in youth guiding their own learning by intentionally creating an instructional space in which students participate actively as co-designers, shaping the learning system. As expressed by Fischer,

The future is not there to be discovered, it has to be invented and designed...If the world of working and living relies on collaboration, creativity, definition and framing of problems and if it requires dealing with uncertainty, change, and intelligence that is distributed across minds, cultures, disciplines, and tools - then education should foster competencies that prepare students for having meaningful and productive lives in such a world...²⁷

Energy innovation is one particularly interesting context in which to inspire and study youth’s local activism because it speaks to minority and low-income youth through the urgency brought about by global warming, because of the cost and equity issues involved, and because it is one of the grand challenges of engineering and the top global challenge according to the World Economic Forum. Thus, working on energy engineering projects for their own communities allows youth to contribute to addressing societal problems of great magnitude, while making a difference in their own community. In our research group, we are particularly interested in

investing youth in exploring solar energy solutions to these challenges because of the promise they hold for decarbonizing the global economy; addressing local and global inequalities by decreasing energy poverty; and improving other facets of electricity infrastructure in poor communities, such as resilience.

Examining Socio-technical Engineering Processes through the Social Value of Energy Model

Two of the team members from the project reported here are scholars actively pursuing a program of research into the development of community-based energy systems that enable communities to reduce poverty. They saw their research mentorship role in the Youth Scholar program as an opportunity to test their inner-city community energy projects model through a community-led, high school-led research exercise to explore how the model can be adapted and applied in a local low-income community in the southwest. Thus, mutual reciprocity was built into the project, thereby ensuring the commitment of mentors and mentees alike, both groups are already invested in aspects of the project through their own previous work.

The Social Value of Energy Model (SVEM) is a sophisticated, multi-layer model for evaluating and informing the design of energy projects designed specifically to address energy-exacerbated poverty^{28, 29, 30}. As shown in Figure 1, the model examines the multiple layers of social practice and technical design that must be successfully interwoven in order for energy projects to achieve significant creation of social value. It is intended as a tool to organize thinking about issues of social value, energy thriving, financing energy and development in communities, ownership models for energy innovation that encourage community development, local partnerships and cooperative structures for energy projects, and regulatory, policy, and legal challenges. Advocates, activists, innovation champions, and other stakeholders can interrogate how each level of the model fits their particular project and community, and how the model can be applied to inform further project design.

Figure 1. The Social Value of Energy Model (SVEM) is intended to guide inner-city community energy projects

The SVEM is guided in part by environmental justice scholars who argue that issues of energy, air and land pollution, and poverty are interrelated, especially in communities suffering from economic and environmental injustices^{31, 32}. For low-income communities, solar energy can be seen as a means of achieving more than just energy production and distribution by addressing

social and environmental issues for communities of lower socio-economic status. Designed appropriately, they can lower energy costs, create new revenue streams, and otherwise improve economic development. They can also redress other community challenges. Historically, communities of color have been excised from positions of political power and subject to systemic divestments in their communities, including access to equal and fair educational, housing, and employment opportunities³³. Cities across the nation are shaped by these historic injustices, which are evident in unequal exposure to environmental and human health hazards, such as water, air and ground pollution, as well as a lack of economic opportunities and investment in historic communities of color³⁴. Local solar projects that are community-driven, community-produced, and community-controlled can address some of these issues. More important than the technological possibilities is how engineering designers and community advocates – in our case, the Youth Scholars - understand the needs of their community. Making sure that their ideas align with the perceived needs of their community, across generations, economies, and cultures, is a critical part of addressing the systemic patterns of injustice that create unjust conditions in the first place.

Purpose

We aimed through the Youth Scholars program to involve youth from a Hispanic, low-SES neighborhood in research to evaluate the effectiveness, relevance, and adaptation of the model for inner city community energy projects. Through mentorship by a senior researcher and graduate student, we adopted as a program goal that the Youth Scholars would learn about not only solar energy engineering but also how to communicate about energy and policy with neighborhood, city, state, and national stakeholders. The project was expected to culminate in participants sharing the design of their community solar energy project and recommendations for further action with community and city leaders. The Youth Scholars also participated in design critique sessions with older summer cohort members, offering and receiving feedback on projects in progress³⁵, thus fostering engagement with ideas about community engineering and the design of innovations for sustainable energy futures beyond their own ideas.

