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From Toys to Tools: UAVs in Middle-school Engineering Education (RTP)

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From toys to tools: UAVs in middle school engineering education (RTP, Diversity)

Abstract

We have developed, implemented, and studied a 16-week, afterschool engineering program aimed at low-income middle school youth. The curriculum is based on Unmanned Aerial Vehicles (UAV/Drones), which participating youth must use and modify as appropriate to conduct a range of scientific investigations, culminating in the aerial survey of a mock town suffering from a natural disaster. Built into the curriculum are numerous opportunities for youth to reflect on the relevance of program activities to their interests and their lives, which prior research has suggested help to increase youth interest and persistence in STEM. Here, we report on the field trial of this program, and examine the efficacy of the program for increasing youth motivation and aspirations in STEM, enhancing their abilities to engage in engineering design practices, and for developing their capacity to use UAVs to address scientific and engineering problems. We also report on the changes the program had on youth perceptions of UAV/Drones: from considering UAVs as “toys” to realizing they can be used as “tools” to support science and engineering practices.

Introduction

Young people who live in high-risk neighborhoods and from low-income families often spend most of their time out of school by themselves without adult supervision [1]. There is an urgent need to study this group of youth and develop after school programs that support their needs and build on their interests [1]. Additionally, youth from low-income and diverse backgrounds are vastly underrepresented in science, technology, engineering, and mathematics (STEM) studies and careers, and educational policy makers stress the need to develop approaches that promote youths’ interests and involvement in STEM [2], [3]. To address these concerns, researchers and science organizations are developing and studying out-of-school time (OST) activities designed to encourage low-income youth to pursue academic studies in mathematics and science and to eventually select a career in a STEM-related field [4], [5].

Engineering Experiences is an out-of-school time (OST) program designed specifically to develop the motivation and capacity of low-income youth to persist in STEM studies and careers. This 16-week program engages middle school youth with in-depth, hands-on engineering activities related to atmospheric and related sciences. This program has been designed and implemented by an interdisciplinary partnership that includes science education leaders from the University Corporation for Atmospheric Research (UCAR), learning scientists and STEM education researchers from the University of Colorado, and the *I Have A Dream*

Foundation (IHAD). IHAD is a national program, organized into local chapters, that supports low-income youth through long-term educational and cultural enrichment programs [6].

When designing programs that aim to broaden participation in STEM, it is important to build on youth interests [7]. This is particularly critical when designing OST programs as youth interest in the content of the program is the most important factor influencing participation and attendance [8]. At the start of this project, we conducted a series of pilot studies and focus groups with over 40 youth from a local IHAD chapter to understand the types of project experiences and STEM topics (e.g., solar power, weather, hurricanes, drones) that they were most interested in. These pilot studies highlighted that the youth we were seeking to engage valued hands-on experiences that emphasized the use of cutting edge technology and that many of the youth were particularly interested in learning more about Unmanned Aerial Vehicles (UAVs); i.e. drones. UAVs proved to be an excellent choice, providing youth with both fun hands-on activities, such as learning to fly, as well as offering an interesting platform for integrating a broad range of engineering phenomena such as load testing, remote sensing, engineering design, and tradeoff analyses.

The 16-week *Engineering Experiences* curriculum has been iteratively refined and studied over a three-year period following a design-based research methodology [9], whereby research data collected during each program implementation is used to guide subsequent changes to the curriculum, the overall program design, staff professional development, and program recruitment methods. In this article, we describe the final version of the curriculum, and report on its implementation and field trial with low income middle school youth (n=8); previous iterations and intermediate findings are reported elsewhere [10]. Consonant with design-based research, our implementation and research activities were guided by a conceptual framework in the form of a conjecture map [11]. A conjecture map is a representation that outlines critical linkages between research hypotheses, program features, and anticipated outcomes. The contributions of this effort include a research-based OST curriculum built around UAVs, a theoretically-informed conjecture map, unobtrusive research instruments designed specifically for use in OST settings, and results and lessons learned that other OST program designers and researchers can build on.

Related work

A central challenge for any STEM-oriented OST program is how to design curriculum that engages and motivates youth, while developing their STEM knowledge and skills. We drew on two areas of prior research to inform our efforts: UAVs and STEM curriculum design as well as research on developing youth interests.

UAVs and STEM curriculum design

UAVs, especially inexpensive models suitable for educators' budgets, are a very recent technology. While there are growing interests by educators and researchers around using UAVs in the classroom, there are very few efforts focusing on designing entire curricula around UAVs.

The majority of OST programs utilizing UAVs are short-term, one and two-day outreach activities (see, for example, [12], [13], [14]). Many of these efforts focus on older students. For instance, Nitschke and colleagues [15] developed a one-day contest for undergraduate and postgraduate students that aimed to help students understand the potential benefits and limitations of UAVs. Other researchers used UAVs to help motivate students to learn control engineering and image processing [14]. Huggard & Goldrick [16] scaled up from one day events to design an entire freshman module on UAVs. One reason for not involving younger youth and the relatively slow uptake of this technology in formal and informal settings is the way UAVs are perceived as "toys" (see, for example, [13]), rather than as autonomous aerial vehicles with the potential to revolutionize engineering curriculum [17]. We drew on these prior UAV outreach activities to understand the types of activities that participants found to be engaging, such as aerial surveys, and to ensure that we were building on recognized practices for ensuring students' safety while learning in the presence of potentially multiple flying objects.

Since our goal was to create a relatively long and in-depth STEM program, we also drew on research and best practices in STEM curriculum design. Within formal educational settings, curriculum design is undergoing profound changes motivated by the *Framework for K-12 Science Education* [7] and the *Next Generation Science Standards* [18]. These documents outline a vision for contemporary science education that includes a shift towards phenomena-based instruction. In phenomena-based instruction, the focus of learning is about figuring out how to explain a phenomenon (e.g., Why did a girl with antibiotic resistant bacteria get so sick?) rather than learning about a set of topics (e.g., the human immune system and evolution) [19]. One premise of this approach is that through "figuring out", youth will be developing deep disciplinary knowledge while engaging in authentic science and engineering practices, such as asking questions and defining problems, planning and carrying out investigations, analyzing and interpreting data, constructing explanations and designing solutions, and engaging in argument from evidence. This led us to design the entire curriculum around a central driving question: How can we monitor a disaster area (a town) to alert the community of possible danger? We structured the curriculum so that each week youth were engaged with engineering design activities to help them to progress towards "figuring out" this driving question.

