How Educators Implement Engineering Curricula in OST Settings (Fundamental)

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How Educators Implement Engineering Curricula in OST Settings

Recent education policy documents call for a renewed emphasis on engineering as a critical practice for student learning in PK-12 settings [1], [2]. Engineering entails specific propositional and procedural knowledge, which Cunningham & Kelly [3] argue are core engineering practices that youth must understand as a part of authentic, inclusive, and equitable engineering learning experiences. Providing youth opportunities for engineering during the regular school day, however, can be challenging due to time and other curricular constraints.

Due to these constraints, out-of-school time (OST) programs have been identified as optimal for science and engineering learning. There is more flexibility than the traditional school setting and more time for exploration and decision making [4], [5], both critical for authentic STEM learning. Programs in these informal OST environments, such as afterschool clubs and camps, often place a high value on 21st century skills and youth development, including fostering teamwork, community building, and creativity, which are important attributes for STEM learning. OST programs serve significant populations of youth underrepresented in science and engineering fields, and thus may be able to reduce the opportunity gap for these youth in STEM fields. Quality OST STEM experiences lead to gains in youth attitudes towards STEM, including increasing interest, identity, and career aspirations, gains in 21st century skills, and possible learning gains [6], [7]. Leveraging these environments requires curricula that are appropriate for the OST setting. Such curricula can engage learners, respond to their backgrounds and interests, and connect with home and communities [8]. High-quality OST engineering curricula thus can enhance youth learning and engagement, and are important tools for OST educators. Recently, engineering curricula have been developed specifically for the OST community. To engage all learners, it is important that engineering curricula provide opportunities for youth to actively engage in the practices of engineering, to see relevancy, to collaborate, and to have opportunities to develop a sense of agency, expertise, and ownership [9].

Educators play a critical role in implementing curriculum and supporting youth learning and development in OST environments. Educators in OST settings come from a variety of backgrounds, with a range of teaching experiences and understandings of engineering. They may or may not have the background to facilitate STEM learning in these environments. In practice, educators' instructional decisions shape the enactment of OST curriculum in specific contexts and for specific learners [10]. OST educators also may have different goals or objectives than teachers in the school environment. These educators are critical in shaping effective STEM learning for girls [11], [12] and underserved populations [13]. Together, educators and curricula can inspire learning in youth, through supporting curiosity and sense making, without offering too much guidance [14].

While a large body of research examines curriculum implementation in school-based STEM [15], less is known about how OST educators make sense of and implement curriculum with an engineering focus. To understand the effect of participation in engineering curricula on youth, it is critical to understand how educators enact curricula in OST contexts. This study examines how two planetary science-based engineering units were enacted in four OST middle school settings. It is part of a larger grant-funded effort to create curricula for OST settings that integrate planetary science and engineering, and to design associated professional development

(PD) for OST educators. Findings will inform researchers, curricula developers, and professional developers as they seek to understand and support positive youth learning and development in OST environments.

Conceptual Framework

Research perspectives on educators' implementation of curricula have developed from an initial focus solely on fidelity to the curriculum [16], to perspectives that acknowledge educators as professionals who continually adjust curriculum during enactment based on a complex interplay of their prior experiences, subject matter knowledge, the specific contexts of their program settings, and students' needs [10], [17]. Less is known about curricular enactment in OST settings. To analyze OST educators' implementation of the study curriculum, we adapted a conceptual framework from Penuel, Phillips & Harris [18] for examining educators' implementation and reasoning. These researchers studied the differences between curricular design and enactment of two elementary school science teachers with two contrasting lenses: integrity of implementation, and an actor-oriented perspective. An integrity perspective is defined as congruency between educators' adaptations of materials, and curricular goals and principles designed into the curricula. This shifts the focus of implementation from exact replication (fidelity), to *integrity:* enactment that meets the learning goals of the curricula and enables students to achieve intended outcomes. The researchers then analyzed enactment with an actor-oriented perspective to understand educators' learning goals, decisions about what to implement or adapt from a unit, and reasoning for implementing in these ways.

We used these two lenses to examine how a sample of educators enacted the OST engineering curricula. We asked: 1) How did educators implement OST curricula? 2) To what extent did they implement the curriculum with integrity? and 3) Why did they make the curricular decisions and modifications they did?

Methods

We used a multiple-case study approach [19] to examine integrity of implementation and actor-oriented perspectives of four educators as they facilitated an engineering design curriculum with youth in their middle-grade OST programs. Below we first describe the project and each of the two units used in the study, followed by a description of the settings and participant demographics.

Project and curricula

The research is part of a larger, NASA-funded project, with the goal to develop and disseminate multiple upper elementary and middle-school engineering units focused on the challenges of space exploration and planetary science. The curriculum engages youth in authentic engineering design tasks in the context of planetary science and space exploration. Concurrently, the project is creating multi-tiered professional development for OST educators as well as complementary planetary science lessons. The development is being supported by extensive field testing, materials design, and a research program, of which this study is a part. The curriculum units foster opportunities for middle-school children in OST settings to become

engineers and solve problems that are identified as "*personally meaningful and globally relevant*" [20]. Each unit has been developed to include fourteen Curricular Design Principles for Inclusivity [21], identified through previous research studies to support student learning, in four overarching categories: *Set learning in a real-world context*, *present design challenges that are authentic to engineering practice*, *scaffold student work*, and *demonstrate that everyone can engineer*. The Curricular Design Principles are detailed under Findings in Table 3.