While technological innovations may address immediate needs, the objective of the summer program was for the participating Youth Scholars to gain an understanding of why their community does not have the same access to such innovations as other local neighborhoods, as well as what kinds of policies and decision-making processes are in place that offer opportunities and create barriers to addressing community needs and wants. The Youth Scholars explored these issues through the SVEM, working with local and state stakeholders, as well as citizens in their own neighborhood.

Methods

Context and Participants

The context of this study was a summer research experience program at an engineering research center embedded in a university in the southwestern US. Within this context, a cadre of five incoming tenth-grade students (three identify as male, two identify as female boys; four Hispanic, all first-generation college-bound) participated as Youth Scholars, traveling to the university each day for five weeks. Two years prior, these youth scholars had completed eighth-

grade in one of two middle schools in a large urban Title I district serving a majority Hispanic student population (94% non-Caucasian; 93% low SES, 17% English language learners).

By way of contextualizing this study, we offer that at the end of their eighth-grade year, these Youth Scholars, along with other graduates of their two middle school alma maters, had been invited to the university campus to participate in a free, six-day solar energy engineering program based on their previous engagement in a school-based engineering program. Eleven students responded to this invitation. The majority of participants in the six-day program were Hispanic; half the cadre reported their primary home language as other-than English. The focus of this relatively short program was on technical knowledge; participants learned, for instance, about how a solar cell is manufactured, how a photovoltaic system works, and how electrons move through a solar module. The central activity of the six-day Youth Scholars program was designing a community solar energy engineering project. Facilitated by a local middle school science teacher, and supported by a cadre of graduate student mentors, the Youth Scholars framed a problem of mutual interest: a lack of solar energy in their low-income neighborhood. They designed a solar cooperative membership model for low-income renters; energy would be generated from solar-panel shade structures erected in area parks. The participants presented their project at the end-of-summer poster session, alongside other members of the diverse summer cohort, provide opportunities for scholars, faculty, and industry members to recognize youth as part of the engineering community.

The context of the current study was a five-week, full-time summer engineering research program to which only the five focal students, who had remained actively engaged in the project throughout the year, were invited during the summer following their freshman year of high school. This expanded program emphasized a socio-technical focus, making it a good match for the aims of this study, focused as it was on engaging minority youth in understanding and addressing socio-technical issues associated with energy engineering projects, an understudied area in K-12 engineering education. Again, the program took place on a university campus where the Youth Scholars were co-mentored by an expert eighth-grade science teacher with background knowledge in photovoltaics and solar energy engineering research, and by an engineer with expertise in sustainability and community solar energy projects. The Youth Scholars, all of whom had previous technical knowledge of photovoltaics and solar energy from a previous short six-day summer program, were introduced to socio-technical considerations through reflection on a multilayer design framework for social value creation through energy engineering. They also met with stakeholders associated with each aspect of the model, including members of their own community, city planners, energy service providers, and solar industry leaders. The Youth Scholars used the framework and their meetings with stakeholders to inform their collaborative design and presentation of a community solar energy engineering project for their own low-income community. Table 1 outlines the key program activities designed to help students gain socio-technical knowledge of engineering through their interaction with the SVPM model and their implementation of that model in their own community energy engineering project.