A second premise of phenomena-based instruction is that youth will find this style of learning more engaging, as the questions youth have at the end of one activity naturally motivates the next. This requires that the designers of curriculum anticipate the questions that youth might have. Researchers have proposed a specific technique, called storylining, to assist curriculum developers in anticipating student questions and developing sequences of activities that are coherent from the students' point of view [20]. A storyline is a way to represent sequence of lessons where each lesson is driven by youth questions and each activity helps youth to make progress towards explaining an anchoring phenomenon. There have been several studies examining the implementation of new curricula using storylines in formal educational settings (see, for example, [21]). However, there have been fewer studies on the use of storylines to design informal learning activities. This paper addresses this gap in the literature. For the final version of the *Engineering Experiences* curriculum, we used the storylining approach to significantly revise our curriculum and we report on our storyline and how it impacted youth engagement.

Building on and developing youth interests

Developing students' interest in science and engineering has long been predicted as an effective means to motivate STEM career choice and career development [22], [23]. Because of their flexibility, OST programs are well-positioned to promote youth interest in science and engineering [4], [24], and several programs [25], [37] have been developed that specifically target low-income youth. While these programs were successful in promoting STEM interest in low-income populations, they also highlighted specific challenges in working with low-income youth. Caplan [24] notes that programs should provide youth "*with opportunities for choice, independence, flexibility, and social experience. It would also seem important to create an atmosphere where youth can make mistakes without fear of judgment and without the pressure of time*" [26]. Other researchers have discussed difficulties with recruiting and retaining low-income youth in OST programs [27], [28]. In this work, we pursued two complementary approaches to more effectively reach and engage low-income middle school youth. The program's content is based on the specific interests of our target demographic (as described in the Introduction) and we integrated "relevance interventions" directly into the curriculum.

Relevance interventions refer to a set of techniques for triggering participants to actively make connections between learning activities and their own lives and interests. According to Hulleman and Harackiewicz (pp. 1410) [29], "*Programs that emphasize personal relevance may be particularly empowering for students who are disengaged from school because of a lack of confidence. Students can become energized if they believe they are competent in science and can successfully perform classroom tasks*". In recognition of the importance of these factors in students' academic success [31], there has been considerable research into a wide array of interventions designed to encourage student interests and motivation in STEM and other academic disciplines, such as utility value [29], [30], value affirmation [32], and mindset [33]. In this project, we implemented a variation of the Hulleman et al. [30] utility value intervention.

Utility value refers to the perceived usefulness of a topic or activity with respect to an individual's short- and long-term goals [34], [30]. A utility value intervention typically asks participants to reflect on the utility of a recently completed activity or course to their own lives or the lives of others similar to them. For instance, Hulleman and colleagues [30] asked undergraduate university students to write a short essay reflecting on the utility of a course they were all participating in. The basic premise of these types of interventions is that they force students to construct relevance relationships for themselves, which in turn, help to spark interest and motivation. The results have been quite remarkable. Hulleman et al. [30] found that the simple essay writing intervention increased students' perceptions of usefulness and interest, especially for students with low expected or actual performance. This research also observed improvements in students' grades within the course. This intervention has also been studied with low-income students in science classes; results suggest it improved both motivation and student learning outcomes and promoted persistence in STEM courses in subsequent years [29]. We adapted this intervention to make it more accessible to our younger cohort of middle school youth, the majority of whom were non-native English speakers. We integrated the utility value intervention into the curriculum in the form of short writing and reflection assignments that were built into youth journaling notebooks. These assignments asked youth to explore the potential relevance of engineering activities to their lives or to the lives of middle school students.

Engineering Experiences program design and implementation

Conjecture mapping, a prominent technique in design-based research, was used to guide the development of the *Engineering Experiences* program and research into its effectiveness. Researchers develop conjecture maps to: (1) document the key features and functions of a proposed learning environment (the *embodiment*) and (2) specify hypothesized linkages between research questions (phrased as "*conjectures*"), the learning environment design, and the new or changed activities that actors in the learning environment will engage in (*meditating processes*) [11]. The goal is to figure out how the design should function and explain how it produces *intended outcomes*. The conjecture map for *Engineering Experiences* (our embodiment) is shown in Figure 1. Two conjectures guided the development of this program:

Conjecture #1: Participating in *Engineering Experiences* can change or enhance youth engineering design skills

Conjecture #2: Participating in *Engineering Experiences* can change or enhance youth motivation and interests in STEM