There were two middle school units enacted in this study. One focused on the challenge of conserving, filtering, and reusing water in extreme environments, and the other challenged students to learn about and design multiple remote sensing technologies, and then to use those technologies to explore a model "mystery moon." Each unit consists of eight one-hour, sequenced activities. Throughout each unit, youth are introduced to engineering practices and habits of mind through an Engineering Design Process (EDP), which they use as a guide while working in small groups to design a solution to an engineering challenge. The EDP begins with *identifying* a problem that needs to be solved and *investigating* what has already been done. Next, engineers *imagine* different solutions and *plan* their designs. Then, they *create* and *test* their designs and make *improvements* based on the test results. Finally, engineers *communicate* their findings to others. Youth learn that these practices are frequently used non-sequentially during the process of engineering design. While focusing on engineering design, youth experience age-appropriate science content, emphasizing planetary science.

Study context

The study took place in four OST programs for middle-school students (grades 6-8) across the U.S. Three programs were afterschool clubs and one was a week-long summer camp sponsored by a community group. The programs were purposively selected using the following criteria: educators and a majority of youth were willing to be part of a research study; programs were willing to implement the curricula during the spring of 2018; and youth in the programs represented a diversity of learners from different backgrounds, cultures, socioeconomic status, and grade levels within middle school. Educators received all curricular materials required for unit implementation. Each of the units was implemented by two educators in different settings.

Study participants

Four educators taught one of the two units in their local OST programs, two in the rural southwest and two in the urban northeast (Table 1). Each educator had prior experience pilot-testing similar units. Fifty-two middle-school youth were participants in the OST programs. The demographics of the 52 youth participants are detailed by program in Table 2. The following sections describe each educator's background and experience.

Program 1 Educator: This educator was a young male of Hispanic heritage who worked as an OST educator in a community organization in the rural Southwest. He had 10 years of experience working with youth, two years in an OST program with youth grades K-8, and had no formal training in education. He had completed a number of college-level STEM courses. He taught related engineering curricula for two years, and participated in professional development (PD) related to the current curricular program. Much of his experience in OST programs was

working with ethnically and racially diverse youth of low socio-economic status (SES). The OST program was a week-long half-day summer camp. Attendees were youth the educator had worked with previously in a community program, as well as youth who responded to an advertisement for free participation in the week-long engineering summer camp. A number of the youth were new to the educator and to each other. Youth were a combination of boys and girls, from groups underrepresented in STEM fields and from majority groups, and from low socio-economic and middle class families.

Program 2 Educator: This educator was a female of American Indian heritage who was an experienced middle-grade classroom teacher in a Title 1 public school on American Indian tribal land. She was a long-time teacher and had also worked in an OST setting for two years. She completed a number of science and engineering classes at the college level and also worked for a few years in a STEM profession. Her PD experiences included multiple days related to this curricula and on STEM curricula in general. She taught related engineering curricula with students for one year prior to the study. The OST program was an afterschool club made up of youth from her current mathematics class at the school. The club met approximately twice a week for 10 weeks, with a two-week hiatus due to external circumstances. All youth in the club were from underrepresented groups in STEM. The majority of youth were girls, and a significant percentage were from low SES families.

Program 3 Educator: This female educator identified as White and was an experienced classroom teacher at a school in an urban area in the Northeast. She completed a few science or engineering courses at the college level as well as two or three days of PD. She had taught science or engineering at the middle school level for approximately 5 years, and had piloted a previous version of the OST engineering curriculum. The OST program was an afterschool club held twice a week for four weeks. Some of the youth were her current students. All youth were from majority groups and few were from low SES families.

Program 4 Educator: This female educator identified as White, and was a former classroom teacher and currently the STEM specialist for her small urban school district. She completed a few science or engineering courses at the college level but had significant PD in science or engineering. She was very experienced teaching middle grade youth and had taught this unit previously in the pilot stage. The OST program was structured as an afterschool club. Most youth were from majority groups in STEM with some from low SES families.

Table 1: Educator and program information

Program	Curricula taught	Program type	Formal teaching experience	Experience teaching this engineering curricula	Participation in engineering PD
1	Water reuse	Summer camp	No	Some	Some
2	Remote sensing	Afterschool club	Yes	Some	Some
3	Water reuse	Afterschool club	Yes	Some	Some
4	Remote sensing	Afterschool club	Yes	Significant	Significant

Table 2: Youth demographics by program

Program	Number of Attendees[1]	Grade level	URM[2] in STEM	Gender
1	17	6th-8th	5 (41%)	59% M/ 41% F
2	15	6th	15 (100%)	33% M/ 67% F
3	10	6th-8th	0	50% M/ 50% F
4	10	6th-8th	2 (20%)	60% M/ 40% F
Total	*52*	*6th-8th*	*22 (42%)*	*50% M/ 50% F*

[1]*Defined as attending 1 or more out of 8 activities*
[2]*Underrepresented minority*

Data sources and collection

Data sources included: 1) Personal background surveys, 2) OST program information completed by each educator before the end of unit implementation, 3) Online implementation forms completed by each educator after teaching each activity, 4) Researcher observations of each activity that were video-recorded and transcribed, and 5) Interviews conducted at the end of the unit with educators that were audio-recorded and transcribed. Data related to integrity of implementation included observations and transcriptions from videotape of educators' talk and action during instruction. Data related to the actor-oriented perspective included educator implementation forms and post-unit educator interviews.