Table 1. Key Program Activities Related to Socio-Technical Knowledge

General	<ul style="list-style-type: none"> • Social Value of Energy Model (SVEM) introduction by one of the model's creators (May 31-June 1) • Students taught the model to other high school students in the program (June 1)
Social Value of Energy	<ul style="list-style-type: none"> • Discussion with one of the model's creators (May 31-June 1; July 23^a) • Discussion with a graduate student designing solar water heaters in Brazil (June 25-26)
Energy Services	<ul style="list-style-type: none"> • Solar energy campus tour – how the university generated and used solar energy (June 13)
Socio-Technical Systems	<ul style="list-style-type: none"> • Discussion with a member of an environmentally-focused local club (June 14)
Energy Enterprises	<ul style="list-style-type: none"> • Conversation with graduate student about standalone versus grid-tied systems (June 28-29) • Students identified all the people they would need help from to build and install, and maintain their project (ongoing)
Ownership, Reinvestment, and Extraction	<ul style="list-style-type: none"> • Students' original co-op project that aimed to keep money saved through using solar energy in the community (previous year through June 18) • Students' re-imagined solar pavilion project that aims to save local school money (June 19 – now) • Discussion with a solar electrician (July 23^a)
Policy and Governance	<ul style="list-style-type: none"> • Discussion about policy with a member of an environmentally-focused club (June 14) • Meeting at city hall to discuss policies and laws that would apply to their community project (June 18)

^a The Youth Scholars participated in the program from May 31-July 2, but returned for one day on July 23 to present their research poster and meet with various stakeholders.

All five authors, one research faculty member and one graduate student in education, one research faculty member and one graduate student in sustainability, and one highly-qualified middle school teacher, participated as facilitators in the program and also contributed to the program's design.

Data Sources and Data Analysis

Data collection took place throughout implementation of the summer program. Data sources included daily survey responses, audio-video recordings and ethnographic field notes of cohort members' participation in core activities, semi-structured interviews to elicit participants' perspectives³⁵ (20-30 minutes), and participant-generated artifacts (e.g., written feedback, project videos/posters). Primary evaluation measures included survey responses, transcribed interviews, focus group reflections, and written artifacts related to participants' engagement with socio-technical engineering knowledge. Observations of participants' engagement in the program, captured in audio-video recordings and field notes, were used as secondary data sources. Table 2 describes the primary data sources used to address both research questions.

Table 2. Data Sources Used to Address RQ1 and RQ2

	Written Communication about Project	Discursive Communication about Project
RQ 1: What knowledge did the Youth Scholars gain about socio-technical aspects of engineering? (operationalized through the SVEM)	Collective interrogation of the SVEM (pre-post)	Pre/post whole group reflective discussion: meta-talk about SVEM (pre-post)
RQ 2: How and to what extent did the Youth Scholars use concepts from the SVEM to think about, explain, and move forward their community solar energy project?	Written artifacts related to the project; i.e., research posters from three time points 1. End-of-summer 2017 (previous technology-focused program 2. Mid-2018 (focal) socio-technical program 3. End-of-summer 2018	Discursive data from formal poster presentations at three time points (includes participants' initial presentation "pitch" and subsequent discourse with audience members) Time points corresponded with poster time points

Data Analysis

Our interpretation of Youth Scholars' understanding and use of socio-technical knowledge to set their own engineering research agendas and move forward their activist work in their low-income community were informed largely through content analyses of the three primary data sources described above. Data analysis progressed through multiple rounds of reviewing the transcripts and examining key artifacts. First, working together, the research team developed a coding scheme based on the SVEM model (Figure 1), defining six coding categories (Table 3).

Table 3. Coding Scheme Derived from the SVEM

Category	Working Definition	Examples
1. Social Value of Energy	Energy is used to increase social value. Focus on end result for the user.	Increased status, benefits of being an energy consumer, costs of energy, risks/burdens of energy systems and energy use
2. Energy Services	The things that energy enables users to do (which then affect #1)	Delivery of services; lack of service = lack of status; light, heat, cool, cook, work, charge devices, access cold water
3. Socio-Technical Systems	Intimate relationship, symbiosis, between the users' actions and ALL that which goes into making #1 and #2 happen. Users engage in some oftentimes superficial action with the suite of tightly-integrated technical systems. Must be (person's action) + (energy service delivery)	Examples: 1. User plugs phone into outlet to charge, phone battery fills. 2. user turns on installed thermostat, house is cooled. 3. user pumps fuel, car makes it to school. 4. user goes to kiosk, pays bill, electricity is delivered, lights turn on. 5. driver hits a power line, power goes out, utility company send out a message, power line gets fixed, lights are back on, house is cooled again,
4. Energy Enterprises	The organizational systems and enterprises that work, often unbeknownst to the users, to make #3 possible	Energy system design, installation, operation, maintenance, expansion, supply chains, accounting systems, maintenance, workforce training, employment of the trained workers
5. Ownership, Reinvestment, and Extraction	How the energy system is financed, how money flows and to whom, and to what extent the energy system reinvests in local communities	Financial design, costs vs. risks, financial gain, investor interest. Create local jobs; catalyze and support local development (social and economic); bolster local businesses; profits remain local; resources remain local; local reinvestment.