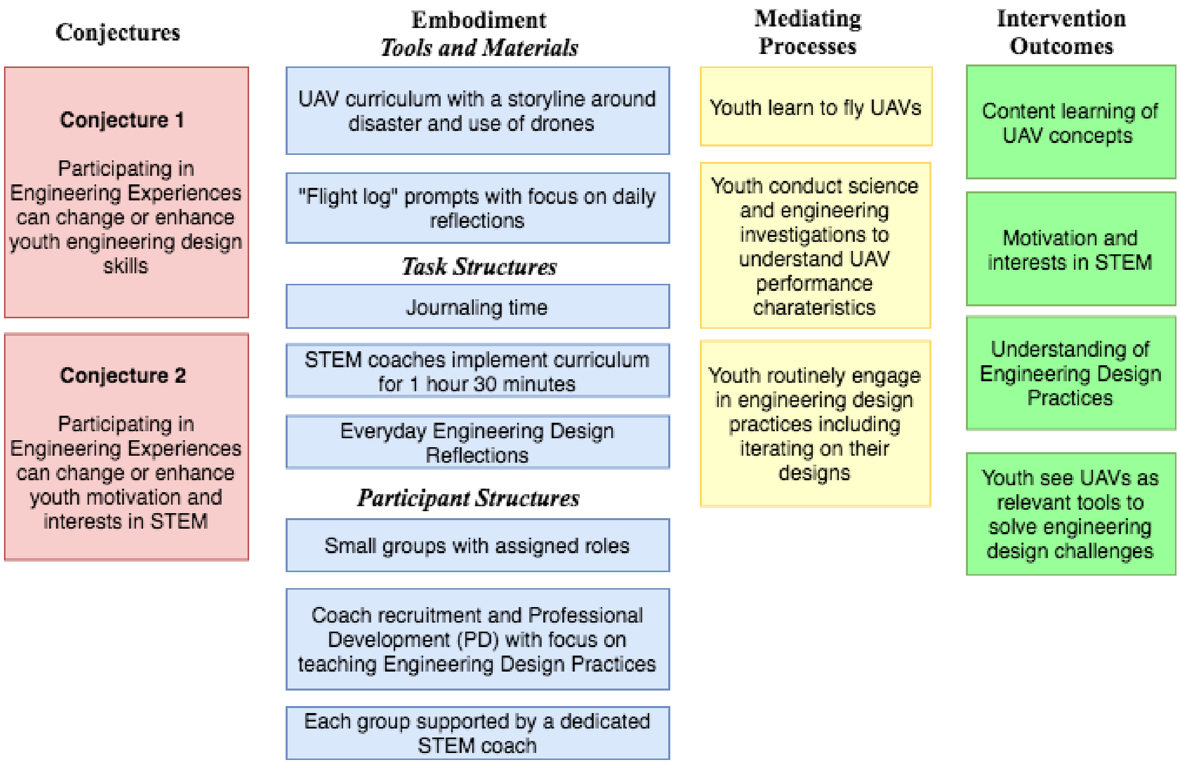

Figure 1: Conjecture map for *Engineering Experiences* (the embodiment)

Participants

Thirteen middle school youth (11 male, 2 female) from a PK-8 School in Colorado participated in the program. Eight of these youth (6 male, 2 female) had completed all study requirements and while the rest of them were involved in the program but they did not complete all the study requirements. At the school, 84% of the students are Hispanic, 12% are Caucasian, and 83% qualify for free-and-reduced lunch (FRL). All the youth who participated were in 7th grade at the time of the study. Participation in the program was voluntary; youth self-selected into the program. Seven of our participating youth were Hispanic and 1 was Caucasian, all of them were currently enrolled in the IHAD afterschool program that took place on the school's premises.

Embodiment

Participant Structures. Participating youth were organized into small groups with clearly assigned roles, such as UAV pilot, safety officer, and spotter. These roles were rotated throughout the semester and every youth had a chance to play each of these roles. Each group of youth was supported by a dedicated STEM coach and another adult volunteer from the IHAD program. Two undergraduate and one graduate student from the engineering program at the University of Colorado were recruited to serve as STEM coaches who facilitated the program. Each coach participated in a professional development program designed to familiarize them with UAVs, the overall curriculum, the engineering design practices being emphasized in the curriculum, and how to support youth engagement with the practices. The professional development occurred before the coaches began working with the students and continued throughout the semester. The professional development focused on the storyline (big picture) of the curriculum as well as the specifics of each of the lessons with a focus on learning to fly, conducting performance tests of the UAV and engineering design challenges. We also involved the coaches with understanding best practices in OST learning including building students background knowledge and the importance of motivation and setting high expectations [39].

Task Structures. Youth met at their school once-per-week for 1.5-hour sessions. We used "flight logs" as a journaling notebook for promoting youth to reflect on their learning experiences and to unobtrusively gather evidence about youth's interests, engagement, and knowledge. Before the start of each session, a team member would paste prompts into the journals that included likert-style and open response questions (see Table 1 for examples). Several of these prompts formed the basis of our embedded relevance intervention and encourage youth to build connections between their activities in *Engineering Experiences* and their interests and lives outside of the program. As youth arrived, they would take their flight logs and respond to the prompts at the beginning of each session. Additionally, at the end of each session youth would reflect on the engineering practices they used during that session.

Tools and Materials. The storyline guiding the 16-week long *Engineering Experiences* is shown in Figure 2. Youth were asked to develop a solution to a problem (phenomenon): how to survey and provide relief to a town that has been damaged and isolated due to a natural disaster. The curriculum was designed considering the driving questions youth would need to answer to solve the problem, and to anticipate questions they might have at the end of each session. In Figure 2, the driving questions for each of the activities are aligned and coded with the particular activity that youth performed. The storyline also shows the engineering practices that youth would need to engage in to make progress on the anticipated driving questions. Engineering practices that we chose to emphasize included asking questions, planning and carrying out investigations, analyzing and interpreting data, designing solutions, and engaging in argument from evidence.

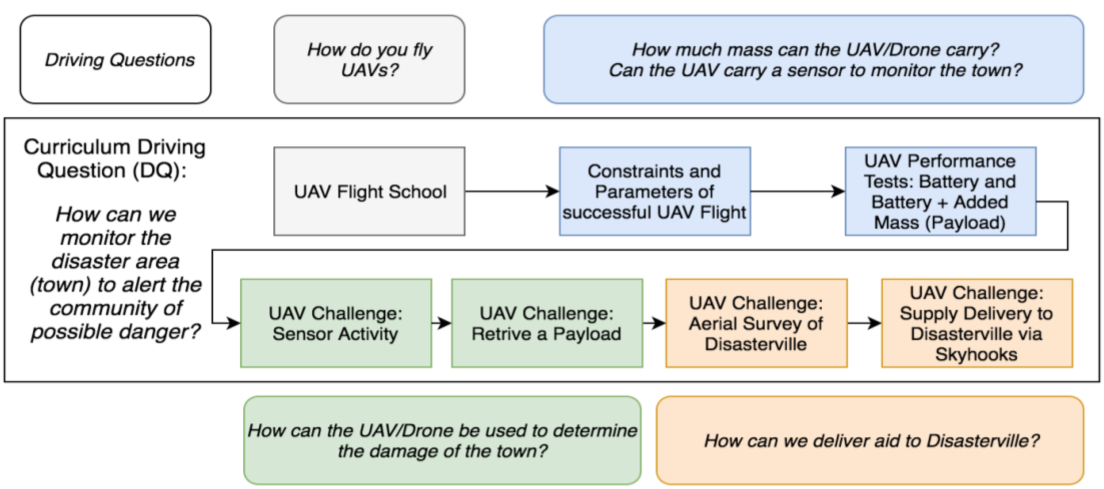

Figure 2: Flow and Driving Questions of the curriculum

In sessions, youth: (1) learned to fly UAVs, (2) used engineering practices to design and conduct experiments to understand UAV performance characteristics (weight, battery life, and flight time trade-offs), (3) used different sensors to monitor simulated difficult to reach areas, (4) modified their UAV to conduct experiments and aerial surveys, (5) planned and conducted aerial surveys of the town of "Disasterville", and (6) raced their UAV to deliver maximum amount of supplies using 3D printed skyhooks.