Analysis

Data related to integrity of implementation were analyzed using descriptive statistics, and data related to an actor oriented perspective were analyzed using inductive methods of qualitative analysis. Two researchers analyzed integrity of implementation, and two others analyzed the actor-oriented perspectives. The researchers who analyzed integrity of implementation compared their interpretations of the rubric, definitions of the design principles in each activity, and their ratings to achieve interrater reliability.

Analysis for integrity of implementation

The research team modified Heck, Chval, Weiss & Ziebarth's fidelity of implementation framework [22] to formulate a rubric of integrity of implementation, including what educators taught, and what they modified, or skipped, in curricular activities. As per Penuel et al. [18], integrity of implementation was defined as "*the degree to which teachers' adaptions are congruent with the goals and principles undergirding the structures of the curricula*" (p. 2). Two researchers analyzed educator transcripts (and in some instances, the original video) for three dimensions of integrity:

- *Enactment integrity,* defined as both enactment that supported youth understanding of the lesson purpose/key takeaways of the unit, and enactment that was aligned with the curricular design principles. For enactment of design principles, researchers first identified the principles that were purposefully designed into each activity by the curriculum developers. Next, for each design principle present in the activity, researchers identified episodes of enactment aligned with the principle (Table 3). For enactment of activities to support lesson purpose and learning goals, researchers quantified the extent the educator

introduced the activity purpose to the youth and the extent the educator discussed the key takeaways with the youth on a three-level scale of (0) absent, (1) present to some degree and (2) explicitly referenced (Tables 4-7).

- *Logistic integrity* was defined as following the guide and the timing of the activities within the unit. Non-implementation (0), partial implementation (1) or complete implementation (2) of activities were identified and quantified (Tables 4-7).

- *Quality of pedagogy* was defined as the extent to which the educator used research-based strategies that supported youth learning (e.g., discourse moves, use of questioning strategies, wait time, responsiveness). Quality of pedagogy was identified and quantified on a three-level scale of (1) inadequate, (2) adequate, and (3) high quality (Tables 4-7).

Analysis for actor-oriented perspectives

Two researchers coded educator implementation forms and end-of-unit interviews to understand educators' perspectives on the unit, what they perceived they enacted or modified from the unit, and their reasons for making changes. The researchers consulted to confirm code definitions and data examples. Analytic induction was used for data analysis, with preliminary codes confirmed or refuted and developed into themes [23].

Results

Table 3 below summarizes the total scores for each educator's enactment of the curricular design principles that were written into the curriculum. Not all design principles were included in each activity. Rubric scores for each educator were given only if a design principle was present. Following Table 3, a case study is presented for each educator using both lenses of analysis.

Table 3: Educators' enactment of design principles during implementation

Design Principle	Enactment across unit (%)			
	Educator 1	Educator 2	Educator 3	Educator 4
Use narratives to develop and motivate students' understanding of engineering's place in the world.	57	100	57	67
Demonstrate how engineers help people, animals, the environment, or society.	25	100	63	100
Provide role models with a range of demographic characteristics.	0	100	0	100
Ensure that design challenges are truly open ended, with more than one "correct" answer.	100	100	100	100
Value failure for what it teaches.	50	100	80	67
Produce design challenges that can be evaluated with both qualitative and quantitative measures.	83	100	83	100
Cultivate collaboration and teamwork.	88	100	88	100
Engage students in active, hands-on, inquiry based engineering.	83	100	83	100
Model and make explicit the practices of engineering.	75	100	75	88
Assume no previous familiarity with materials, tasks, or terminology.	100	100	33	100
Support the needs and abilities of different kinds of learners.	100	100	0	100
Cultivate learning environments in which all students' ideas and contributions have value.	75	100	63	100
Foster students' agency as engineers.	71	100	57	86
Develop challenges that require low-cost, readily available materials.	N/A[1]			

[1] Not applicable in this study, as educators were provided materials.

Integrity of implementation analysis

Educator 1 implements many of the principles curricula developers designed into the activity, but not all (Table 3). For instance, he often skips opportunities to describe how engineers help solve real-world problems. His pattern of implementation is to introduce the activity purpose or design challenge to youth, elicit their ideas and experiences related to the topic, briefly review the logistics of the activity, and then set youth to work. At times, he does not emphasize the lesson purpose (Table 4). Most groups work well independently. While groups work, he circulates from table to table, asking questions to check for understanding or to push their thinking. A few groups are less independent, and at times he becomes more directive and does more of the thinking for them, particularly with youth he has worked with previously.

During the activities, the educator consistently encourages youth to have fun, to engage with the activity, and to learn through investigating properties of materials, persisting, and learning from failure. The educator maintains an attitude of humor, positivity, and encouragement for all youth throughout the week. When questioning, he typically accepts all answers, whether correct or not.

Logistically, the educator follows the guide sequence in general but often limits time for sense making or reflection. For instance, he frequently minimizes or skips sections of the activities that require whole group discussion, writing, or reflection; thus each activity runs about 15 to 20 minutes under the suggested time. He infrequently emphasizes the activity's purpose with the whole group (Table 4). His use of questioning strategies with the small groups appears to support development of engineering habits of mind and sense making. The educator often uses quality pedagogical strategies that support youth, such as open-ended questioning (Table 4). Overall the educator facilitates a youth-directed experience that foregrounds completing the activities and learning through interaction with the materials.