6. Policy and Governance	The institutions that support energy system design (#1 and #5), as well as catalyze energy-based local social and economic development, through rules, laws, regulations, and incentives.	Support local ownership (see #5); appropriate incentives (avoid disincentives); appropriate regulatory frameworks and institutions; regulations, laws, rules, and guidelines; anticipate capacity and processes for SVES; design and contract for SVES; local decision-making; hold enterprises accountable for practices and outcomes.
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We first applied the coding scheme to the collective written interrogation of the model data and then to the subsequent whole group discussion at pre-and-post time points in order to address RQ1, and then to all remaining forms of data to address RQ2. The first three authors iteratively examined data individually and met for collective work sessions to compare and negotiate interpretations of observational and interview data, to analyze and interpret survey data, and to synthesize our understandings relative to project goals.

In our first pass through the data, we applied the coding scheme as we read through each data source looking for evidence that the students were engaging the constructs associated with each element of the model. In a second pass we clustered all of the coded material as pertaining to particular elements, looking across to identify patterns to how participants were engaging that particular element. After coding all the data and checking with the peer consultants, we conducted another round of coding. Looking closely at all the data to which each code was applied, we sought to identify themes within each coding category. Using constant comparative methods, we sought to determine patterns across data sources through multiple iterations of examination³⁶. The fourth and fifth authors acted as peer consultants, checking and helping to refine interpretations. Their disciplinary expertise was critical to refining and applying the coding scheme.

Findings

Quantitative and qualitative analyses provided evidence that the program successfully supported participants' socio-technical engineering knowledge, engineering identity development, increasing agency and ownership of their community energy project, and engineering communication practices, though to varying degrees. It also suggested potential programmatic changes and improvements to the existing social value model for guiding community energy projects. For instance, the Youth Scholars had difficulty differentiating between some layers of the social value model. Further, their community energy project might have avoided some pitfalls by considering policy and governance issues earlier in the design process.

Research Question 1: What did the Youth Scholars learn about engineering as a socio-technical endeavor?

Analysis related to Research Question 1 was concerned with how students were exhibiting knowledge (e.g., accurate conceptions or examples), lack of knowledge (e.g., misconceptions, questions), a direct application to their community energy project, or a focus on the technical side of engineering. Comparison of the Youth Scholar's pre-post data related to their interrogation of the SVEM model shows that these students gained new understandings of socio-technical aspects of engineering through their program experience. Table 4 shows the number of written responses in the *interrogate the model* activity that were coded as showcasing knowledge or lack of knowledge of engineering as a socio-technical endeavor.

Table 4. Responses to Interrogating the SVEM as a Measure of Socio-Technical Knowledge

Code	Pre	Post
Misconception	14	0
Accurate conception	2	29
Accurate example	0	6
Question admitting a lack of knowledge	9	0
Direct link to their project	2	4
Focus on the technological side	7	0
Total	34	40

Examining the data in terms of each element of the model (Table 5) prompts further insights about the Youth Scholars attention to and understanding of different aspects of engineering as a socio-technical endeavor.

Table 5. Responses Related to the Five Elements in the SVEM

Socio-Technical Code	Pre	Post	Example of Post-Administration Responses
Social value of Energy	0	2	What people can get out of the energy. i.e., a solar canopy will provide a place for social gathering etc.
Energy services	1	6	Heating/cooling is generated by energy to warm people up or cool them down (example) Tools that are powered by energy and used by people Services that use the energy that the use of energy gives, e.g., lightbulbs for light, cars for transportation.
Socio-technical systems	1	5	How the people and the technology go hand in hand
Energy enterprises	0	9	Energy enterprises operate and maintain their business of installing and designing energy projects
Ownership, reinvestment, and extraction	0	2	Ownership – making sure you are allowed to own certain things or share
Policy and governance	0	4	Draw an arrow from energy enterprises to policy & governance) and wrote, “depending on policies, enterprises can think of whether or not they should implement their energy systems”

The Youth Scholars’ initial conceptions of energy engineering projects displayed a focus on the technology side of the system. Their ideas were still dichotomous with the technology and social conceptions not being integrated or impacting each other. At the end of the program; however, this dichotomy was no longer evident in any of the students’ responses. During the whole group reflection, one student summarized their new understanding of the integrated socio-technical

nature of energy: “It's like people taking care of the technology while the technology takes care of them.”