The first segment of the UAV curriculum can be characterized as "UAV Flight School". Youth had to first learn to fly the UAVs as a prerequisite to performing subsequent science or engineering activities. Youth learnt basic terminology about UAVs (pitch, roll, yaw) which they used to communicate to each other while flying; learn the operation of the joysticks and buttons on the UAV controller; and practiced increasingly challenging flights to learn how to take off, land, and maneuver in-flight.

After the youth have learned to be successful flyers, they conduct a pair of scientific investigations to measure UAV performance over the new few sessions. Both experiments provide data about the UAVs' capabilities that support planning of later challenges. They also help transition youth's mindsets from "we're flying drones" to "we're conducting investigations that include data collection with UAVs". Youth measure the battery lifetime of the UAVs during flight (about 8-10 minutes), which determines the possible duration of a mission and the potential range of the UAV. In another lesson, youth progressively attach small weights (washers) to the UAVs to determine how heavy of a payload can be carried. This "carry payload" activity introduces the first small taste of engineering design to the UAV lessons; youth use their choice of pipe cleaners, rubber bands, and other craft materials to attach the weights to the UAVs.

Once youth got a sense of attaching weights to the UAVs next they were introduced to the need for sensors in monitoring a disaster area. Balloons and aircraft are routinely used to carry instruments to different heights and locations to measure atmospheric properties, such as temperature, humidity, pressure, and gas concentrations, in situ. UAVs are increasingly employed for this purpose as well, to serve as a platform to carry instruments that measure properties of the atmosphere. In the *Engineering Experiences* program, we wanted youth to experience the engineering practices associated with flying sensors or instruments, beyond the UAVs camera, on their aircraft. We introduced the "sensor" activity which was new to this implementation. Youth use sensors to monitor simulated difficult-to-reach and/or dangerous environments (i.e., high temperature, CO2, humidity) of a potential hazard (i.e., volcano). Groups of youth take turns to fly temperature, CO2, and humidity sensors on their UAV to detect some property of the indoor and outdoor environment of their school. We used science experiments like adding baking soda with vinegar to prepare a mock-up volcano with CO2 emission. Youth record data generated from the sensors and report it to their peers and STEM coaches/adults. This provided youth hands on experience of flying sensors on their UAVs but still the activities were severely limited by a couple of factors. The hobbyist-level UAVs the youth were flying can only carry a small payload of roughly 30 grams. Although some sensors this light are available, extremely light-weight sensors are prohibitively expensive for most educators. Also, because all of our flying was mostly conducted indoors, it was very difficult to artificially produce localized environmental conditions (such as increased temperature or humidity) indoors that generate large enough signals to be measured by drone-borne sensors. As an alternative to hands-on engineering activities flying sensors on UAVs, we developed a "UAV Mission Board Game" to expose youth to the engineering concepts and decisions involved with flying instruments on aircraft.

The concept for the UAV Mission Board Game was inspired by two similar games developed at Arizona State University (ASU) in support of NASA missions: Marsbound (http://marsed.asu.edu/lesson_plans/marsbound) and Astrobiobound (http://marsed.asu.edu/lesson-plans/astrobiobound). In the two ASU space mission simulation games as well as our UAV mission game, youth choose a suite of instruments to include on their spacecraft or aircraft from a larger inventory of options, balancing the likely value of the data returned by each instrument against the cost and weight of that device. In our UAV board game, youth are initially given $800 of game money and a pretend UAV and must choose which instruments to purchase and install on their aircraft. Youth are told they will fly their UAV to a nearby volcano to monitor it for signs of an impending eruption. Instrument options include a variety of cameras including an infrared model (good for spotting hot lava!), sensors that detect various gases including sulfur dioxide and carbon dioxide, an aerosol detector for spotting volcanic ash, and an infrared thermometer. There are also a few options for the UAV's battery, with differing weights, costs, and energy capacities. Each equipment item is represented by a card, which lists the object's mass and cost. Instrument cards also include a value for the number of "Science Data Points" earned by that particular instrument when hovering over the volcano.

The goal of the game is to collect the most Science Data Points (SDP), so instruments with high SDP values are desirable but usually also costly and/or heavy. Youth must optimize their suite of instruments, as real engineers do, to balance overall weight and cost against potential for collecting science data. Youth move their UAV game pieces in a series of steps, each representing one minute of flight time, along the path representing the 5-minute flight to the volcano. On the way, they draw "Flight Event Cards" that represent unforeseen events that can impact the mission. When the youth's UAV arrives at the volcano, it begins to collect valuable science data for each minute it spends on-station over the volcano, based on the sum of Science Data Points for all instruments carried. Upon completing their first volcano monitoring mission, youth count up their Science Data Point total and are rewarded for their efforts with further funding based on the amount of data collected. Youth proceed to fly two more missions to the volcano. Between missions, they can invest their newfound wealth in costlier but also lighter or more capable instruments, cameras, or batteries. Youth can swap out instruments that seemed less effective for other combinations that might provide better results. In this way, youth iterate over the course of three flights, learning as they go which combinations work best and adapting their equipment and strategies along the way.

The board game allowed youth to experience several aspects of engineering practices that complemented youth's hands-on work with actual UAVs. The board game emphasizes constraints and optimization in engineering design, accounting for unforeseen problems and building in a margin of safety, and the use of iteration and testing to improve a design over a series of trials.

The final three lessons present youth with design challenges. In the first design challenge lesson, youth use their UAVs to retrieve a payload from far end of the school cafeteria and return it to a target landing zone. Youth design skyhooks to attach to the UAVs that pick up the payload, again using their choice of rubber bands, pipe cleaners, paper clips, tape, and the like. It is exceptionally challenging to grab the payload with a simple mechanical hook, such as a bent paper clip hooking a loop on the top of the payload. We placed magnets inside the payloads and provide youth with magnets to incorporate into their skyhooks, to make the challenge more reasonable to complete successfully.

The second design challenge required youth to use the UAV's camera to survey the mock-up "Disasterville" town. The UAVs used in the program had small video cameras that provide a live feed to a smartphone or tablet. We built a pretend town from blocks and toy cars and small figurines, then hid it from student view behind a low "mountain range" (a plastic tarp draped over some chairs, see Figure 3). We wrecked some portions of the "town" to represent damage caused by a disaster (tornado, volcano, etc.), and provided youth with a map and photos of the town in its pre-disaster state. Since youth could not see the Disasterville town directly because of the intervening mountain range, they had to fly their camera-bearing UAV over the town to survey the extent and location of damage.