The youth clearly are engaged. During the culminating Showcase, in which groups present their findings, many youth describe designing filters that meet the criteria for their selected extreme environment (to transform waste water into grey water, and in one case to "*almost pure*"). Most groups indicate that they understood that the purpose of filtering water was to improve water quality and about half the groups mention using at least one of the three indicators (color, clarity, and pH) as evidence that their filter improved their sample. During the Showcase, many youth are vocal presenters, identifying that they are engineers solving a technology problem, and have assumed identities as budding engineers. Youth appear to have used the EDP and some engineering habits of mind successfully.

Table 4: Integrity analysis of Educator 1 during unit implementation

Logistic integrity (of 8 activities)			Enactment integrity: Introduction of lesson purpose and discussed key takeaways[1]	Quality of pedagogy[2]
Non-implementation	Partial implementation	Complete implementation		
0	7	1	1.2	1.9

[1] Average rating on scale: 0=did not introduce, 1=somewhat introduced, 2=completely introduced
[2] Average rating on scale: 1=low quality, 2=moderate quality, 3=high quality

Actor-oriented analysis

In the end-of-unit interview, Educator 1 describes that he had been looking for challenges and leadership opportunities for teens when he was asked to participate in the program. From previous experience working with youth, he knows it is important to "*let them take ownership,*" and he thinks the engineering curricula provides such decision-making opportunities. He appreciates that the curriculum provides engineering design challenges that are attainable for many of the youth, but also that it continues to push the older youth, through modifications such as the addition of a budget during the *improve* step of the Engineering Design Process. He has thought a lot about how he can engage older youth, both through being high energy and showing interest in the topic. He identifies a personal interest in the topic of water quality, which he feels

makes it easier to garner youth interest and help them make personal connections. He comments, *"I think it was a good topic to focus on…water reuse and filtration and stuff like that. I felt it was relevant to where we live, in the desert… and it's something that the kids can relate to every day."* He describes how he worked to connect the unit to their lives:

> While they had all these intense environments they were testing for, the surface of Mars and a floating research lab, I tried to just get them to think about water quality in their own home, especially [for] some of them [who] grew up in lower income neighborhoods like I did. It's just one of those things …you grow up hearing, 'Don't drink water from the tap, unless you [filter water].'

His own purposes in facilitating the unit for youth development are evident by his relaxed implementation and interaction style, and the way he provides opportunities for youth to be challenged and to direct their own learning. For instance, one of the few modifications he identifies in implementation is when he allows youth to add their own constraints to the piping activity, which he calls the *"No Filter Challenge"* and the *"No Crossing Pipes Challenge,"* and allowing them to be creative in filtering the water for appropriate uses. He feels that providing freedom for exploration is critical:

> I tried to give them as much freedom as possible, because I feel like with this age range, they learn most of it on their own…With [the] example of mixing (adding detergent to something that was too acidic) [to make it more basic], I don't think that would have happened had I not given them that much freedom to experiment with their filter types.

Educator 2

Educator 2 implemented the remote sensing curriculum unit in an afterschool program at her school. As their classroom teacher, Educator 2 is very familiar with youth, and she runs afterschool enrichment. She is very busy after school, with wrapping up school day business, bus duty, and setting up snacks. She often has little time to prepare for the day's OST activity, and has received extensive support from others for material preparation. In the interview she identifies that her preparation strategy was to skim the Educator Guide before starting and to highlight key points with youth.

Integrity of implementation

This educator's implementation is aligned with principles designed into the curricula (Table 3). Particularly striking is her fostering of youth agency as engineers. She frequently refers to youth as engineers or engineering teams, announces that a sibling of a participating youth has recently graduated with a degree in engineering, and makes a point of identifying the level of education that is required to become an engineer.

The educator frequently frames the activity's big picture, and then jumps right in, at times without complete explanation of the activity logistics or purpose (Table 5). As younger middle-graders, youth in this program often struggle with the science content underlying the unit, such as understanding color filters and LiDAR. She works hard to make sure youth understand what

they are doing, and uses a range of pedagogical strategies, such as sequenced questioning and connecting content to everyday life, modifying several activities in order to do so (Table 5). Because the afterschool schedule allows for 90 minutes for the club (rather than the typical 50 minutes), she often extends the activities. Her pedagogical strategy is strong (Table 5), including sustained questioning and eliciting ideas from individuals and table teams, and through whole group discussions. She actively works to make connections to the daily life of youth and the community, and uses examples she thinks the youth will understand. At times she deemphasizes important steps in the Engineering Design Process. For instance, she treats Activity 5, which emphasizes that engineers continually strive to improve their designs, as an extension of the prior activity, in which youth construct their first design, and spends little time discussing the importance or purpose of improving (Table 5).

Educator 2 uses multiple pedagogical strategies to elicit youths' ideas and to publicly recognize youth who offer creative ideas, different perspectives, or new solutions to the design challenges. While some youth are more engaged than others, this educator ensures all are held accountable for working together and communicating within their teams. She uses positive recognition and brings her own enthusiasm and wonder into the group discussions.