The students initially demonstrated many misconceptions about socio-technical aspects of engineering relevant for implementing community engineering projects as represented in SVEM model (Figure 1). For example, as three of the students discussed social value, they decided it meant educating the public about energy and helping them care about it. Another student explained that energy's ability to power lights was an example of the social value of energy. At the end of the program, though, this same student reflected that the social value of the light is not just the light itself, but what the light allows people to do. For example, “the energy powers the light so you can hang out with your friends after dark.” The students' reflection about their understanding of the model at the end of the program did not include any misconceptions.

Finally, when first assessed on their understanding of the model, students asked many questions that demonstrated a lack of knowledge. In a conversation between three of the students about the term “extraction” on the model, they either asked direct questions seeking more knowledge or posited an idea in the form of a question:

Student 1: How is extraction related to energy enterprises? What is extraction?

Student 2: I put, “What is extraction?”

Student 1: If something goes wrong and you have to extract the problem?

Student 3: That's what it sounds like. It takes away from something?

After their participation in the program, students' responses reflected their knowledge and ability to explain and illustrate portions of the model. For example, one student explained the policy and governance part of the model by connecting it to their previous project of constructing shade structures in local parks:

You can't just put something somewhere just because you want to. Because you don't want to hurt people by what you're doing. That's why there's policy and government so you don't have people- get all your permits and stuff - so you know that before you put this no one's going to get hurt. It won't catch on fire or it won't explode.

This response demonstrated the students' understanding of the role of policy and governance within the model, but also demonstrates a consideration of the possible social and technical impacts of their design.

In the post assessment, the Youth Scholars' responses exhibited correct, but not always complete understanding of some elements of socio-technical issues as represented in the SVEM. Specifically, the students failed to identify or explain the specific kinds entities that comprise energy enterprises in either the written artifacts and the subsequent whole group reflection. Although they recognized the processes and functions of energy enterprises, they did not exhibit clarity about the components that typically (or atypically) have rights and responsibilities for designing, installing, maintaining, etc. energy systems. Finally, analysis identified evidence that Youth Scholars were making at least some linkages between the elements of the SVEM (See, for instance, the illustrative example for Policy & Governance in Table 5).

Research Question 2: How and to what extent did the Youth Scholars use concepts from the SVEM to think about, explain, and move forward their community solar energy project?

Research Questions 2 was addressed through analysis of artifacts and discourse associated with presentations the students at three time points across the program (one for a research conference held at the end of the previous summer's program, one for an engineering competition at the mid-point of the focal summer's program, and one for the end-of-program poster session that was the culminating program event. Across the three time points and for all data sources, we observed evidence of students' increasingly sophisticated understanding and ability to apply socio-technical knowledge in community energy projects aimed at actively creating positive change in these Youth Scholar's own low-income communities through their first project, a community solar energy cooperative, and their second project, the design of a solar pavilion to inspire underrepresented youth in their low-income neighborhood.

For the first presentation, delivered to an authentic engineering research and industry audience in the same way as for the other two presentations, both the poster and discourse data suggested that the Youth Scholars were considering all socio-technical elements represented in the SVEM, though only at low levels for four of the elements. For instance, only one *social value* was articulated in the poster, that the solar cooperative would save community members money. Likewise, the only *energy service* identified was that the solar panels would provide shade. Furthermore, few linkages were made between *energy services* and *social value*. For instance, the Youth Scholars failed to articulate the diverse *social value* that might come from having shade in parks (e.g., increased usability, opportunities for social bonding through park visits). In terms of the element of *socio-technical systems*, although there were few explicit references to the connections between social systems and technical systems in the solar coop design, either in the discourse or the poster, an image in the poster did infer such connection. A map was accompanied by the caption: "Here is a map of neighborhoods in our Phoenix area that have a small percent of solar usage", intimating a connection between neighborhood characteristics and the lack of energy services.