Figure 3: Disasterville scenario of a town hit by a tornado

The final activity was a UAV race challenge. In this activity, youth had to deliver small buckets representing water to a designated landing zone target near Disasterville. Youth once again were supplied with pipe cleaners and rubber bands and the like, which they used to design and build a skyhook to hold the bucket during the aid flight. Designs need to balance the requirements that the buckets remain attached during takeoff and the flight to the landing zone but must allow the bucket to detach when the UAV touches down in the landing target without any further human intervention. Once youth were able to design skyhooks using craft materials, they were asked to choose 3D printed models of skyhooks. Based on their prior experience in designing skyhooks youth had to decide which 3D skyhook they would attach to their UAVs and use in the race.

Research methodology

Our research examined the degree to which participating in *Engineering Experiences* yielded the intended outcomes as shown in the conjecture map (Figure 1) and thus support the research hypotheses embodied in our two conjectures. Namely, we consider how the UAV curriculum influenced youth's interests and motivation, their beliefs and attitudes towards UAVs and engineering, and their understanding of engineering design practices.

Data collection and analysis

We collected qualitative and quantitative data that included journal prompts, project artifacts, observations, and interviews with youth participants. Journal prompts asked youth to reflect on their interests, performance expectations, relevance of the program to their lives, and their use of engineering practices. Table 1 shows example prompts and how they are aligned to each of our research constructs. Youth were asked to rate the degree to which they agreed with the prompts on a 5-item scale. Every week a member of the research team would paste in the appropriate prompts in the youth “flight log” books. At the end of the day, a research team member would transcribe all data, anonymize them, and store it in a secure location. Each of the prompts were administered multiple times throughout the 16-weeks to measure pre and post changes.

Table 1. Research Constructs

Construct Name	Definition	Example Prompts
Attendance	Reasons for youth to choose the engineering program and for continuing to attend the program	I am here because... (check all that apply or Yes/No): ● my friends wanted me to come here ● of the coaches/adults who teach the program ● of the activities this program offers ● I get to learn more about Engineering ● I thought I would be good at stuff here ● I thought it would help me with school ● my parents wanted me to come here
Interest and Future	Level of interest of youth and options to choose engineering in future	Say how much you agree or disagree with each statement below. ● *Engineering Experiences* has helped me become more curious about things I wasn't interested in before ● By trying *Engineering Experiences*, I discovered an interest I didn't know I had ● I know how my interest in engineering can become a career. ● Before starting *Engineering Experiences*, I didn't know that I could make a career out of it. ● After starting *Engineering Experiences*, I know I don't want to do engineering for a career.
Qualities of Learning Environment	Youth's perception of the learning environment whether they have peer support, if the program is openly networked or not	Say how much you agree or disagree with each statement below. ● I can always find something fun to do when I come to *Engineering Experiences* ● I like to work with other people in *Engineering Experiences* ● There are some things in *Engineering Experiences* that look so hard, I don't think I could ever try them ● When I get stuck I can get helpful suggestions from someone about how to solve the problem
Utility value/Relevance	Youth's perception of the relevance of the program to their lives and/or their community	What we did today in *Engineering Experiences* (check all that apply): ● Matters to me ● Matters to my community ● Matters to our group in *Engineering Experiences* Write one sentence about why it matters to you, your community, or your group.
Program Experience	How youth feel about the program and about themselves after	Say how much you agree or disagree with each statement below. ● In school I do not feel successful ● In this program I know I am capable ● I belong here

	attending the program	● I can take risks when I am at this program ● I feel *Engineering Experiences* is really difficult for me ● It feels like family when I come here
Engineering Design Practices		
Today in *Engineering Experiences*, I… (Check all that apply) ❏ Asked about a problem ❏ Figured out what constraints or criteria might limit possible solutions to a problem ❏ Came up with multiple solutions to address a problem ❏ Researched how other people have tried to solve a problem ❏ Chose a solution I/we think is the best ❏ Planned to design my/our solution ❏ Made my/our solution following a plan ❏ Tested out my/our solution ❏ Analyzed how my/our solution worked ❏ Came up with ideas to make my/our solution better ❏ Shared my/our solution and got feedback from others on how to make it better ❏ Revised my/our solution based on my tests or feedback from others ❏ Shared my/our solution with people outside of Engineering Experiences like my parents or community members		

The "Attendance" prompt asked youth to reflect on the level of importance of four reasons to attend the program: their peers, content of the program, adults teaching the program, and their expectancy value in the program [8]. Here, the expectancy value theory proposes that individuals are motivated to engage in an action to the extent that they feel capable of succeeding (expectancy) and view their involvement as worthwhile (value) [35]. The "Interest and Future", "Qualities of Learning Environment", and "Program Experience" prompts asked questions related to youth's interest level in choosing a career in engineering, their experiences in the program, and outcomes after participating in the program. These prompts were based on those used in the "Survey of Connected Learning" [38] since they had a set of well-designed prompts that were strongly aligned with our research conjectures. The "Utility Value/Relevance" prompt asked youth to reflect on the importance of *Engineering Experiences* to their lives, their community, and/or their group in the program [30]. The daily "Engineering Design Practices" prompt had youth reflect on and select the practices they did on that day and were drawn from steps in the engineering design process. Data collected from the "flight log" books was coded to identify youth level of interest throughout the curriculum, the future interests in pursuing a career in engineering, experiences in the program, and changes in the relevance of the program to youth lives.

We conducted one semi-structured interview in the 10th week of the program with participating youth. 5 out of 8 youth with informed consent participated in the interviews. They were compensated with $5 gift cards. Youth were asked about their views on engineering and UAVs, and we posed an engineering design challenge question and asked them to describe how they would go about addressing it. In the interviews youth were also asked to sort cards that mentioned four possible words to describe UAVs: scientific instrument, vehicle, toy, and tool. They had to arrange the cards in the order of one to four, with one being the most relevant description according to them and four being the least relevant [36]. The engineering design challenge question was aligned with the central problem that youth were solving in the curriculum. It had them think of a solution to provide relief to people affected by a disaster. Youth were asked follow-up questions based on their responses. All interviews were transcribed and coded by the research team. Youth responses to the engineering design challenge were coded to identify the design moves proposed by the youth, the evaluative criteria or constraints that the youth used to assess the quality of their proposed solution, and the reasoning youth provided, if any, to justify their design choices.