Table 5: Integrity analysis of Educator 2 during unit implementation

Logistic integrity (of 8 activities)			Enactment integrity: Introduction of lesson purpose and discussed key takeaways[1]	Quality of pedagogy[2]
Non-implementation	Partial implementation	Complete implementation		
0	6	2	1.2	2.3

[1] Average rating on scale: 0=did not introduce, 1=somewhat introduced, 2=completely introduced
[2] Average rating on scale: 1=low quality, 2=moderate quality, 3=high quality

Actor-oriented analysis

This educator has previously taught a related unit and likes the curricular approach. She notes that the environment at the school is very traditional, with a scripted curriculum, a focus on meeting certain standards within a set timeline, and on students passing tests through memorization. Thus her stated goal for youth participation in the engineering program is to offer something afterschool that will allow more freedom for her students to explore and use their hands. When she heard about the topic of planetary science, she thought it would be exciting for them to learn. She expresses a desire to make the experience different from the regular school day. She describes making modifications in her implementation, when she feels the atmosphere getting too "*school-like*" and perceives youth energy waning. For instance, she explains that she tried not to talk too much at the beginning of the activity to get them started with the activity as quickly as possible. She notes more than once that the curricula allows for "*freedom*" and "*leeway*" for youth to explore ideas, and that she does not have to "*spoon feed*" correct answers to meet curricular deadlines as in the traditional school day.

The educator is very focused on the youth reaching the goal of the activity and experiencing success. At times, she adjusts the activity to make sure they "*get it*", or when they

struggle with the materials, such as when the activity calls for using colored filters to see hidden data:

> It didn't work exactly the way… not exactly... the kids weren't seeing it. I had to improvise a bit with it. I think I ended up doing word searches. So I made one... I put [the name of the school mascot] and put [the letters] in the right color, whatever color was supposed to pop out, and then I put the filter up for them to see: 'Look now you only see the A.'

She works to foster teamwork and effective communication, by asking questions and encouraging them to share their ideas. She comments on how she sees youth talking to one another and collaborating on solving problems more than they typically have opportunities to do so during the regular school day:

> [I] saw a lot of dialogue, and that's what I was proud of them for. They did it naturally. It was just something that just came with what they were doing. It wasn't something that had to be forced…For the most part, they really worked as a group, as a team, which is something that I was really proud to see them doing.

She describes seeing youth learning, particularly in their understanding of the EDP, which by the end of the unit, they were able to identify more steps and describe it as a cycle:

> I asked, 'What did we do today?' Whereas at the beginning, I think they were only mentioning one or two [steps of the EDP] but at the end, they added more to the design process and they saw it more as a cyclical process rather than just 'We're done.'

She also recognizes growth in their engineering habits of mind, particularly persistence:

> [When] they were trying to get the topography of part of the site I was really surprised at the energy level. I thought by the second session, they would be... 'Oh, I'm done, I'm finished, not going to do anymore.' But they were still trying to improve it... So I had to give them a [time] limit because it was already time to go, and they were still trying to go back and do it again to try to get better.

The educator works to make connections to careers and opportunities for the youth, and she starts referring to them as "*engineers*." She explains how professionals speak to one another and collaborate. She sees some had started to dress up on the days of the club and act more responsibly. She describes how her students who typically act up a bit in class and are not the typical high achievers, start to shine in this OST environment, being creative, responsible and "*thinking outside the box,*" and she encourages these youth further.

Educator 3

This educator is an experienced classroom teacher of some of the attendees in the afterschool program and is familiar with the youth. She is well prepared during every activity, and runs a very structured, well-managed environment, in spite of the amount of messy materials in the *water reuse* unit.

Integrity of implementation

This educator's implementation primarily follows the sequence for each lesson (Table 6). She holds the Educator Guide and often reads from it directly. Early on in the unit, she is focused on the logistics of doing the activity correctly, and at times does not stress the larger conceptual storyline of the unit (needing to engineer a process to reuse water). She implements much of the guide as written, (Table 6). She infrequently emphasizes engineering practices or habits of mind during the activity, but reviews the Engineering Design Process (EDP) with youth at the end of each activity. At times, she switches her reference between science and engineering, sometimes in the same sentence. At one point she refers to the EDP as "*the engineering scientific method.*"

The pedagogical style of this educator is often didactic (Table 6), which may be an artifact of the presence of multiple researchers and video cameras. She does most of the talking when working with the whole group. When youth are working on design tasks in small groups, she asks directed questions and ensures youth are following correct procedures. For most questioning the educator follows the IRE (initiation, response, evaluation) form of classroom discourse [24]. She asks some open-ended questions, but when youth give a response that is not what she expects, at times she corrects them.

The educator's relationship with the youth is respectful and kind. By Activity 5, it appears most groups have ceded agency to one youth in their group who makes the decisions and controls the materials. By the time of the last two activities the educator increasingly reminds youth to be engaged and stay on task.

As the unit draws to a close the educator instructs youth to "*show what worked and how you did it*" to parents in the upcoming Showcase.