The SVEM element that was most elaborated in this first presentation was *ownership, reinvestment, and extraction*. Having created, administered, and analyzed a survey asking whether community members would prefer solar energy to be integrated in their community through privately owned rooftop installations, road signs and traffic signals, or a community solar co-op, the Youth Scholars included on their poster three bar charts depicting the results, exhibited their understanding that energy services can be owned privately, administered through government agencies, or owned collectively by the community. They also included a description of each level (Silver, Gold, Platinum) at which community members could "buy into" the solar co-op, though they did not include information about the energy services or social value that customers could expect as a result of their investment.

By mid-program, the Youth Scholars had improved in their articulation of socio-technical issues related to their community energy project, elaborating on most elements of the model. Noteworthy is the inferred agentive positioning of the Youth Scholars themselves as an *energy enterprise*, as designers of a community solar coop. Whereas in the first poster the group introduced themselves through a photograph of themselves walking through the university campus on which the summer program took place, in the second poster they introduced

themselves through three photographs depicting the group in action, conducting energy experiments and meeting with their undergraduate summer engineering research experience colleagues. Furthermore, the caption accompanying the first poster focused on the Youth Scholars as students with an idea: “We are high school students, each from different schools. We are the students who have a problem that might affect us in the future. The Solar Coop is the group with an idea!”. In contrast, the caption accompanying the second poster positioned the Youth Scholars as engineers and as contributors to an energy enterprise: “Assisting other engineers at the engineering research center, inspired to help our neighborhood get more affordable and clean energy.”

We noted that the Youth Scholar’s second research poster did not exhibit improvement in applying the element of *social value*; saving money was still the only social value identified. Instead of articulating specific *social value* their proposed project would bring to the local community in which they planned to implement it, the Youth Scholars described in their poster and through their discourse with audience members that the project would bring benefits to and avoid harm to the world in general. But such articulation of broad and vague goals does not exhibit a sophisticated understanding of social value creation through energy engineering. Furthermore, the Youth Scholars’ second poster exhibited a higher level of applied knowledge of *ownership, reinvestment, and extraction*, articulating ways that ownership of technologies shapes the design of a system. Finally, it also exhibited increased sophistication in considering *socio-technical systems*, explaining how the technology needed to take into account the need for people’s safety.

Finally, the Youth Scholars’ third presentation, showcasing their second project, a school solar pavilion to inspire underrepresented youth, exhibited application at high levels for four out of six elements of the SVEM. As an example, we offer that their poster identified and described no less than four different ways the solar pavilion would bring *social value* to the community for which it was intended (i.e., opportunities for career exploration, sustainability, promoting healthy habits, and encouraging students to be change makers). Moreover, through their elaboration on these social values, the Youth Scholars integrated information exhibiting an increase in the sophistication of their application of other SVEM elements, and in their ability to integrate their consideration of these elements. For instance, they included a specific example of how the *social value* of sustainability would be achieved through delivering a specific quantity of kilowatts of energy (*energy services*) through installation of a specific-sized system that interfaced in particular ways with customer’s needs (*socio-technical systems*). Additionally, through a design sketch accompanied by a description of the components of the solar pavilion design, the Youth Scholars exhibited an increasingly sophisticated understanding of *energy services*, distinguishing them clearly from *social value* for the first time in the dataset. Notably, references to *energy enterprises* and *ownership, reinvestment, and extraction* were missing from the third poster, although the students articulated elaborate understandings of the application of these elements in their discourse with audience members. Perhaps, when creating their poster, the Youth Scholars’ breakthrough in understanding of how to apply the concept of social value temporarily eclipsed their fragile understanding of these other socio-technical elements.