Our session observation protocol focused on observing the degree to which youth were engaged in different activities, the degree to which youth were enacting various engineering design practices, and how the participating adults supported the youth's experiences. Members of the research team observed every session and the lead author was the main observer in all three implementations of this program. This helped in maintaining consistency in our observations across the implementations. At least two researchers observed several sessions of the program to ensure that we were consistent in our observation foci. Additionally, we collected the project artifacts that youth designed throughout the 16-weeks. The main artifacts were the skyhook designs and sketches that youth made to help them design their skyhooks.

Results

Our results are organized in terms of our two conjectures.

Conjecture #1: Enhancing engineering design practices

The "Engineering Design Practices" prompt was not effective as a measure of youths' understanding of engineering practices. During the initial weeks youth would read through the options and choose engineering practices they had used that day. But later in the program they began to automatically check off all the practices even those they had not used. This could be because the prompts had become repetitive, or since they were administered at the end of the day the youth may have been ready to leave school and go home.

Our session observations provided a significant source of data since the protocol we used focused youth engagement with engineering design practices. Overall, compared to prior iterations, youth were engaged for longer period of time and exhibited a deeper level of engagement with engineering design practices. Their engagement was particularly notable whenever youth had the opportunity to design/choose attachments for the UAVs. Specifically, youth were engaging in more testing of specific designs, more iterations of their designs, and ultimately creating more sophisticated designs in this implementation. For instance, youth were augmenting their UAVs with multiple skyhooks, distributed over each of the 4 wings, and using weights to keep the UAVs balanced during flight (Figure 4b). While, in prior iterations youth had much simpler designs involving only a single hook (Figure 4a). In earlier versions, youth were limited in their ability to iterate due to the short durations of each session (45 minutes to one hour); however, interviews with youth in earlier iterations also revealed that they were not motivated to iterate as they perceived their designs as "good enough." In this implementation, we found youth actively engaging in adding new constraints to their designs after testing them out and changing their designs to optimize them. For instance, when surveying the Disasterville town, youth had to attach a camera to the UAV in such a way that they get the best footage of the town. Youth kept checking the best camera angle, the most feasible camera position and each time they tested their design by flying the UAV over Disasterville until they were satisfied with the video footage.

Figure 4: (a) Design of a simple skyhook, (b) design of a more complicated skyhook to distribute the load

Interview data adds supporting evidence: youth often discussed the need to improve their designs, ask questions to solve the problem, and the need to collect data to justify their decisions or processes. For instance, one youth mentioned, "*I would use some research data and say if I tested it on my own processor or designer city I made on my own. So, I would show them evidence and anything else that I used to do with the drone*" [P1]. In response to a question about tackling an engineering problem of delivering supplies to an earthquake affected area, a youth mentioned that he would ask questions like, "*what resources we have to build what we need, like the plane needs like programming, the rocket it needs like fuel to get there?"* [P3]. While another wanted to define the scope of the engineering problem and said, "*I would ask questions like how many people died, like estimate the population, if someone is stuck or if someone has already evacuated?"* [P4]. Youth would use prior investigations to make decisions about how to solve a problem, saying "*... would be successful because most people have done it before and there is a lot of research showing that rockets and drones are really helpful"* [P3].

The project artifacts collected also support this finding of improvement in youth designs, they made sketches of the skyhooks before designing them. Also, during the UAV race when youth had to choose from multiple 3D printed skyhooks (Figure 5(a), 5(b)), they kept in mind their prior knowledge in designing skyhooks like distribution of weight, battery life, shape of hook, etc.

Figure 5: (a) 3D printed skyhook with supplies attached, (b) Youth testing the 3D printed skyhook

Conjecture #2: Motivation and interest

While the overall number of participants was small (n = 8), we had consistent attendance throughout the 16-week program with 100% of the youth completing the program. In our experience, this high level of consistent attendance in an OST program is rare.

Initial attendance prompts showed that content was the key driver for youth to attend the program, most of the youth (7 out of 8) rated it to be "pretty important" to them. While other reasons to attend the program in the first place were adults who facilitated the program and reasons for youth to believe they would be good in the program, i.e., their expectancy value in the program. Follow-up attendance responses or reasons why youth kept coming back to the program consistently, showed that there was an increase in youth (from 0 to 3) considering the content of the program to be "super important" to them. The STEM coaches/adults who facilitated the curriculum were another "super important" reason for youth to keep coming back to the program. Additionally, quotes from youth like "*It's a drone class and that's pretty cool*" [P4], or "*I am interested in learning how to drive a drone"* [P8], show that the content of the program mattered a lot to them.

From the "Interest and Future" prompt, we found that before attending *Engineering Experiences*, 5 out of 8 youth did not know that they would be able to make a career in engineering. But toward the end of the program, in their interviews youth expressed views about engineering that were strongly positive and concrete. For instance, one youth considered engineering to be about "*creating man made objects that make human life easier*" [P2] while another youth said "*engineering is creating stuff that could help you or others around in your community"* [P1]. Half of the youth (4 out of 8) reported that by trying *Engineering Experiences* they had discovered an interest they didn't know they had.

Additional data from interviews informed us about the changes in youth perspectives on UAVs, from considering them as "fun" and "toys" to defining them as "scientific instruments" and/or "tools." From the card sorting question, we found all youth who were interviewed (5 out of 8) considered "toys" as being the least favorite description for UAVs. Youth perception about UAVs was geared more toward being useful for scientific purposes and investigations like "*see how much pressure is in the air for the UAV to fly"* [P5] or "*I could see a drone being is a scientific instrument. It's very helpful because ... if there were ever an incident you can go there yourself or you could take something that you could control"* [P1]. Another youth mentioned, "*Because scientific instrument would help make finding people that are stuck in floods or buildings after like a mass destruction, an earthquake or a hurricane. We can check area to see what happens"* [P3]. These responses show the shift in youth considering UAVs as scientific instruments or tools, this was a change from what we had observed in our prior iterations. Two possible reasons for this shift could be the storylining approach and introduction of the "sensor" activity. Foregrounding the purpose of UAVs to help determine the damage of a disaster town and using UAVs to provide relief to people trapped in Disasterville gave youth a better understanding of the different functionalities of UAVs in real life.