Table 6: Integrity analysis of Educator 3 during unit implementation

Logistic integrity (of 8 activities)			Enactment integrity: Introduction of lesson purpose and discussed key takeaways[1]	Quality of pedagogy[2]
Non-implementation	Partial implementation	Complete implementation		
0	4	4	1.2	1.6

[1] Average rating on scale: 0=did not introduce, 1=somewhat introduced, 2=completely introduced
[2] Average rating on scale: 1=low quality, 2=moderate quality, 3=high quality

Actor-oriented analysis

The educator likes the opportunities provided by the curricula because she finds it important for youth to engage in hands-on learning. She feels they learn about persistence and learn that there is often more than one right answer. Her goal for implementing the curriculum is to enrich the youth and expose them to new opportunities. She describes that she had never taught this engineering unit before, so she was nervous at the start. But she gains confidence over time and feels she has let their experience "*be sort of organic and grow on its own.*" She described that an educator has to be comfortable with "*controlled chaos*" and have a different

teaching style than in typical instruction. She describes "*I think that it's really important that you have to try not to do it for them, and I think that that has become easier and easier for me.*" She feels that both the teacher and the youth have to learn different roles. "*You have to let go of the: 'I'm the teacher and I have the answers.'*" She appreciates that OST provides longer stretches of time to engage in activities than in the classroom, but also identifies attendance challenges because there is a different level of commitment by the youth and parents. Overall, despite the extra work at the end of the school day, she sees that the youth are getting something out of it, so it is worth it to her. In particular, with youth who have already participated in an engineering unit previously, she sees in their presentations that the youth are able to "*synthesize their knowledge.*" She is particularly pleased that they are still talking and working on improving their model water towers (from the first pre-activity), weeks later.

> It was really important to them and so I don't think they saw [towers that did not hold up] as a failure, I think they did really take it as a learning experience. "Okay, what have I learned and how can I fix it next time?" So they've learned that part, the improvement step, they've learned pretty well, which I think is pretty exciting as a teacher.

While part of an OST experience, she identifies that youth developed confidence and control over their learning, which she feels will carry over into the classroom.

Educator 4

Educator 4 is the school's STEM coordinator, and is very experienced with teaching engineering curricula. Because she does not feel confident in her knowledge of the content area, Educator 4 prepares by researching the topic of LiDAR, a new technology for her. She implements the program in an afterschool setting very close to the end of the school year. Due to competing spring sports, youth attendance is inconsistent. The educator had to combine the final two one-hour activities into one due to attendance constraints.

Many of the youth are 8th graders, and have participated in engineering curricula for at least two years. The educator knows them well and has an easy and playful rapport with them. Youth appear to enjoy the challenge of the activities and many are vocal and engaged.

Integrity of implementation

This educator enacts many curricular design principles (Table 3). At the beginning of the unit she reminds youth about the iterative nature of engineering design and the importance of improving on one's design:

> A really important thing… is that you're not going to be successful on your first try…After you test, where are you going to have to go to? Improve and then you're going to have to do what again? You're going to have to test again. And chances are really good that you're also going to have to improve all over again, and then test again.

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At the beginning of the unit the educator tends to skip many questions in the guide including reflection questions (Table 7). She infrequently discusses the steps or purpose of the EDP. At times, she merges certain sections of activities together, and at other times she extends

the activity, particularly when they are exploring new technologies. She frequently adds to an activity by using relatable examples to build youth understanding, spending significant time helping them understand the science content. For instance, when introducing light, she has students trace out the way light travels using illustrations in their engineering notebooks, and also spends significant time helping them to understand filters. When describing straws as a model for LiDAR, she has them play with a 3-D pin art board and guides them in discussion of the limitations of models: *"Can you see some limitations for how the straws are a good model for LiDAR or some limitations where maybe it's not so good? What makes it a good model for actual LiDAR?"* Because she combines Activity 5 and 6, she provides little time for them to improve their designs (Table 7). She modifies the Showcase by role-playing as the scientists that the youth are "working" with, and has the youth present their findings and recommendations to her.

The educator has a good rapport with the youth, praises their work frequently, and uses many high quality pedagogical strategies such as questioning (Table 7) to support learning. She actively works to foster their identities as engineers, reminding them that they "*role-play as engineers*" during the unit, and has them think about themselves and their future in the STEM workforce:

> If I was the boss of a company, and was looking to hire engineers for my company, I would be asking you questions like this: 'Why should I hire you? What is a special talent that you have that will make you a valuable employee? Why would the other people that already work here want to have you on their team?'

She works hard to cultivate an environment in which all student contributions have value:

> 'Do you think I would have lost my $450 million rover if I tried to land there? You gave me some good advice... So do you think I'll consult with your engineering firm again? I absolutely would. You saved me a lot of money. Maybe you even saved... what if we didn't send a rover. What if we had a live mission there? You may have saved lives too.'

Table 7: Integrity analysis of Educator 4 during unit implementation

Logistic integrity (of 8 activities)			Enactment integrity: Introduction of lesson purpose and discussed key takeaways[1]	Quality of pedagogy[2]
Non-implementation	Partial implementation	Complete implementation		
0	7	1	1.4	2.1

[1] Average rating on scale: 0=did not introduce, 1=somewhat introduced, 2=completely introduced
[2] Average rating on scale: 1=low quality, 2=moderate quality, 3=high quality

Actor-oriented analysis

This educator identifies herself as a STEM teacher who is very experienced teaching engineering with curricula developed by these designers. She participates because she wants to offer something afterschool that would allow more hands-on, project-based learning, which she

feels is missing from the school day. She believes the OST program should differ from the regular school program, should connect to youths' lives, and should expose them to STEM career opportunities, particularly important for this age group. She believes the learning experience should be enjoyable and be youth driven, with opportunities for youth to explore and "*figure it out*" on their own, since youth need to experience and learn from failure. *"I find that if the kids own their work they have a much better outcome than if I say, 'You need to do A, B, C, and D.'"*

She identifies that she had made some modifications based on youth needs. For instance, she gives additional time for investigating mirrors because the youth had not experienced a periscope before, and she feels they need more time to explore. She also spends less time explaining the EDP because participating 8th grade youth have had a lot of experience with it. She views herself more as an "observer" than a director of learning with this group; she does not feel like she needs to ask a lot of probing questions because the youth are engaged and investigating on their own.