Note, that policy and governance issues were all but invisible in the three presentations across the program. They were, in fact, never explicitly referenced in any of the three posters (although the Youth Scholars did briefly discuss them in their discourse with audience members during the

third presentations). This is most surprising for the third presentation, which was created after a discussion with a city hall representative made the students aware of city policies that would interfere with the implementation of their first designed project.

Discussion and Implications

Findings from this study suggest that, as a group, the Youth Scholars left the summer research experience program with a more sophisticated understanding of engineering as a socio-technical field than when they entered the program. In particular, their experiences in the program led them to a clearer distinction between social value and energy services, and an ability to clearly articulate social values that community solar energy projects could bring to their families, neighbors, and community. Our evidence for this claim is that they applied it in their posters, lab meetings, and post-pitch more than the pre-pitch. They learned to consider their customers' needs, rather than just design what they thought would be cool. This is valuable for youth, who, developmentally, struggle to move beyond themselves and their own needs - this is part of their developmental challenge³⁷.

We intentionally structured the summer program around the SVEM to help Youth Scholars increase their socio-technical knowledge as they continued to work on a community solar energy project for their shared low-income community. Thus, activities and specific speakers the students engaged with on a particular day or week centered on increasing students' knowledge of one or two specific aspects of the SVEM. Considering this structure and model in terms of the findings presented, we focus this discussion on two main take-aways.

First, students' socio-technical knowledge did increase from the beginning to the end of the program, especially as that knowledge was connected with their activist work on a community project. Second, we as mentors and program facilitators should have been more explicit in making connections between the activities, stakeholders, and specific socio-technical components (as represented in the SVEM). This group's knowledge about socio-technical aspects of engineering increased during their participation in the summer program. Their activist involvement in trying to design and enact a solar project that would benefit their community was central to their increased knowledge. For example, in her notes about a speaker's presentation, one of the students explained that the purpose of the students' project had remained the same even when they had to redesign their project. Their goal was "to bring solar into our community. We have this goal because it could help the comfort, health, and income of the community." They wanted to create positive change within their own community through the new knowledge they were gaining, and their knowledge and understanding increased as they engaged in meaningful action for their community.

In their community-centered project work, the students especially demonstrated a focus on social value. They learned to consider stakeholders' needs rather than just what they believed would be a "cool" project to implement. This was evident in the posters they created and in their discussions with other program participants during weekly lab meetings. Further, their final pitch of their new solar pavilion project included more of a focus on the project's social value than their pitches on their previous community solar project, even though they had been working on it for a much shorter time. This outward focus on social value is valuable for youth, who,

developmentally, struggle to move beyond themselves and their own needs - this is part of their developmental challenge, according to Erickson's model of identity development³⁷.

However, we also noticed that the students tended to also mislabel other aspects of socio-technical energy systems as social value as well. We believe this is related to the fact that the students only had contact with their engineering mentor for 3-4 days during the program because of other commitments he had. The teacher-facilitator who worked with the students each day, only had as much training as the students did, so they were figuring the work out together. So, while the students generally discussed and engaged ideas about energy systems, socio-technical knowledge, engineering enterprises, and other aspects of the SVEM model correctly, they were not always familiar enough with the terms to label their ideas correctly. They chose instead to use the general label of "social value," perhaps because it was included in the name of the model they were using. In future iterations of the program, we plan to make more explicit effort to help students recognize differences between various aspects of socio-technical knowledge, as represented on the SVEM model, and to use those labels in their discussions and presentations to help others understand the various aspects that must be considered in a project targeting increased social value.

Findings also suggest potential programmatic changes and improvements to the existing social value model for guiding community energy projects. For instance, the Youth Scholars had difficulty differentiating between some layers of the social value model. Further, their community energy project might have avoided some pitfalls by considering policy and governance issues earlier in the design process.

Limitations and Future Directions

As the findings from this study were based largely on data collected at the group level, future analysis needs to closely examine the learning trajectories of each participant in the program. Furthermore, although our analysis provided evidence that the program successfully supported participants' understanding of engineering as a socio-technical endeavor and their ability to apply that knowledge to a community energy engineering project through which they themselves were committed to making a positive difference in their community. Much work is left to interrogate the influence of the Youth Scholar program on participants' engineering identity development, agency and ownership of their community energy project, and engineering communication practices.

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