Discussion and conclusion

To date, *Engineering Experiences* has provided middle school youth from low income and diverse populations with opportunities to fly, design, and use UAVs in a variety of problem-solving tasks, building towards a scientific and humanitarian mission ('Aerial Survey of a Disaster Area). Our conjectures were informed by our findings from the implementation of the 16-week long *Engineering Experiences* curriculum. Our modified approach helped in improved attendance, motivation, and engagement of low income youth and increased student perception of coherence of the program. Using "flight logs" was helpful in unobtrusive data collection and we plan to keep using them as a data collection mechanism in future implementations. While there were still issues with all youth completing each of the prompts, the perception of having "too many surveys" was never an issue since the prompts were made part of the curriculum and youth were used to the routine of filling in their "flight logs" during each session.

Enhancement in youth engineering design skills

With the help of the storylining approach and foregrounding the problem that youth were solving, youth improved in their use of several engineering design skills. Thus, being able to make better designs over time. The content of the program influenced their design decisions like in the case of the 3D printed skyhook activity. We hypothesize that the curriculum's emphasis on engaging in argument from evidence helped youth to convince themselves and their peers that more work was needed to improve their designs. For next iteration we will need a better way to track youth reflection of the engineering design practices - we think asking them to talk through their designs or record videos of the practices they used will better capture their understanding and use of engineering design. While we have room for improvement, we argue that learning environments where youth are (1) engaged over multiple weeks, (2) iterating on designs, and (3) using evidence and prior research to support their designs are possible to support in OST learning spaces.

Motivation and interest in engineering

We saw improvement in youth motivation and interest in this iteration of the program as measured through daily observations of youth time on-task and their consistent program attendance. These results were different from our prior iterations where there was dropping attendance even though the program was shorter (10-weeks) than this implementation. This supported our findings of enhancement of youth motivation and interest in engineering and excitement of working with UAVs. As described in results, the majority of youth were consistently present in all sessions. Furthermore, all of the youth who were part of this implementation came back to the program in the following semester to work on interest-driven engineering based projects. This offers some evidence that participating in *Engineering Experiences* can positively influence low income youth to persist in STEM programs.

We can also infer from our data that the curriculum was effective in helping youth make a connection with UAVs and not just consider them as "toys" for fun activities but also use them "*to save people.*" The UAVs served as a platform to attach instruments and conduct science and engineering investigations. The transition of youth considering the UAVs as "scientific instruments" show the potential to delineate UAVs as platforms for instruments rather than them being the tool itself.

Thus, our findings provide insights that the content of the program matters to at-risk youth and can help increase their motivation and interest in STEM related fields and motivate them to opt for engineering as a career. For future implementations, we plan to conduct pre and post interviews to be able to measure differences in youth understanding of UAVs and engineering.

Limitations

Our results are based on a small number of youth; thus, there are limitations on generalizability of our findings. However, we believe that these findings identify the utility of the *Framework* [7] for guiding the design of informal learning curriculum and that further design-based research in this area is warranted. To be able to generalize our findings we plan on extending this curriculum to adapt the storyline to address different scenarios that students in different local contexts (rural, suburban/urban) will best relate to, either by introducing different types of disasters or by developing new storylines based on actual uses of UAVs (such as monitoring crops). Our plan is to co-design the curriculum with our partners to develop new storylines that fit their purpose. We also plan to enhance the existing suite of UAV activities with a small number of new activities that, based on experience with prior use of the UAV curriculum, are likely to be popular with end-users and their students or fill a gap in terms of topics addressed. We believe these new activities, along with the existing set, will provide a well-rounded set to serve as seeds for ideas by end users as they develop their local version of the curriculum.

References

[1] J. S. Eccles and J. A. Gootman, *Community programs to promote youth development*. Washington, DC: National Academy Press, 2002.

[2] R. A. Duschl, H. A. Schweingruber, and A. W. Shouse, *Taking science to school*. Washington, DC: National Academies Press, 2007.

[3] "STEM Education Data and Trends. 2014. [Online]". 2018 [Online]. Available: https://www.nsf.gov/nsb/sei/edTool/data/workforce-07.html. [Accessed: 03- Feb- 2018]

[4] K. P. Dabney, R. H. Tai, J. T. Almarode, J. L. Miller-Friedmann, G. Sonnert, P. M. Sadler, and Z. Hazari, "Out-of-School Time Science Activities and Their Association with Career Interest in STEM", *International Journal of Science Education, Part B*, vol. 2, no. 1, pp. 63-79, 2012.

[5] G. G. Noam, P. J. Allen, A. M. Shah, and B. Triggs., In *The Growing OutofSchool Time Field: Past, Present, and Future*, H. Malone and T. Donahue, Ed. IAP, 2017.

[6] J. Kahne and K. Bailey, "The Role of Social Capital in Youth Development: The Case of "I Have a Dream" Programs", *Educational Evaluation and Policy Analysis*, vol. 21, no. 3, p. 321, 1999.

[7] *A framework for K-12 science education*. Washington, D.C.: National Academies Press, 2012.

[8] T. Akiva and C. G. Horner., "Adolescent motivation to attend youth programs: A mixed-methods investigation", *Applied Developmental Science*, vol. 20, no. 4, pp. 278-293, 2016.

[9] "Design-Based Research: An Emerging Paradigm for Educational Inquiry". *Educational Researcher*, vol. 32, no. 1, pp. 5-8, 2003.

[10] S. Bhaduri, A. Gendreau, V. S. Koushik, T. Sumner, J. Ristvey, and R. Russell, "Promoting Middle School Students' Motivation and Persistence in an After-School Engineering Program", in *STEM Teaching & Learning in the 21st Century*, J. Johnson and J. Barnes-Johnson, Ed. Peter Lang Publishing, 2018.

[11] W. Sandoval, "Conjecture Mapping: An Approach to Systematic Educational Design Research", *Journal of the Learning Sciences*, vol. 23, no. 1, pp. 18-36, 2013.

[12] C. Molina, R. Belfort, R. Pol, O. Chacón, L. Rivera, D. Ramos, and E. I. O. Rivera, "The use of unmanned aerial vehicles for an interdisciplinary undergraduate education: Solving quadrotors limitations.", in *In Frontiers in Education Conference (FIE)*, pp. 1-6, 2014.