The educator believes in offering a lot of praise and encouragement to the youth, and feels it is important because there are "*no right or wrong answers*." She notes the younger youth need this opportunity more frequently because they are not used to learning from failure. She also notes that sometimes youth have ideas in their heads but need help "*getting them out,*" so she asks probing questions to help them articulate their thoughts. She likes to listen as these youth explain their ideas to other youth, as she feels this is an indication of their learning and understanding.

By the end of the unit, she is impressed with the level of confidence the youth express in the devices they built and the research they conducted to identify landscapes on remote planets using remote sensing. When revealing the landscapes at the end:

> I said, 'You did a really good job on that.' And they were like, 'Yeah, we really did, we really captured this height and this depth. And by capturing that, we really did give good advice to our scientist.' That was fabulous.

Discussion

Using a dual lens of integrity of implementation and an actor-oriented perspective suggests *how* and *why* these four OST educators implemented the PLANETS curriculum units in different program settings. From analysis of the actor's perspective, an "*insider's view of curricula implementation*"[18], educators' decision making during instruction is well-aligned with the purposes the designers have for curriculum. These educators are choosing to facilitate engineering curricula to support goals for youth that include opportunities for active learning, development of 21st century skills, decision making and ownership over learning, and persistence. They believe that youth participation in engineering curricula will support meeting these goals. Additional goals that educators have for youth, such as career exposure, leadership, and connecting to their community, were further identified by educators as important and emphasized through their implementation. Overall, educators implemented in a way that was aligned with their beliefs for OST youth, including providing opportunities for development of

youth agency, persistence, self-direction, and interest. Through the flexibility of OST programs, educators extended learning that is often constrained by a traditional classroom context.

Integrity analysis identifies that educators also made a number of modifications or deletions in implementation of the curricula. Some of these modifications they recognized and did purposefully based on youth interest and need, such as providing more time to explore new materials or technologies, or allowing youth to add new challenges to the activities (e.g., Educator 1). Educator 4 knew that the youth had multiple exposures to the Engineering Design Process; therefore she emphasized it less in the curricula. She also modified implementation to allow more time for youth to engage with technologies new to youth, such as periscopes, and spent considerable time helping youth to understand connections with the science content, both areas she identified as important to youth.

At times, educators made modifications or deletions that may not have been intentional, may have limited the learning experience for youth, and were not aligned with the intended enactment of the curricula designers. For instance, at times educators de-emphasized the activity purpose or take way, did not help youth make connections about how activities built into the larger unit story-line, or skipped steps in the Engineering Design Process (e.g., improving on a design). It may be that the educators had lost sight of the larger story-line, that they themselves lacked an understanding of these connections, or that they lacked content knowledge. For instance, Educator 1 was very excited that youth were trying to engineer a process for reusing water in a home (Activity 3), which they created and called "*The No Filter Challenge.*" This missed the purpose of the activity and larger unit, that filtering is necessary for water reuse for different purposes.

At times, educators' active learning philosophy for OST, and desire to make hands-on learning different from school, led to implementation in such a way that was not aligned with the intentions of the curricula and may have unintentionally led youth to miss the learning goals. For instance, Educator 2 explained that she did not want to talk too much at the beginning of each activity and wanted to get youth into the activities as quickly as possible, which led to less time framing the activity purpose. Educator 1 identified youth-directed and active learning experiences as an important way to engage middle-grade youth, and subsequently spent more time on exploring materials and less time on discussion and reflection.

For Educator 3, her philosophy for OST from an actor-oriented perspective with a stated hope for youth agency was aligned with curricular goals, but may have conflicted with her experience as a traditional teacher, and possibly her lack of experience with this particular unit.

Research on curriculum and instruction in school contexts emphasizes that curriculum and pedagogy continually interact with learning environments and youth such that curriculum is continually "in motion" during implementation [17]. The unique environment of OST presents similar and new challenges. Educators identified a number of affordances for youth engineering in OST, including flexible timing, and freedom from having to "meet" specific standards. However, OST contexts also led to challenges that affected implementation. Educators identified that the informal nature of OST led to a lower level of commitment for youth and families, with afterschool sports and other activities often a higher priority. With a multiple-activity unit that

builds to the resolution of an engineering challenge, inconsistent attendance affects the unit flow and may limit the youth experience. Similarly, since OST is seen as "extra" and not school, the educators had a number of competing priorities on site that affected their preparation time and focus.

Many OST STEM educators lack background in STEM [25], and this was evident at times during educator implementation in this study. Although the units were focused on engineering design, there were many important science concepts in the activities which informed engineering design. At times educators provided youth with incomplete or incorrect explanations, such as labelling grey water as waste water. In another instance, one educator routinely conflated science with engineering.

In terms of integrity of implementation, OST educators mostly implicitly or intuitively enacted the curricula in alignment with design principles, and they often used research-based pedagogical strategies that supported youth learning. They provided critical time for exploration, creativity and team-work. Other aspects of their implementation were less likely to support goals for youth development. For instance, by only partly implementing many of the activities, they were less likely to spend time to clearly explain the lesson purpose, or provide important time for reflection and sense making. These aspects of the activities are critical for developing youth understanding of the unit, but perhaps less important for other important goals of OST, such as engagement, ownership and agency.

An actor-oriented perspective explains some reasons educators emphasized certain aspects of the curricula over others, while program context and educator background provides other explanations. Ultimately, similar to formal educators [18], OST educators will implement in a way consistent with their beliefs, context and experience.

These case studies focused on four educators as they implemented engineering curriculum that integrated planetary science content. The findings are not generalizable to all OST educators as they implement science and engineering curricula. However, the findings are useful to understand how educators implement engineering curriculum in OST settings, and may inform the reader about applicability in other contexts [19]. Implications for professional development providers, curriculum developers, researchers, and policy makers are presented.

Conclusion and Implications

This study has a number of implications for supporting OST educators as they implement engineering curricula with youth. As identified by Penuel, Philips and Harris [18], both an integrity perspective and an actor-oriented perspective of curriculum implementation can inform the design of professional development experiences for educators, and the development of "educative" curriculum, as well as to ultimately understand youth STEM experiences in OST.

Implications for professional development

Because OST educators frequently lack time for professional development or preparation and have competing priorities, this preliminary research suggests that supports should be targeted

to a specific unit and activity. Educators are interested in information that meets their immediate needs, such as how to gather and prepare materials, identify the main learning goals for youth, and recognize places where youth might struggle and need extra support, particularly with understanding related science content. Unless they plan to teach the unit more than once, OST educators will likely not seek deep pedagogical content knowledge for a specific curriculum. As suggested by our findings, even experienced educators may need support distinguishing the epistemic practices of science vs. engineering [2], as well as engineering habits of mind, identified as essential by researchers who are developing innovations in K-12 engineering education [3].

Reviewing a detailed unit map during professional development can ensure that educators see the purpose of the activity in the larger context of the unit. Important information to include are the key learning goals youth will gain from experiencing an activity, in order to apply that learning to the engineering challenge. Other aspects to build into a unit map include understanding the purpose of the entire unit, where each activity fits into the overall unit, why the activity is at a particular point in a sequence, and how the activity supports youth to be successful in the final design challenge.

Educators also need a deeper understanding of key science and engineering concepts in the unit, and the importance of pedagogical strategies, such as closure and reflection following an activity. Although knowing all design principles curriculum developers purposefully include in a unit would be unnecessary and overwhelming, understanding the main principle(s) in each activity may support overall enactment. Because educators often skipped the reflection questions at the end of the activity, key science and engineering reflection pieces can be embedded into the unit map. These would not only remind educators to emphasize the ideas with youth who are present, but they can also help educators bring new youth up to speed, given the high turnover experienced in OST programs.

Though emphasized supports should be immediately applicable to the current curricula being implemented, the educators in this study wanted to support youth development, including their communication, critical thinking, collaboration, and leadership skills. Pedagogical support for how to accomplish these goals can be provided for those seeking additional information. For example, some general guidance and examples of how to ask open-ended questions that push youth thinking, and how to develop engineering habits of mind and 21st century skills could be provided. Additionally, support on how to help youth design fair tests, discuss conflicting test results, and how to persist through failure would be helpful for educators seeking this guidance.

Implications for curriculum developers

Findings from this study have implications for curriculum designers. The busy context of OST facilitated by educators with competing priorities led to little focus on material or activity preparation. Educators also identified limited budgets for acquiring and gathering materials. Thus, providing OST curricula that require little preparation time, and simple, easily accessible materials is more realistic for OST contexts. Often curricula include pedagogical "tips" in the margins, which were infrequently utilized by educators in this study. Therefore, including only the most critical information, key steps, and/or reflection questions, along with a rationale for

their inclusion, might increase integrity of implementation. This study also illuminated the reality of the transient nature of youth in OST programs. Each activity in a unit should revisit the purpose, findings, and goals from prior activities to ensure coherence for youth who may not have had the benefit of attending prior sessions.

Engineering curricula often engage youth in investigations of materials and their properties, to inform their final design solutions. Frequently these investigations rely on knowledge and/or application of scientific concepts. Science content was at times a challenge for three of the educators in this study. In OST, developers must presume educators, much like youth, may have limited scientific prior knowledge. Short, targeted descriptions of the science concepts introduced, properties of the materials involved, and expected results would enable educators to better support youth as they conduct their investigations. Additionally, activities which help educators and youth explore the relationship between science, engineering, and technology would be beneficial. Science can be emphasized as both the basis of and purpose for engineering technologies (as in the remote sensing unit), or an engineering problem can serve as the purpose for learning science (investigating filter materials and water quality in the water reuse unit). Understanding these connections might help move the development of integrated STEM curricula forward. To make explicit how science and engineering learning experiences align with youth development goals in OST, developers should consider building explicit links to these goals into the curriculum.

Implications for researchers and policymakers

Understanding educator implementation is an important first step to identify how science and engineering experiences impact development of Engineering Habits of Mind and other important OST STEM youth development goals [4], and ultimately how these develop positive attitudes and interest in STEM. While the sample size in this study is limited, the dual perspectives of integrity analysis and actor-oriented analysis surfaced and suggested explanations for the variation in implementation and decision making of four OST educators. Expanding this work to include more OST educators in other contexts may provide a further understanding of curriculum implementation. Examining the interactions between educator implementation and youth development of engineering habits of mind and other youth development goals is another area in need of further research, in order to understand how STEM development and learning occurs in OST contexts.

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