[13] J. Burg, V. P. Pauca, W. Turkett, E. Fulp, S. S. Cho, P. Santago, D. Cañas, and H. D. Gage, Engaging non-traditional students in computer science through socially-inspired learning and sustained mentoring. In *Proc. 46th ACM SIGCSE*, pp. 639–644, 2015.

[14] S. R. Yokokawa, H. Oneda, S. Osawa, and K. Ozaki. Development of a teaching material that can motivate students to learn control engineering and image processing. In *17th International Conference on Computer Science and Engineering (CSE)*, pp. 413–419, 2014.

[15] C. Nitschke, Y. Minami, M. Hiromoto, H. Ohshima, and T. Sato. A quadrocopter automatic control contest as an example of interdisciplinary design education. In *14th Int. Conference on Control, Automation and Systems (ICCAS)*, pp. 678–685, 2014

[16] M. Huggard and C. Mc Goldrick. Droning on: Reflections on integrating uav technology into a computer engineering design laboratory. In *Proceedings of the 47th ACM technical symposium on computing science education,* 2016, (pp. 504-509). ACM.

[17] J. Froyd, P. Wankat, and K. Smith. Five major shifts in 100 years of engineering education. *Proceedings of the IEEE, 100*(Special Centennial Issue), pp. 1344-1360, 2012.

[18] NGSS Lead States. (2013). *Next Generation Science Standards: For states, By states*. Washington, DC: The National Academies Press. Retrieved from http://www.nextgenscience.org/

[19] B. J. Reiser. Designing coherent storylines aligned with NGSS for the K–12 classroom. Paper presented at the *National Science Education Leadership Association*. Boston, MA, 2014.

[20] Y. Shwartz, A. Weizman, D. Fortus, J. Krajcik, and B. J. Reiser. The IQWST experience: Using coherence as a design principle for a middle school science curriculum. *The Elementary School Journal*, *109*(2), 199-219, 2008.

[21] S. Severance, W. R. Penuel, T. Sumner, and H. Leary. Organizing for teacher agency in curricular co-design. *Journal of the Learning Sciences*, *25*(4), 531-564, 2016.

[22] S. Hidi, K. A. Renninger, and A. Krapp. The present state of interest research. *The role of interest in learning and development*, 433-446, 1992.

[23] R. W. Lent, S. D. Brown, and G. Hackett. Toward a unifying social cognitive theory of career and academic interest, choice, and performance. *Journal of vocational behavior*, *45*(1), 79-122, 1994.

[24] M. Caplan. Scientists for Tomorrow: The evaluation and lessons learned from a self- sustained initiative to promote STEAM in out-of-school-time frameworks in underserved, community-based organizations. Paper presented at *2017 ASEE Annual Conference & Exposition, Columbus, Ohio*. https://peer.asee.org/28812

[25] A. Sahin, M. C. Ayar, and T. Adiguzel. STEM Related After-School Program Activities and Associated Outcomes on Student Learning. *Educational Sciences: Theory and Practice*, *14*(1), 309-322, 2014.

[26] NIOST, 2007. A review of the literature and the INSPIRE model STEM in out of school Time - National Institute on Out-of-School Time - Wellesley College

[27] S. C. Lauver and P. Little. Recruitment and retention strategies for out-of-school-time programs. *New Directions for Student Leadership*, *2005*(105), pp. 71-89.

[28] S. P. Whalen. Three years into Chicago's Community Schools Initiative (CSI): Progress, challenges, and lessons learned. *Chicago: University of Illinois at Chicago*, 2007.

[29] C. S. Hulleman and J. M. Harackiewicz. Promoting Interest and Performance in High School Science Classes. *Science*,*326*(5958), pp.1410-1412, 2009 doi:10.1126/science.1177067

[30] C. S. Hulleman, O. Godes, B. L. Hendricks, and J. M. Harackiewicz. Enhancing Interest and Performance With a Utility Value Intervention. *Journal of Educational Psychology*. *Advance online publication,* Oct, 2010. doi: 10.1037/a0019506

[31] D. S. Yeager, M. D. Henderson, D. Paunesku, G. M. Walton, S. D'Mello, B. J. Spitzer, and A. L. Duckworth. Boring but important: A self-transcendent purpose for learning fosters academic self-regulation. *Journal of Personality and Social Psychology, Vol 107(4),* Oct 2014, pp. 559-580. doi: 10.1037/a0037637

[32] D. K. Sherman, K. A. Hartson, K. R. Binning, V. P.-Vaughns, J. Garcia, S. T.-Barba, S.Tomassetti, A. D. Nussbaum, and G. L. Cohen. "Deflecting the trajectory and changing the narrative: how self-affirmation affects academic performance and motivation under identity threat." *Journal of Personality and Social Psychology* 104, no. 4 (2013): 591.

[33] D. Paunesku, G. M. Walton, C. Romero, E. N. Smith, D. S. Yeager, and C. S. Dweck. Mind-Set Interventions Are a Scalable Treatment for Academic Underachievement. *Psychological Science*,*26*(6), pp. 784-793, 2015. doi:10.1177/0956797615571017

[34] H. Gaspard, A.-L. Dicke, B. Flunger, B. M. Brisson, I. Häfner, U. Trautwein, and B. Nagengast. Fostering adolescents' value beliefs for mathematics with a relevance intervention in the classroom. *Developmental Psychology,* 51(9), pp. 1226-1240, 2015. doi: 10.1037/dev0000028

[35] J. S. Eccles (1983). Expectancies, values, and academic behaviors.

[36] J. I. Smith, E. D. Combs, P. H. Nagami, V. M. Alto, H. G. Goh, M. A. Gourdet, C. M. Hough, A. E. Nickell, A. G. Peer, J. D. Coley, and K. D. Tanner. Development of the biology card sorting task to measure conceptual expertise in biology. *CBE-Life Sciences Education*, *12*(4), pp.628-644, 2013.

[37] H. J. Malone and T. Donahue, *The Growing OutofSchool Time Field: Past, Present, and Future.* IAP, 2017.

[38] A. Maul, W. R. Penuel, N. Dadey, L. P. Gallagher, T. Podkul, and E. Price. Measuring experiences of interest-related pursuits in connected learning. *Educational Technology Research and Development*, *65*(1), 1-28, 2017.

[39] S. Bouffard & P. Little. Promoting Quality through Professional Development: A Framework for Evaluation. Issues and Opportunities in Out-of-School Time Evaluation. Number 8. *Harvard University Harvard Family Research Project*. (2004).